THE EFFECT OF GRAZING MANAGEMENT ON THE SPATIAL HETEROGENEITY OF A PERENNIAL RYEGRASS SWARD AND THE UTILISATION BY GRAZING DAIRY COWS

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MARCH 2004

A thesis submitted towards the fulfilment of the requirements for the degree of Doctor of Philosophy comprising a report of studies undertaken at SAC, Education and Training Division, Auchincruive Campus, Ayr; in the Faculty of Biomedical and Life Science, University of Glasgow

ABSTRACT

Swards in the mid season become a mosaic of frequently grazed shorter patches and taller infrequently grazed patches. The spatial heterogeneity of such swards can result in poor utilisation by grazing animals during the mid season. This study investigates how grazing pressure and topping, as grazing management tools affects the spatial heterogeneity of a continuously stocked perennial ryegrass (*Lolium perenne*) sward, together with the utilisation of the infrequently grazed areas by grazing dairy cows.

Increasing the grazing pressure in mid season significantly reduced the height, herbage mass and proportion of infrequently grazed patches within the sward by up to 4 cm, 1.5 t DM ha^{-1} and 10% respectively. This was only significant when the grazing pressure reduced the frequently grazed patch height to 6 cm or below. Frequently grazed patch height of 8 or 10 cm did not significantly affect the spatial heterogeneity of the sward. An asymptotic relationship was observed between frequently grazed patch height and infrequently grazed height and proportion. Grazing dairy cows utilised the infrequently grazed patches through reduced avoidance and significantly greater intake over a 2 to 3 week period. Grazing behaviour was also modified, with a trend for reduced bite rate and increased grazing time with greater utilisation of the infrequently grazed patches. The affect of utilising the infrequently grazed patches on the milk production per cow was negative, significantly reducing yield by 3 kg cow^{-1} d^{-1} without affecting fat and protein composition. The higher stocking rate, in order to maintain the grazing pressure, would be likely to increase milk yield on per hectare basis.

Topping, as a management tool used from early season through to the mid season, enhanced the sward morphology of the infrequently grazed patch through increased tiller density, leaf content, reduced dead material, increased crude protein and digestibility compared to frequently grazed patch. The height and herbage mass of the infrequently grazed patches was significantly reduced. The proportion of infrequently grazed patches was significantly reduced by 10% only by topping at the 2 weekly interval and not by the 4 weekly interval. Topping at both frequencies

initially reduced the total dry matter intake of cows but had no effect on milk production per cow. This may have been due to the greater ability to select a leafy diet within the infrequently grazed patches, which would be of higher digestibility, allowing for the maintenance of yield at lower dry matter intakes compared to cows on the non-topped swards. Grazing behaviour was altered through increased bite rate, grazing time and selection of infrequently grazed patches of cows on topped swards.

The frequency of topping affected morphology and utilisation of infrequently grazed patches. The greater the frequency of topping the greater was the tiller density and leaf content of the infrequently grazed patches by mid season. Dairy cows utilised these patches through actively selecting to graze them, thereby significantly reducing the proportion within the sward by 10% compared to topping less frequently.

Grazing management can affect the spatial heterogeneity of a continuously stocked sward in the mid season through morphology and dynamics of the patches, together with greater utilisation by grazing dairy cows.

ACKNOWLEDGEMENT

I would like to thank my present and past supervisors, Dr Nick Offer, Prof. Cled Thomas and Dr George Fisher for their helpful advice, encouragement, and valuable discussions, which have allowed me to complete this study.

The technical support team, whose commitment and hard work allowed for the execution of the work and provided excellent and willing technical support. I thank all of the farm staff for their co-operation and help with experimental work.

Ian Nevison, for his helpful guidance and advice on statistical analysis and experimental design.

Finally, I am indebted to my family and friends, and in particular my husband, Keith for his support and encouragement throughout and my daughters, Emma and Sarah for their acceptance of the times I wasn't there.

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GLOSSARY OF TERMS

AFRC	Agricultural and Food Research Council
ANOVA	Analysis of variance
cm	Centimetre
CP	Crude protein
CV	Coefficient of variation
d	Day
DM	Dry matter
EB	Energy balance
FG	Frequently grazed
FW	Fresh weight
g	Gram
h	Hour
Ha	Hectare
HFRO	Hill Farming Research Organisation
HP	High Grazing Pressure treatment
IG	Infrequently grazed
K	Potassium
kg	Kilogram
l	Litre
LSD	Least significant difference
m	Meter
ME	Metabolisable energy
Min	Minute
mg	Milligram
MJ	Mega Joule
MP	Moderate Grazing Pressure treatment
N	Nitrogen
n	Number
NDF	Neutral detergent fibre
OM	Organic matter

P	Phosphorous
s.e.d.	Standard error of difference
s.e.m.	Standard error of mean
s.d.	Standard deviation
SR	Substitution rate
SSH	Sward surface height
t	Tonne
T	Treatment
WSC	Water soluble carbohydrate

CHAPTER 1. INTRODUCTION

Grassland in the UK accounts for 11.5m ha which is approximately 65% of the agricultural land (DEFRA, 2002). The proportion of temporary and permanent grassland is approximately 60%, or 6.6m ha, with a trend over the last 5 years of a reduction in grassland <5 years old, with slight fluctuations for grassland >5 years old. Livestock numbers have also shown a trend for a reduction of dairy cows by a total of 20%, to 2.2m between 1992 and 2002, however, the average lactation yield per cow has increased by 25% to 6530 l (DEFRA, 2002).

The milk industry is responsible for 20% of the total agricultural output of the UK and 45% of the grass based livestock industry (DEFRA, 2002). This is obviously a major commodity within the UK, which has seen a severe reduction in the purchase price paid to producers during the late 1990s. With the introduction of the CAP reform in 2005 this too will affect the dairy industry's structure and the viability of many small producers. The efficiency and profitability of dairy farming in the future will depend on how well the resources are managed.

One of the major resources of a livestock farm is grassland. Therefore, the management of grass will influence the success of the enterprise. The proportion of milk produced from forage has increased steadily during the 1990s within Scotland, together with the Utilisable Metabolisable Energy (UME) of milk production, measured as GJ/ha and average annual lactation yield. Annual milk yields continue to rise at the expense of milk from forage and UME, since 2000 (Figure 1.1). The increase through the 1990s could be attributed to improvements in forage conservation or grazing utilisation or indeed both these aspects of grassland management. Peel *et al.* (1988) concluded that, on average, only 67% of the herbage production was utilised by livestock. If milk production is to remain profitable then more attention needs to be made to the value of grass.

Grazed grass is the cheapest form of feed on an ME basis compared to conserved forage and compound concentrates (Mayne, 2001). The cost has been estimated to be in the ratio of 1:2:4.5 grass:silage:concentrate (Leaver, 1983) or 1:1.3 for grazed grass:silage (Keady & Anderson, 2000).

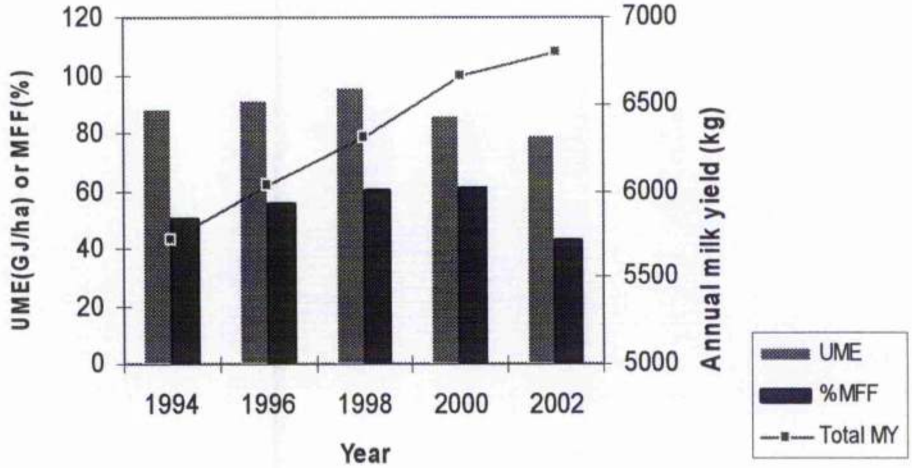


Figure 1.1: UME (GJ/ha), Milk from Forage (MFF) and Annual milk yield (kg) from 1994 to 2002 on dairy farms (data supplied by SAC Milkminder with a year running from previous April to March).

Profitability of dairying has declined within the UK over the last 10 years. To halt and reverse this trend a reduction of production cost is essential. This could be achieved by increasing the scale of production or by developing systems which, have a greater reliance on grazed grass. Realistic targets of milk output per cow from grazed grass should be 30kg day $^{-1}$ in May falling to 20kg day^{-1} by September (Mayne *et al.*, 2000). Higher milk yields have been reported with grazed grass intake of over 18kg DM day^{-1} (Gordon *et al.*, 2000; Dillon *et al.*, 1999) however, this is under experimental conditions over relatively short periods of time and in early summer and unlikely to be sustainable for any length of time.

Rotational grazing or continuous stocking, have been shown generally to deliver similar milk production (Evans, 1981; Pulido & Leaver, 2003), unless under high stocking rates, when rotational grazing would appear to be more advantageous and allows increased flexibility of management (Mayne *et al.*, 2000a). For high yielding cows, the residual sward height of 8-10cm in early season can generate swards in mid- season with poorer sward characteristics and quality than swards grazed more tightly in spring (Fisher & Dowdeswell, 1995; Stakelum & Dillon, 1990). This can result in a greater reduction in herbage intake and milk production in mid season than is desirable. Management strategies to overcome the sward deterioration due to poorer utilisation in spring include leader/follower grazing, topping and alternating cutting and grazing. Continuous stocking systems are less easy to control if utilisation has been poor in spring, since management options are more limiting. However, a major proportion of dairy farmers in the UK operate continuous stocking. There are few decision support systems (or management strategies) for utilisation of deteriorated swards, which have a relatively high proportion of taller under-utilised patches in mid season, as a result of poorer utilisation in spring.

Grazing is antagonistic to grassland production as it means the removal of green leaf and reduction of the leaf area for photosynthesis. The leaf area index at which Perennial ryegrass is thought to intercept maximum light is 7.1 (T'Mannetje, 2000). Values above or below this are not maximising net growth. Therefore, the optimising of photosynthesis and growth contradicts with efficient harvesting of the product. Good stocking management requires optimisation of both photosynthesis and dry matter utilisation. Therefore frequency of defoliation is critical and dependant on the selective grazing by the animal, the amount of herbage available and the quality and structure of the sward. Stocking density affects the selective ability of grazing animals and the frequency of defoliation of tillers. Decision support models and management guidance need to consider the interaction of stocking density and animal production per ha which can be sustainable over a given period of time.

The plant/animal interactions ongoing within a grazing sward are complex and in a continual flux. In order to effectively manage the sward while achieving optimal livestock production there needs to be a better understanding of these interactions. Ultimately this will then allow for strategies to enhance the utilisation of the grazed sward.

This study was conducted to investigate the plant/animal interactions in a heterogeneous or patchy sward in the mid season in which taller infrequently grazed patches were indicative of a sward under-utilised by continuous stocking in the early season. Three major management tools were investigated in order to determine if these would enable an increased utilisation of the infrequently grazed patches and the effect this would have on the milk production. The dynamics and morphology of the two patch categories within the sward (shorter, frequently and taller, infrequently grazed patches) were measured, together with the grazing behaviour, intake of grass and milk production by lactating dairy cows, allowing for a better understanding of the plant/animal interactions involved. Grazing was managed as continuous stocking.

The three main experiments were designed to investigate:

1. The effect of manipulating the grazing pressure in mid season on the patch dynamics, grazing behaviour and animal production under continuous stocking.
2. The effect of frequently grazed patch height on the patch dynamics of the sward and the interaction with the grazing dairy cow under continuous stocking.
3. The effect of topping and topping frequency from early season on the morphology of infrequently grazed patch and the effect on animal behaviour, intake and production of dairy cows.

The quantification of these plant/animal interactions should enable the development of strategies of grazing management suitable for improving grassland utilisation in the mid season, thereby increasing the profitability and sustainability of milk production under continuous stocking in the UK.

CHAPTER 2. LITERATURE REVIEW

2.1 INTRODUCTION: PLANT/ANIMAL INTERACTIONS

Grazing systems comprise complex relationships between the plant and the animal. The process of grazing defies the plant its ability to produce herbage and as a result many species modify their growth in order to avoid being grazed. Grazing management has the task of optimising both the herbage production and utilisation (Parsons *et al.*, 1983) therefore requiring a compromise between accumulation of leaf area, photosynthesis, and defoliation interval. Grazing directly affects the plant, not only through removal of herbage and hence growth, but also through trampling causing damage and deposition of excreta smothering or causing nutrient enrichment. In response, plants alter their canopy structure to avoid complete leaf removal and hence allow for survival of frequent defoliation. The sward is not necessarily uniform or homogenous with relation to species, canopy structure or maturity, allowing the potential for selection by the grazer. It is therefore a combination of the sward and the selection within it by the animal, which ultimately determines the quality, and quantity of the diet consumed. Much work has looked at the relationship between sward characteristics and animal grazing behaviour/production (Bircham & Hodson, 1983; Hepp, 1989; Milne & Fisher, 1994; Bullock & Marriott, 2000). The inter-relationship can be diagrammatically represented as in Figure 2.1.

There is wide variation of grazing management which determines response by animal and plant, e.g. continuous vs. rotational grazing, fertiliser regime, age of sward, stocking densities, sward composition, animal species, reproductive status, genetic merit and stocking density of the grazer, thereby influencing the interactions within the whole system of grazing.

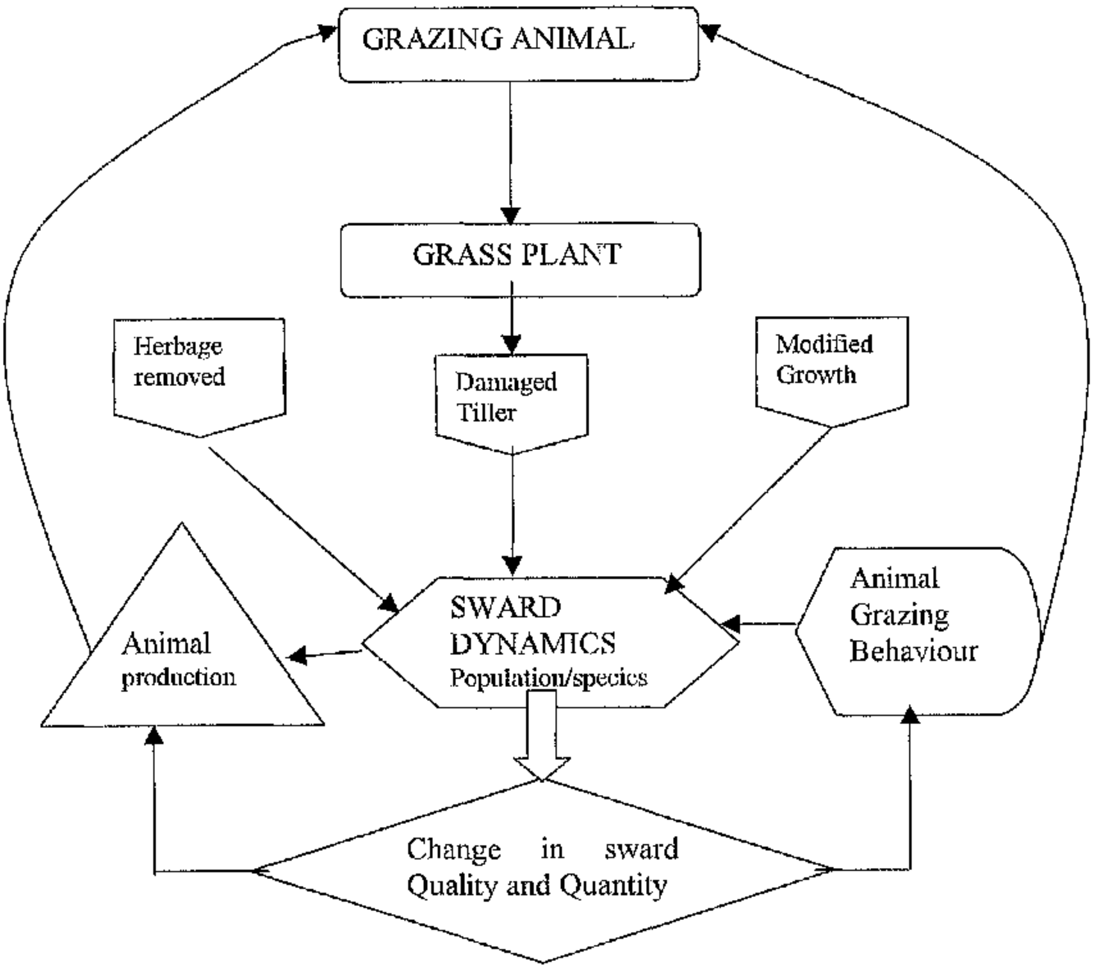


Figure 2.1: Diagrammatic scheme for the plant animal interactions involved during the grazing process

2.2 PHYSIOLOGY OF GRASS GROWTH

2.2.1 Vegetative growth

During vegetative growth the grass plant produces leaves made up of a blade or lamina connected to a leaf sheath, which remains rolled or folded to form the pseudostem of the plant. The apical meristem can be found at or close to ground level at the base of the pseudostem. Each time a new leaf is produced an axillary meristem is produced in the axial of the previous leaf, which was produced on the opposite side of the pseudostem axis. These axillary meristems have the potential to form a tiller. There is a limit to the tiller sites which are filled and are a result of species and defoliation regime it is exposed to (Mazzanti *et al.*, 1994). In order for the grass plant to survive and spread by non reproductive means it is essential that each tiller, in its lifetime, will produce at least one new tiller. In periods after stress an increase in tiller number or site filling is often crucial to vegetatively regenerate and maintain the plants survival.

For vegetative swards in which only leaf is being produced, the plant morphogenesis (defined as the dynamics of generation and expansion of plant form in space, Chapman & Lemaire, 1993), can be described by leaf appearance rate, leaf expansion rate and leaf lifespan. These variables determine the sward characteristics and productivity and are dependent on external factors together with genetical control, which are summarised in Figure 2.2 (adapted from Lemaire & Chapman, 1996).

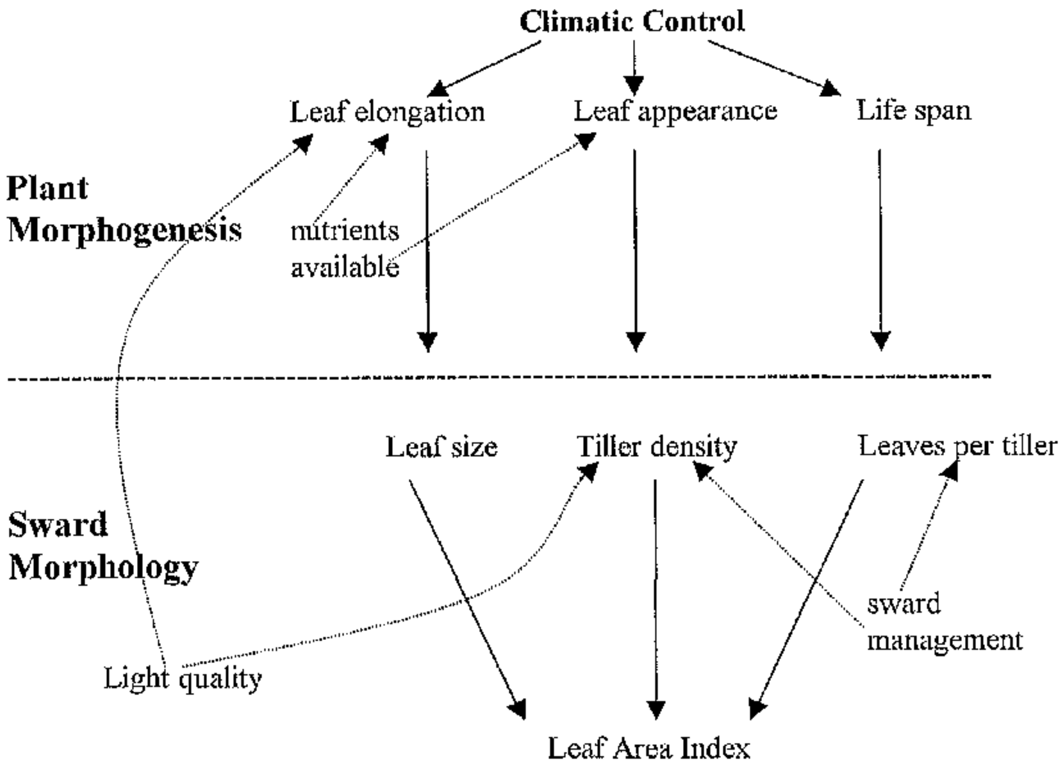


Figure 2.2: The external factors which determine plant and sward morphology (adapted from Lemaire and Chapman, 1996)

Leaf size is the product of Leaf Expansion Rate (LER) and Leaf Appearance Rate (LAR) since the leaf expansion period is a constant fraction of the leaf appearance interval (Dale, 1982). Tiller density is dependent on the leaf appearance rate, however the overriding control soon becomes light quality at the base of the sward. Leaf size and lifespan also contribute to the leaf area index, which will result in shading and hence a reduction in filling of tiller bud sites. Few new tillers are found when a sward intercepts 95% of the incident radiation (Robson, 1973). Genotype also plays an important control on the tiller density of a sward (See Section 2.2.4.1).

The leaf lifespan and leaf appearance rate controls the number of green leaves per tiller. These variables are determined by LAR and LER, which themselves are controlled and respond to the climatic conditions, especially temperature and day length (see Section 2.2.4).

Leaf area index of a sward is the product of leaf size, tiller density and leaf number per tiller. For intermittently defoliated sward the tiller density increases until a Leaf Area Index (LAI) of 3-4 is achieved after defoliation. The sward will reach ceiling yield when LAI will remain static, however plant morphogenesis continues to be dynamic without the net accumulation of dry matter (Parsons & Chapman, 2000).

2.2.2 Reproductive growth

The transition from the vegetative to the reproductive phase of growth is marked by the appearance of a double ridge structure of the apical meristem. This is then followed by the elongation of internodes below the meristem and developing flower head, producing true stem which pushes the inflorescence up through the leaf sheath to emerge from the uppermost leaf, known as the flag leaf. For most perennial species, only tillers, which are vernalised, i.e. experienced low temp and short-day length followed by lengthening day in the spring, show reproductive growth. *Phleum pratense* is the exception to this general rule. The tillers, which undergo the change to reproductive growth, cease to produce leaves and are therefore destined to die. For perennial ryegrass, it is only the tillers produced during the spring which, through lack of vernalisation, remain vegetative and allow for the perennation of that mother plant.

Photoperiod and temperature not only initiate flowering but also continue to determine the rate of inflorescence development and rate of stem elongation. In most grasses the time from initiation to emergence ranges from 25 to 70 days (Langer, 1974). Vegetative tillers decline during reproductive growth. Swards which are grazed hard during the early inflorescence development have fewer reproductive tillers with lower stem content and high tiller density than those grazed laxly at this time, or grazed hard when inflorescence development has progressed (Korte *et al.*, 1984; Fisher & Roberts, 1995).

2.2.3 Root growth

Grasses have two root systems, the seminal and the adventitious roots. Seminal roots account for up to 5% of the total root mass in the first year of perennial grasses however, due to their highly branched nature, they occupy a greater soil volume than their weight would suggest (Langer, 1974). Seminal roots are important for the first few months within perennial grasses after which they disappear.

Adventitious roots arise from nodes at base of stem, which may mean some roots appear from above the soil surface and act as supporting organ for the plant, e.g. maize. Stolons and rhizomes have adventitious roots at each node which allow for fragmentation and ramification of the plant through the sward and explains the persistence of Couch grass (*Elymus repens*) and Marram grass (*Ammophila arenaria*) in swards.

Root growth in temperate species has a lower optimum temperature than above ground parts. Garwood (1967) showed how root growth is seasonal. In early spring there is an increase in new root mass close to soil surface. Later in spring these roots elongate deeper into the soil horizons while new root formation ceases. Summer shows a cessation in root growth resuming again in autumn.

Light intensity greatly affects root growth with shading of leaves being more detrimental to root growth than shoot growth. This is thought to be caused by a reduction in carbohydrate supply from the shoots (Langer, 1974). A similar result occurs when grass is defoliated until such time as leaf area can supply the carbohydrate down to the roots.

2.2.4 Factors Affecting Plant Growth

2.2.4.1 Genotype

All annual grass and some perennial species produce tillers which are intervaginal, however some perennial species form rhizomes and stolons by tillers growing horizontally from the sheath. This has a major effect on not only the growth habit of a grass species but on its ability to compete above and below ground. Rhizomatous species tend to produce a lower total harvestable yield, however they are more drought resistant and competitive within the canopy.

Tillering is genetically controlled within some species, e.g. Perennial ryegrass (*Lolium perenne*) producing up to twice the number of tillers per plant than Timothy (*Phleum pratense*) (Ryle, 1966) and higher tiller densities than Tall Fescue (*Festuca arundinacea*). However, a number of environmental factors also greatly influence tillering in species which will be reviewed in later sections.

There is a variation of seasonality of growth between species and cultivars within species. Perennial ryegrass cultivars showed different patterns of seasonal growth with regards to root production, leaf appearance, tiller appearance, rate and density (Matthew, 1996). This may explain why some cultivars respond differently to different grazing management.

Leaf appearance varies between species. Lemaire (1988) showed that under the same grazing conditions Perennial ryegrass (*Lolium perenne*) maintained 3 leaves per tiller, each produced every 11 days and surviving for 33 days. Tall fescue (*Festuca arundinacea*) maintained 2.5 leaves per tiller each appearing at 22 day interval and surviving for a total of 57 days. As a result of the difference in leaf dynamics between these species, the tall fescue leaves and tillers are larger than those of Perennial ryegrass.

2.2.4.2 Environment

2.2.4.2.1 Temperature

Temperature is the greatest influence to leaf appearance, expansion and senescence. Generally, leaves grown under higher temperatures extend more rapidly for a shorter period to a greater final length but are narrower and thinner with more lamina relative to sheath than those grown under low temperatures (Robson *et al.*, 1988). The optimum temperature for temperate species is within the range of 20-25°C for day temperature and a slightly lower night temperature. Long periods of higher temperatures actually decreases leaf growth. Sub-tropical and tropical species grow under higher temperatures (Figure 2.3).

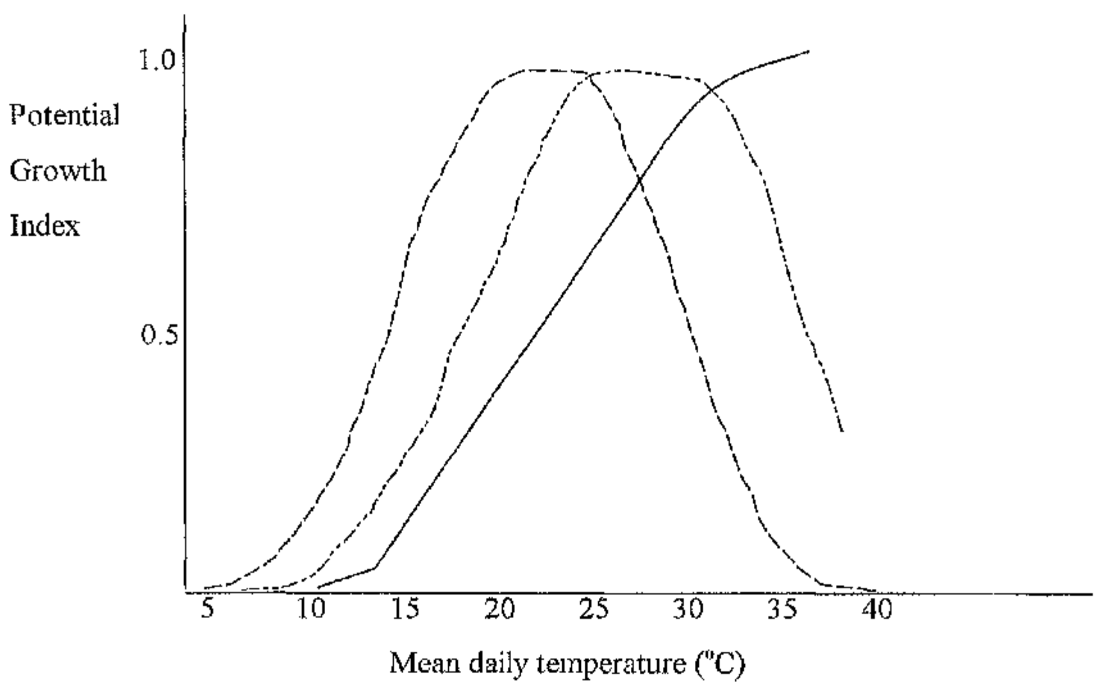


Figure 2.3: The effect of temperature on the potential growth index of temperate grasses (------), subtropical grasses (-..-..-..-..) and tropical grasses (____) (Adapted from Fitzpatrick and Nix, 1970)

The rate of leaf extension is very sensitive to current temperature and responds to changes within minutes, however, the width of the leaf is determined by the conditions during the primordial stage of the leaf's development. In spring, many temperate grasses are able to expand leaves faster than if given the same temperature in the autumn (Robson *et al.*, 1988). Leaves produced within higher temperatures tend to be longer and thinner with an overall larger leaf area than leaves produced under lower temperatures.

Tiller production is very temperature dependent. This is mainly through increased rate of leaf production and hence axillary buds, which ultimately if filled, will form a new tiller. Competition for light, moisture and minerals will interact to determine the tiller bud development.

Reproductive growth is also controlled in some species by temperature together with a photoperiod requirement. Perennial ryegrass must experience low temperatures (0-10°C) and a short photoperiod (8h day^{-1}) in order to induce flowering. The exposure to longer photoperiods (10-13h day^{-1}) triggers the onset of reproduction. Warm or cool Spring temperatures will accelerate or delay the development of the inflorescence by a period of days. Under experimental conditions, exposure to high temperatures (20-25 °C) at this time showed that this may cause a reversion to vegetative growth and death of the inflorescence (Robson *et al.*, 1988).

2.2.4.2.2 Light

The quantity of light has a very direct affect on the photosynthetic capacity of the leaf, however, the effect of low light intensity in dull cloudy days or by shading is less dramatic on leaf growth than might be expected. A greater proportion of assimilated carbon is retained within the shoot and less transported to the roots. The leaves produced under shade are thinner and longer to maximise the leaf area for photosynthetic activity. Leaf appearance rate is less sensitive to low light than leaf morphology. Short term variation in light, within or between days, has little immediate effect as carbohydrate storage in the shoot base buffers the short-term reduction in photosynthesis (Ryle, 1966). Photoperiod or length of the light period on a daily basis influences the leaf size. Ryle (1966) found an increase of photoperiod from an 8 hour day to 16 hour day doubled the leaf area for Cocksfoot (*Dactylis glomerata*) whereas for Perennial ryegrass the increase was between a third and a half. This is through the increase in cell size rather than cell number.

Light intensity also affects tillering of plants with most temperate species showing a decline in tiller number as light intensity is reduced from 100% to 5% (Langer, 1977). It is also suggested that it is the quality of the light and not intensity alone which influences tillering. Shade by other plants lowers the ratio of red:far red wavelengths and it is this which causes a decline in tiller bud development (Parsons & Chapman, 2000).

2.2.4.2.3 Water

The process most affected by water deficiency within leaf growth is cell expansion. Cell division can continue with cells accumulating until a water supply is re-instated. This often results in an explosion of growth after a drought period due to expansion of these accumulated cells (Jones, 1988). Drought reduces the rate of leaf appearance and this leads to a reduced tillering rate which reduces tiller number rather than a reduction through greater death rate of tillers (Barker *et al.*, 1985).

Grass growth is reduced where available soil water falls below 25% of maximum or when evaporation from herbage cannot be met from the root uptake (Pearson & Ison, 1987). Some grassland species evaporate more water per unit of dry matter and are more sensitive to water availability. Water use efficiency has been shown to be generally greater for those with the C_4 pathway compared to those with the C_3 pathway (Christie, 1984).

2.2.4.2.4 Nutrients

There are a number of elements that are essential for normal plant growth. These were categorised by Jeffrey (1988) into those which limitation has a direct effect on growth; that is Nitrogen (N) and Phosphorus (P). Alternatively, Potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Sulphur (S), Molybdenum (Mo), Copper (Cu), Zinc (Zn), Boron (B), Sodium (Na) and Chlorine (Cl) make up the second category which are essential but usually supplied by soils at non growth-limiting rates.

Nitrogen has greatest effect on grass growth due to its direct effect on both the size of leaves produced through greater leaf extension and also photosynthesis capacity of the leaf. Tiller rate does not increase, however site filling has been shown to increase substantially (Lemaire & Chapman, 1996). Photosynthesis is affected, both directly through the requirement of N for photosynthetic enzymes, and also indirectly through the effect on the leaf expansion and leaf area and hence light for interception for photosynthesis to occur.

Phosphorus and potassium, although essential, are less limiting to grass growth while their effect on legume growth is much more dramatic reducing growing points and branching if deficient (Parsons & Chapman, 2000).

2.2.4.3 Defoliation frequency

In grazed swards, a variation in herbage defoliation interval between patches and the effect on plant regrowth, together with the nutrient variation caused by faeces, all contribute to generate a sward which has spatial variability in terms of height, plant morphology and quality (Garcia *et al.*, 2002). Patches which are grazed more frequently tend to be vegetative containing greater leaf content, while those less frequently defoliated allow for reproductive tillers to be produced altering the morphology and quality of these patches compared to the frequently grazed patches (Ginane & Petit, 2002). If these patches are dynamic and constantly changing spatially within the sward, the heterogeneity will not be detrimental to the overall growth and production of that sward, since it is only defoliation intervals out of phase that is being observed at any point in time (Parsons & Chapman, 2000). However, when the heterogeneity within the sward remains static due to continual selective grazing by the animal, then the infrequently grazed patches will have reached ceiling yield and therefore not contributing to the net growth in production of that sward. This type of heterogeneity is detrimental to grass growth (Parsons & Chapman, 2000).

2.3 SWARD MANAGEMENT AND PLANT GROWTH AND MORPHOLOGY

The structure of the sward reflects its species composition and the management imposed on it. The plant units or phytomer compete for space, light, water and nutrients both above and below ground level. This affects the size and shape of leaves and tillers and therefore the total biomass of the sward. Grazing interferes with tiller morphology by a number of mechanism associated with the animal and the removal of herbage. Generally grass plants under grazing have a larger number of smaller tillers than those under cutting (Briske, 1996).

2.3.1 Grazing vs. Cutting

Species may differ in their tolerance of leaf removal due to their growth habit and regrowth ability (Briske, 1996). The position and number of meristems dictates ability to avoid damage to the plants by grazing animals. Grasses which remain in vegetative state with meristems close to ground level will help in maintaining high tiller population. The proportion of biomass or leaf removed is dependent on the growth habit, i.e. upright taller tillers versus prostrate horizontal types, will get greater defoliation purely on how the tillers present themselves within the sward. Recent studies have shown that animals do not graze to a fixed bite depth but to a proportion of the tiller height which varies between the studies from 35% to 70% (Wade *et al.*, 1989; Ungar *et al.*, 1991; Laca *et al.*, 1992). Sheep and cattle grazing the same sward do not differ in the proportion of tiller removed but bite area allows for the larger bite mass of cattle (Orr *et al.*, 1997). This fixed proportion may be effective to maximise bite mass while not encountering the pseudostem and dead material at the base of the sward, which would have lower nutritional quality, less easily prehended and require greater manipulation. Livestock can show preference to particular species due to palatability attributed by roughness, hairiness, sugar content, digestibility and mineral content (Derrick *et al.*, 1993). This selective grazing is associated with sheep while cattle are more passive grazers.

When grazing pressure is increased grass leaves become more prostrate, leaf size is reduced while tiller numbers are increased (Lemaire & Chapman, 1996). Clover plants when grazed hard become more fragmented with shorter petioles. There is a trade-off between light interception and the avoidance of grazing which allows the plant to resist grazing while being competitively able to retain a presence in the sward. The mechanism is one of either avoidance or tolerance, both relying on morphological or biochemical and physiological processes, which either reduce probability of grazing or promote growth after defoliation respectively (Briske, 1996). Grasslands with a history of grazing tend to be dominated by species tolerant to grazing (Marriott & Carrère, 1998).

Cutting of a sward removes the animal effects, i.e. dung, urine, trampling and preferential or selective grazing (Leaver, 1985; Wilkins & Garwood, 1986). A cut sward would be expected to be more uniform spatially with respect to plant morphology and growth. Swards cut under a silage regime have much lower tiller densities up to a tenfold difference than those which are continuously stocked and defoliated frequently (Parsons *et al.*, 1983a). The difference in tiller density becomes more marked as the season progresses (Jones *et al.*, 1982). Tiller numbers, although smaller under cutting, each have a larger lamina area which has a consequence on the photosynthesis ability of the canopy (Jones *et al.*, 1982). The effect of cutting frequency will result in the same plant morphology response as the effect of grazing severity in that tiller density will be greater with more prostrate growth.

2.3.2 Grazing Systems

Experimental evidence in comparing rotational grazing (defined as defoliation at intervals with a period of re-growth between) and continuous stocking (defined as animals having access to the area for the majority of grazing season) would suggest that grass production and milk yield per hectare are similar when operated at similar stocking rates (Ernst *et al.*, 1980; Evans, 1981; Pulido & Leaver, 2003). When stocking rates are high, then rotational grazing systems achieve greater production (Grant *et al.*, 1988). Pulido & Leaver (2003) showed that tiller density was greater under continuous stocking, however there was no significant difference in the proportion of green or dead material in the sward. Wade (1989) studied the frequency of defoliation at the individual tiller level within rotational and continuous grazing under different stocking rates. He found the same relationship relates to either continuous or rotational with the only difference being the proportion of the sward area grazed daily by the animals (Figure 2.4).

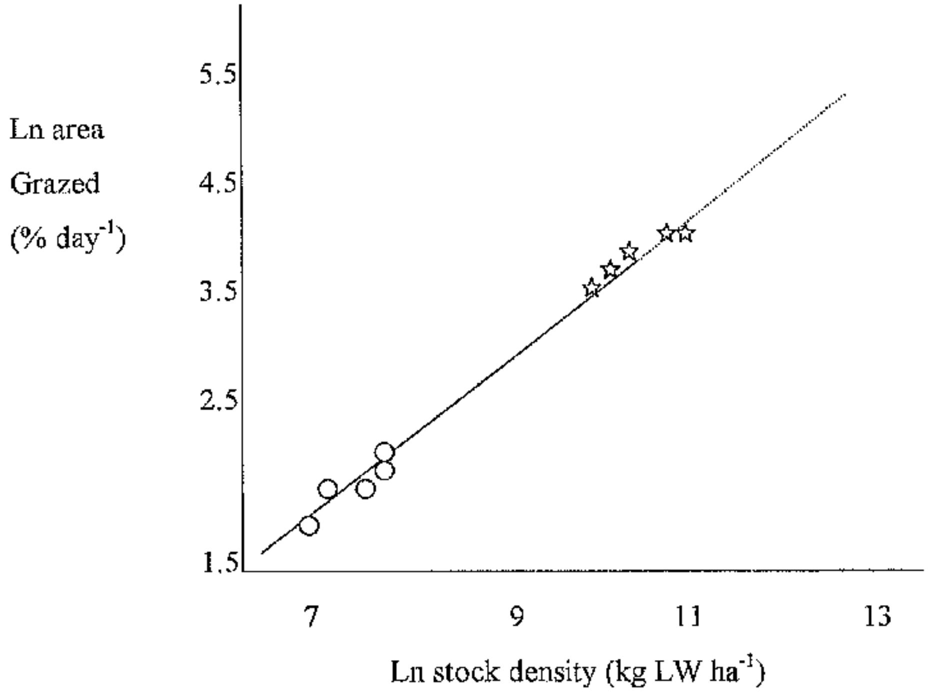


Figure 2.4: Relationship between area of pasture grazed and stocking density, as natural Logarithm (Ln) under continuous stocking (O) and rotational grazing (*) (adapted from Lemaire & Chapman, 1996)

The high yielding dairy cow requires high herbage allowance whilst leaving relatively high residual herbage mass, if production is not to be compromised. Under these criteria rotational grazing systems allow options for controlling the high residual sward not feasible within continuous stock, e.g. mechanical topping, leader-follower grazing and mob stocking mid season (Mayne & Peyraud, 1996). From a grazing management viewpoint, rotational grazing has advantages over continuous stocking with greater forewarning of, and flexibility to manage, grass deficits or surpluses (Mayne *et al.*, 2000a).

The frequency of defoliation was measured to be between 5 and 9 days for individual tillers under continuous stocking with sheep (Curll & Wilkins, 1982). The variation was due to stocking density affect. Rotational grazing defoliation interval can vary greatly with season and stocking density, however suggested recommendations are 18 days in early season increasing up to 50 by late autumn (Mayne *et al.*, 2000a).

The canopy structure of swards continuously grazed is different to those grazed or cut intermittently. Leaf area index (LAI) is maintained at much lower values, e.g. 2-3, than rotationally grazed swards, however, interception of radiation is similar (Jones *et al.*, 1982). This is suggested to be due to the more prostrate growth habit of tillers frequently defoliated. Tiller densities also diverged between the two managements from early season with those of the continuous grazing achieving much higher levels. These grazed swards maintained a stable above ground biomass throughout the season compared to the marked fluctuations of the intermittent defoliated sward.

2.3.3 Nitrogen Fertiliser

Environmental concerns over the losses of Nitrogen from a grazing system have led to investigations into how to reduce N inputs in the form of fertiliser and supplementary feeds, whilst maintaining production. Reducing N fertiliser usage on grazed swards can markedly reduce herbage intake through a reduced herbage mass and height. Therefore, stocking density is reduced to maintain the herbage allowance at a lower herbage mass (Mayne & Peyraud, 1996).

Much work has looked at the response of swards, both cut and grazed to levels of fertiliser N (Jackson & Williams, 1979; Morrison *et al.*, 1980; Hopkins *et al.*, 1990; Deenan & Lantinga, 1993; Rowarth *et al.*, 1996 and Peyraud & Astrigrraga, 1998). Generally it is agreed that there is a variable response, however this was always greater under cutting than grazing.

Herbage response was shown to follow a linear phase of 15-30 kg DM kg $^{-1}$ up to levels of 400 kg N/ha. Above these rates of application the response diminishes until maximum yield is achieved (Morrison *et al.*, 1980), Figure 2.5.

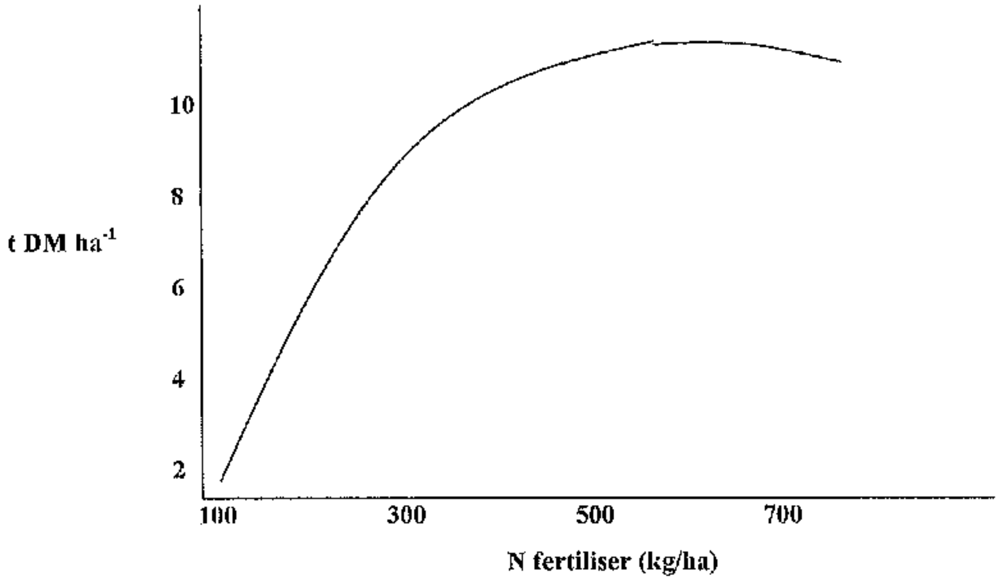


Figure 2.5: The response of perennial ryegrass to fertiliser N application rates (Morrison *et al.*, 1980)

The effect of N fertiliser rate on the tiller density was much less than the seasonal changes of tiller density naturally occurring. Any difference was temporary and in favour of low N (Deenen & Lantinga, 1993). Van Loo *et al.*, 1992 observed a decline in tiller density when 0 kgN/ha was applied to Perennial ryegrass. The recovery of tillers when optimum N was applied to these plants was not immediate, probably due to need for new tiller buds to be formed.

The effect of fertiliser N on species composition of the sward have consistently indicated increasing N increased content of *Lolium perenne*, *Elymus repens*, *Dactylis glomerata*, *Festuca pratensis* and Poa species if present in a sward. Whilst *Cynosurus cristatus*, *Festuca ovina* and *Trifolium* species decline with N applications (Hopkins & Green, 1978; Sandford, 1978; Milne, 1997).

The diversity of species has been shown to remain low when fertiliser N is applied compared to no N. Jones & Hayes (1997); Montford *et al* (1993) showed the 'hump' back model predicted by Grime (1979) could also be applied to fertiliser N (Figure 2.6).

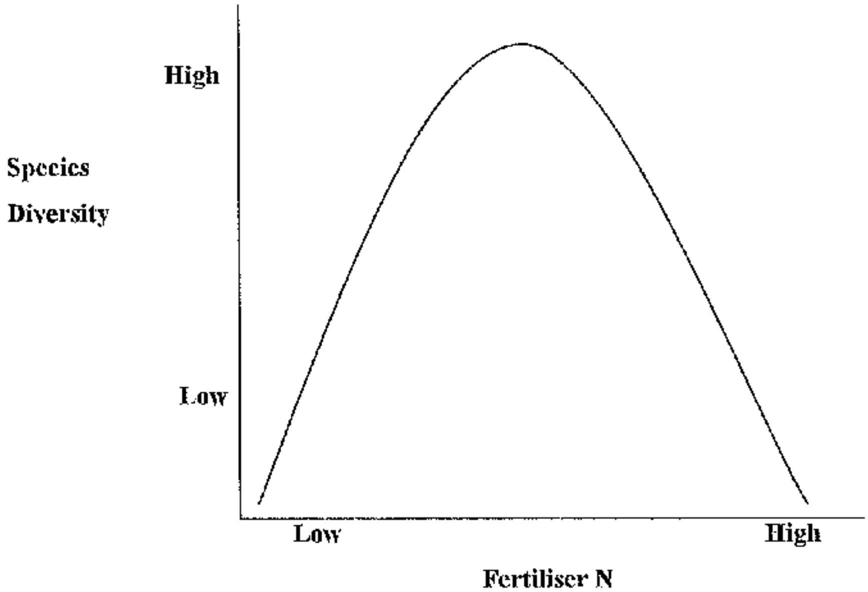


Figure 2.6: Effect of N fertiliser on species density 'hump' back model by Grime, 1979

Nitrogen fertiliser rates also affect the nutritional quality of grass. Increasing the N fertiliser rate increases CP content in grass (Valk *et al.*, 1996). CP reaches a maximum soon after N fertiliser is applied as a result of rapid uptake of N by the plants, and then declines rapidly as growth progresses (Peyraud & Astigarraga, 1998). Nitrogen fertiliser can reduce WSC concentration in the herbage (Valk *et al.*, 1996; Valk *et al.*, 2000). The effect on structural carbohydrates is minimal (Peyraud & Astigarraga, 1998).

2.3.4 Stocking Rates and Densities

One of the most influential factors which determine the output per ha or individual performance of an animal is the stocking rate, defined as the number of livestock units per ha over a given period of time (Hodgson, 1979; Mayne *et al.*, 2000). Stocking density, on the other hand, is the number of animals per unit area of land being grazed at a point in time (Hodgson, 1979). Therefore, under continuous stocking, stocking rate and stocking density tend to be identical, where as under rotational grazing stocking density is higher than the overall stocking rate.

The relationship between output and stocking rate was summarised by Jones & Sandland (1974) for growing beef cattle (Figure 2.7). Jones concluded that liveweight gain per ha was maximised at a stocking rate half of that which gave zero liveweight gain, at which point animal performance was reduced by 24% relative to the maximum achievable.

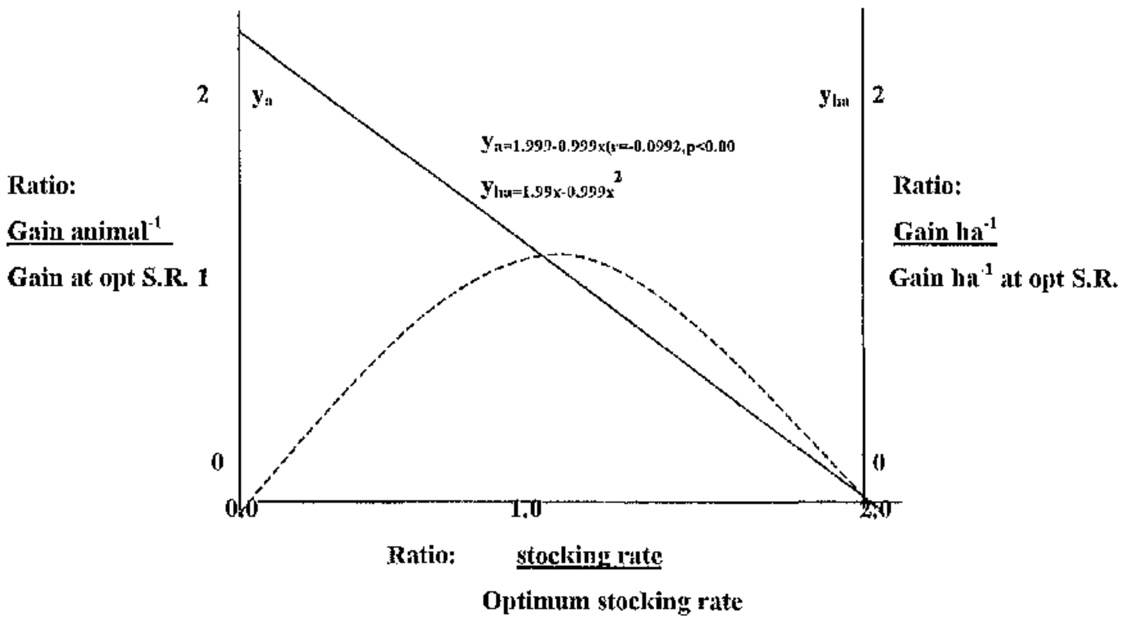


Figure 2.7: The relationship between Stocking rate (S.R.) on gain ha^{-1} and gain head^{-1} from grazing experiments in a wide range of environments and pasture species (Jones & Sandland, 1974)

Pringle & Wright (1983) summarised New Zealand research with dairy cows and showed a relationship between stocking rate and milk fat production per ha and per cow (Figure 2.8). They suggest a critical stocking rate above which fat yield per cow progressively declines, however, beyond the critical stocking rate, fat yield ha^{-1} continues to increase until a maximum is reached.

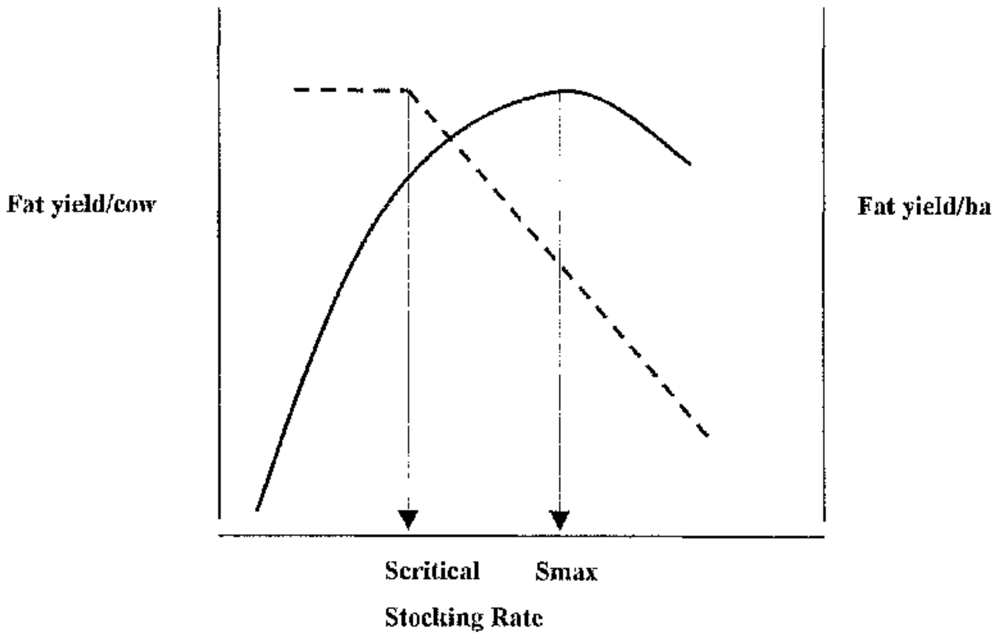


Figure 2.8: Effect of Stocking Rate on fat yield per cow (----) and fat yield per ha (——) for dairy cows showing suggested critical and maximum stocking rate for fat yield/cow and fat yield/ha respectively (modified from Pringle & Wright, 1983)

Journet & Demarquilly (1979) quantified the effect of increasing the stocking rate by 1 cow ha^{-1} with a 10% reduction of milk yield per cow coupled with a 20% increased yield per ha. The influences of stocking rate on output is through its effect on herbage allowance (weight of DM per animal) or grazing pressure (no of animals per unit mass of herbage). At low herbage allowance, grazing pressure is high and competition between animals increases leading to reduced herbage intake and production per animal, however the efficiency of utilisation of herbage is high. As the grazing pressure is reduced, through a reduction in stocking rate, then individual intake and performance increases while overall utilisation of grazed grass may fall (Stakelum, 1996).

The effect of stocking rate on the sward structure and morphology has been reported by Baker & Leaver (1986), Stakelum & Dillon (1990), Da Silva *et al.* (1994) and Fisher & Roberts (1995), all concluding the beneficial effects of applying high stocking rate in spring on sward density, leaf content and nutritional quality (Table2.1).

Table 2.1: Summary of work investigating the effect of early season stocking rate on sward characteristics in mid season

		Early Season		Mid Season		
Author	**Animal/ grazing system**	**Stocking rate (cows/ha)**	**Sward height (cm)**	**Tiller Density 000/m²**	**ME (MJ/kg DM)**	**Milk Yield kg/day**
Baker & Leaver	Dairy Cows	3.98 L	8.7	15.3	11.2	20.5
1986	Continuous	4.26 M	6.5	15.2	11.3	21.5
		4.54 H	6.2***	16.1 ns	11.5 ns	21.6 ns
Stakelum &	Dairy Cows	4.0 L	9.7	0.61$	750!	16.3
Dillon 1990	Rotational	5.0 M	8.1	0.68$	760!	17.6
		6.2 H	5.8 ***	0.73$ *	770! *	18.6
Da Silva *et al.*	Dairy Cows	2.5	1800#			47.0
1994	Rotational	3.6	1800#			47.5 ns
Fisher & Roberts	Dairy Cows	4.9 L	10.5	18	No	20.5
1995	Continuous	7.4 H	5.8	25	Difference	18.6 **

$= proportion green leaf != OMD g/kg #= kg DM residual mass *=$P \leq 0.05$ **=$P \leq 0.01$ ***=$P \leq 0.001$ ns =non significant.
N.B. Sward Height measurement using HFRO sward stick for Baker &Leaver and Fisher &Roberts. Rising Plate meter used for height by Stakelum & Dillon and Da Silva *et al.*

2.3.5 Topping

Topping is defined as defoliation through mechanical cutting at any point during the season. It is a management tool often used by the farmer in order to remove excess growth accumulated in grazing fields which has resulted from undergrazing and selective grazing at certain times, as opposed to using a mower and cutting the field for a silage crop. The traditional summer topping to remove old flowering stalks and weeds is generally for aesthetic purposes and does not enhance productivity. On pastures entirely grazed, topping may be necessary to encourage a continuous supply of leafy, highly digestible regrowths and minimise rejected areas and reproductive growth of tillers (Harkess, 1968; Dillon & Stakelum, 1988).

Research has investigated the use of topping to enhance sward characteristics and ultimately animal production (Bryant, 1982; Holmes & Hoogendoorn, 1983; McDonald, 1986; McDonald *et al.*, 1986; Stakelum & Dillon, 1990; Fisher & Roberts, 1995 and Boa *et al.*, 1998). This work has covered a wide variation of grazing management, livestock species grazing, topping frequency and timing. Table 2.2 summarises this work which concludes:

- Early season topping enhanced sward characteristics more than mid season topping.
- Topping reduced the number of reproductive tillers and dead matter within the sward.
- The advantage of topping on the production of milk or lamb was positive or neutral.

Table 2.2: Summary of Topping Research

Author	Species	Grazing system	Topping Timing	Topping Frequency	Topping Height	Sward Improvements	Animal Production Improvements
Bryant, 1982	Dairy Cows	Rotational	Spring and early Summer	3 weekly intervals or after each grazing	?	-	Topping after grazing increase milk fat by 10% & 6% over control and mowing before grazing respectively
Holmes & Hoogendoorn, 1983	Dairy Cows	Rotational	Spring	Once with lax and hard grazing treatment	?	Increased leafiness visible. 20% yield increase in summer for laxly grazed sward	-
McDonald, 1986	Lambs	Rotational	Various early/mid/ late	Once or multiple	5cm-8cm	Improvement only observed when minimum density of seed heads present >600/m^2. Quality & digestibility improved. Protein content ↓ dead matter ↑. Clover production only marginal improvement. Topping early in season gave best results of quality. Multiple topping not significantly better than once.	-
McDonald *et al.*, 1986							↑ Liveweight gain of lambs on sward which had >600/m^2 seed heads. Lamb growth no different to no topping when topping late summer
Dillon & Stakelum, 1988b Stakelum and Dillon, 1990	Dairy Cows	Rotational	April, June pre grazing	3 weekly intervals	6cm	Topping reduced tall grass area by 13% compared to untopped	↑DM intake for topped sward ↑ Milk yield up to 8%
Fisher & Roberts, 1995	Dairy Cows	Continuous	June	Once	6cm	No difference in ME of sward, tiller density not enhanced by topping	↑Milk yield cow^{-1} but not increase per ha^{-1} with topping
Bao *et al*, 1998	Dairy Cows	Rotational	May/June	After the first 2 grazing cycles	5cm	↓Herbage mass and SSH	Animals grazed tall grass areas sooner in defoliation of paddock when topped

2.4 THE GRAZING PROCESS AND HERBAGE INTAKE

2.4.1 Ingestive Behaviour

Herbage intake of grazing animals can be considered in terms of balances between effects of metabolic, physical and behavioural control (Hodgson, 1985). The normal pattern of a cow's behaviour consists of periods of grazing, ruminating and resting (Leaver, 1985). The typical activity of a grazing animal can be described in terms of a steady forward movement of the heard swinging from side to side in front of the forelegs with herbage gathered by the tongue and/or lips and gripped by the lower incisors and dental pad before being severed by a jerk of the head. This herbage is manipulated by the tongue and jaw to the back of the mouth for swallowing (Hodgson, 1985). Many variants to this pattern are possible, e.g. frequency of biting and variations in boli size prior to swallowing.

Allden & Whittaker, 1970 suggested that daily herbage intake (I) was the product of the weight of herbage consumed per bite (IB) the rate of biting (RB) and the time spent grazing(GT) (equation 1)

$I = IB \times RB \times GT$ (Equation 1)

This concept has been the framework for much of the work on grazing behaviour and development of methods to measure these variables has allowed progress in understanding sward-animal interactions.

2.4.1.1 Intake per bite

Intake per bite is the product of bite volume and bulk density (weight per unit volume) of the grazed horizon (Parsons *et al.*, 1994; Rook, 2000; Ungar *et al.*, 2001). The bite volume can be further defined as product of bite area and bite depth (Mayne & Wright, 1988; Parsons *et al.*, 1994). Bite area is defined as the mean surface area of a sward, from which herbage is severed when an animal takes a bite, and bite depth equals the difference between sward height before grazing and the average residual height of the grazed tillers (Laca *et al.*, 1992).

The change in intake per bite is a consequence of the change in sward characteristics which affect bite volume or the density within the volume. It is the bite depth element of bite volume which is most influenced by sward characteristics (Hodgson, 1986). Bite area is controlled more by the animal's anatomy, in particular the mouth and body size (Rook, 2000). The breadth of the incisor arcade is proportional to body mass (M) to the power 0.36 on short swards or to the power 0.75 on non height limiting sward (Illius & Gordon, 1987). Edwards *et al.* (1995) state that intake per bite is not always restricted by mouth dimensions in the case of sheep, for example when sometimes their mouths are inserted sideways into swards in order to get larger mouthfuls.

Bite rate and grazing time can compensate for the variation in intake per bite. Phillips and Leaver, 1986 measured an increase in grazing time and bite rate to compensate for reduced intake per bite as the season progressed (Figure 2.9).

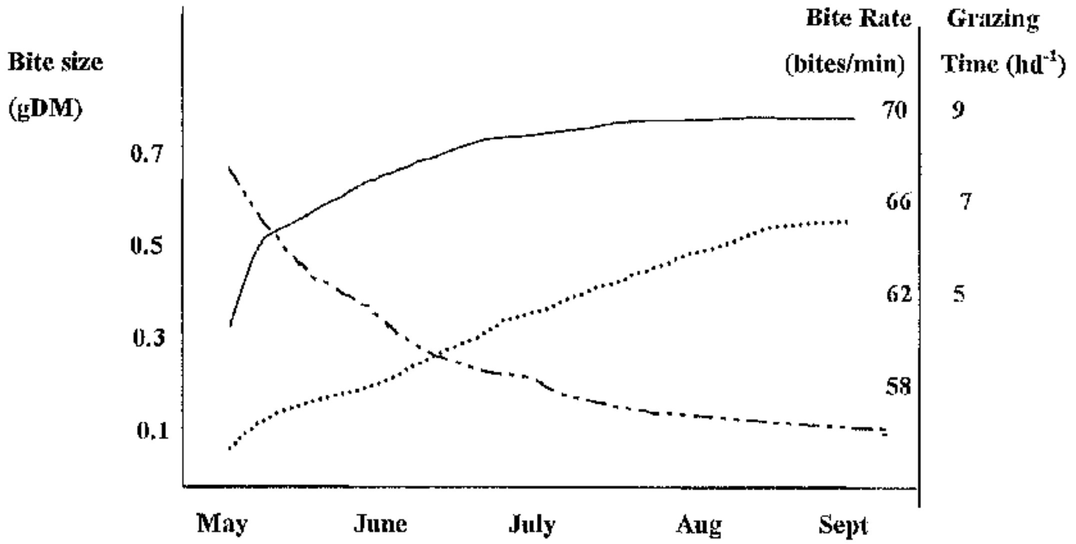


Figure 2.9: Seasonal variation in bite size (........), bite rate (..........) and grazing time (——) (Phillips & Leaver, 1986)

2.4.1.2 Grazing Time

Animals may not be able to compensate fully for low intake rate due to constraints on grazing time with a maximum of 12 h day^{-1} being recorded (Phillips & Leaver, 1986; Rook *et al.*, 1994). This is thought to be limited due to other constraints such as daylight available and requirement for ruminating. More commonly, daily grazing time would reach a plateau between 9 and 10 hours d^{-1} with 80% of grazing occurring during daylight (Rook *et al.*, 1994). Sheep and cows grazing in groups are synchronised with greater synchronisation at the start of a meal than the end, suggesting social facilitation at the beginning but physiological control at the end (Rook, 2000).

Grazing system has been shown to affect the grazing behaviour of dairy cows in that under rotational grazing, the time spent grazing and ruminating was less than for continuous stocking (Ernst *et al.*, 1980; Pulido & Leaver, 2003).

It has been shown that under some conditions the ability to compensate through increased grazing time is not implemented, e.g. Rook *et al.* (1994) showed that cows grazing very short swards and offered a supplement decreased their grazing time compared to those in taller swards offered the same supplement. These effects may be related to low marginal energy gain of additional grazing time under those restrictive sward conditions.

2.4.1.3 Bite Rate

Bite rate is affected by the time required to search and select for and process, i.e. sever, manipulate, chew and swallow the herbage (Rook, 2000). Searching and selection time will limit the bite rate if swards are spatially heterogeneous, compared to the homogenous dense sward when the next bite is readily available and processing time will be the limiting factor of bite rate (Ungar, 1996).

Jaw movements, swallowing and head movement, comprise a bite and further jaw movements are required to chew. Prehension jaw movements sweep the tongue and gather herbage into the mouth. Head movements are for reaching a new bite (Ungar, 1996). Black & Kennedy (1984) suggest the number of jaw movements per unit time is fairly constant in sheep, however Penning *et al.* (1991a) suggest the proportion of biting and chewing can change, dependent on intake per bite. For cattle the situation is more complicated as they can manipulate and chew within a single jaw movement - known as compound jaw movements (Laca *et al.*, 1994). Laca *et al.* (1994) found that time per bite increased quadratically with intake per bite because the number of manipulative jaw movements decreased, while compound jaw movements and chews per bite increased. Small bites are handled less efficiently, since ideal handling time per unit mass scales exponentially as bite mass declines (Parsons *et al.*, 1994). This explains why an increase in bite rate may not compensate for low bite mass and may be insufficient to maintain intake rate due to increased processing time (Rook, 2000). Bite rate is therefore constrained by bite mass.

Table 2.3 summarises recent published literature of ingestive behaviour. Factors which affect the components of ingestive behaviour and therefore intake rate and animal performance are classified into animal, sward and management, many of which will be discussed in following sections.

Table 2.3: Range of ingestive behaviour of dairy cows from recent experiments

Author	Intake per bite ($g\ DM\ bite^{-1}$)	Bite rate ($bites\ min^{-1}$)	Grazing time ($min\ d^{-1}$)
Gibb *et al.*, 2002	0.23-0.34*	51.9-64.2	554-629
Christie *et al.*, 2000	0.57-0.73	45-50	429-503
Gibb *et al.*, 2000	0.41-0.51	42.7-60.8	458-568
McGilloway *et al.*, 1999	0.47-1.28	51.6-68	-
Gibb *et al.*, 1997	0.33-0.48	47.5-59.4	632
Mayne *et al.*, 1997	0.41-1.1	-	-

*= $g\ OM\ bite^{-1}$

2.4.2 Foraging Strategies

Grazing strategies are used by herbivores in order to cope and adapt to their environment and changes, which occur within it. A strategy refers to a relevant pattern of foraging behaviour (Laca & Demment, 1996) or suite of decision making processes involved in the selective grazing observed (Gordon & Lascano, 1993), Figure 2.10. The animal faces the challenge of obtaining enough energy and nutrients to survive and reproduce efficiently in an environment with spatial and temporal variability (Provenza & Balp, 1990; Gordon & Lascano, 1993).

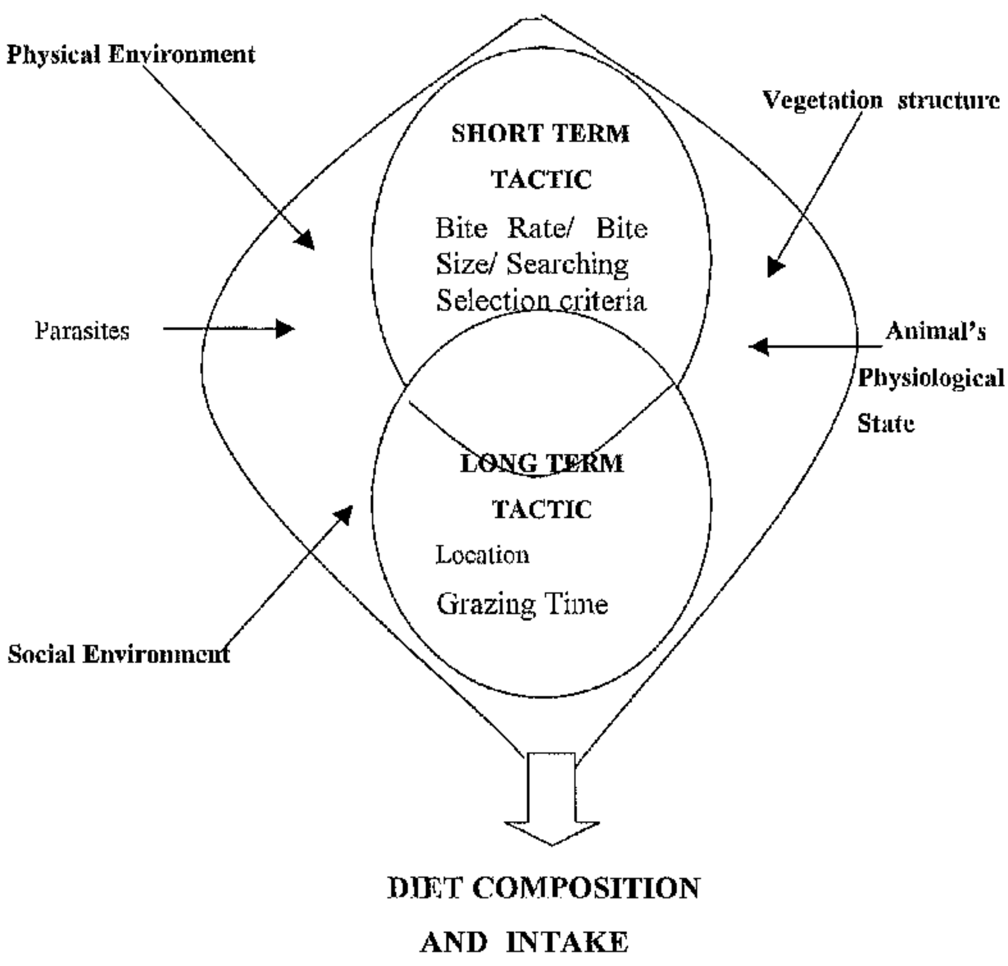


Figure 2.10: Decision and interactions involved within the components of foraging strategy. (adapted from Gordon & Lascano, 1993)

The degree of complexity of the decisions will reflect the heterogeneity of the environment in which the animal is foraging. Simple monocultures show little heterogeneity if compared to rangelands with a wide range of vegetation communities. However, at a different level no sward is homogeneous; heterogeneity exists in terms of soil, defoliation pattern, faeces and urine distribution which can be both in the horizontal and vertical plane within the sward (Milne, 1991). The vertical heterogeneity exists through live and dead material, bulk density and species within horizons with higher bulk densities coupled with greater dead material and litter, together with white clover being found in greater proportions towards the bottom of the sward (Gordon & Lascano, 1993). This differential distribution varies with management applied and time of year.

2.4.2.1 Foraging Behaviour

Models have been developed in order to understand and predict foraging behaviour. Provenza & Balph (1990) assessed five explanations of diet selection and how these models meet the challenges encountered by the foraging animal. Their work is summarised in Table 2.4.

Table 2.4: A comparison of 5 explanations for foraging behaviour by ruminants facing 5 foraging challenges

Foraging explanation	Reason ruminants select diet	Challenges addressed	Is explanation mechanistic?	Are assumptions valid?
Euphagia	Inherent recognition of nutrients and toxins	1, 2	Yes	Maybe
Hedyphagia	Nutrients taste good toxins taste bad	1, 2, 3	No	Possibly
Morphophysiology and size	Body adapted to utilise some forage better than others	1, 2, 3, 4	Yes	Yes
Learning	Consequences	1, 2, 3, 4, 5	Yes	Yes
Optimal Foraging	Most benefit, least cost	1, 2, 3, 4	No	Not always

Challenges:

1 Nutritional variation
2 Plant chemical defenses
3 Plant morphological defenses
4 Environmental patchiness
5 Unfamiliar environments

The optimal foraging theory is recognised as being more appropriate to a carnivore than a herbivore and that patch use models may be more useful and appropriate than prey models (Bazely, 1990). Patch models assume the food is distributed in clumps and predict that foraging animals will leave patches of declining intake rates. One such patch use model, Marginal Value Theorem (MVT) was investigated by Bazely (1990) using sheep with patches of differing height and colour and concluded that sheep use these variables as cues to select patches and that patches were left before fully depleted as predicted by the MVT. There is conflicting evidence as to whether grazing animals can recognise and judge the value of patches prior to grazing. Illius & Gordon (1990) concluded that, for cattle and sheep, continual sampling of patches was necessary. Edwards *et al.* (1996) found that sheep could learn to associate a food reward with a cue. Further work by Edwards *et al.* (1997) indicated that sheep formed associations between cues and rewards distinguishing by sight and smell. Laca (1998) concluded that cattle showed spatial memory returning to preferred food locations.

The animal state has also been acknowledged as influencing the foraging behaviour of ruminants; these include gut fill, physiological/reproductive status, fat and other energy reserves, water balance, blood levels of metabolites, dietary experience and position relative to herd and resources (Laca & Dement, 1996). No single model has taken all these factors and the behavioural processes of diet selection into account.

2.4.2.2 Selective Grazing

Animals can be selective as to the species and plant components which they defoliate. The heterogeneous sward both horizontally and vertically, complicates the grazers choice (Milne, 1991). Selection is that defined by Hodgson (1979) and Newman *et al.* (1995) as the plants and plant parts as consumed by the animal arising from its preference, defined as the discrimination exerted by the animal between the sward components. Work using fistulated animals (Tayler & Deraz, 1963; Laredo & Minson, 1975 and Le Du, 1981) would indicate that both sheep and cattle are able to select material of higher digestibility than human sampling of the sward would suggest. Sheep are generally more selective than cattle as a result of their narrower muzzles and the ability to graze lower into the sward (Rook, 2000). Sheep and cattle have been shown to follow the same sequence of species preference but sheep take longer to switch to the less preferred species as they were able to be more selective (Rook, 2000). Sheep have been shown to prefer white clover and to select a higher proportion of white clover within their diet than attributed by the proportional area within the grazing field (Rutter *et al.*, 1997). Both dairy cows and sheep showed a diurnal pattern of preference, choosing white clover in preference to grass in the morning and vice versa over the course of the day (Rutter *et al.*, 2001). The basis of selection is contentious. This has been suggested to be due to intake rate (Black & Kenney, 1984), nutritional balance (Provenza & Balph, 1990), vegetation density (Black & Kenney, 1984) or plant height and species mixture (Illius, 1992). Whichever the driving force, the result of selective grazing not only alters the canopy structure but also the plant-plant competition and relative abundance of species within a multi species sward. Constant dietary selection by grazing animals may lead to local extinction of preferred plant species, however, the effects are transient and can be changed rapidly by altering management allowing the community to be in a constant state of flux (Newman *et al.*, 1995; Rook, 2000).

2.4.2.3 Meal Patterns

The pattern of grazing within daily time period has been shown to be concentrated to daylight hours (Phillips & Leaver, 1986) and within this period there is evidence to show that a large meal is taken prior to sunset and the next largest meal at dawn (Gibb *et al.*, 1998; Orr *et al.*, 2001; Rutter *et al.*, 2002). Ruminating time is mainly concentrated in the hours of darkness although it is interspersed between grazing bouts during the daylight hours (Phillips & Leaver, 1986). Environmental factors may affect the diurnal pattern of grazing, e.g. daylight length, rainfall and temperature although these effects are relatively small (Rook *et al.*, 1994; Rook, 2000).

Increased DM intake in the evening also corresponds with the time of day when herbage DM and WSC concentrations are at their highest and therefore animals may be adopting an optimal foraging strategy taking advantages of these optimal conditions (Orr *et al.*, 1997; Orr *et al.*, 2001). An alternative suggestion is a strategy to ensure rumen fill prior to darkness when grazing will be limited (Penning *et al.*, 1991b).

Gibb *et al.* (1998) reports significant effects of time of day on bite mass and bite rate, resulting in an increased intake rate over the course of the day. Rutter *et al.* (2002) found that both total jaw movement rate and also the proportion of these jaw movements that were bites, tended to be greater in the evening leading to increased intake rates but with fewer chewing movements. Orr *et al.* (2001) investigated effects of giving cows their daily grass allowance in a strip grazing system either in the morning or afternoon. They found that total grazing time was similar, however afternoon allocation resulted in a larger evening meal, higher intake rate during the first hour after allocation through higher bite rate and bite mass. The total OM intake was similar between the treatments, however milk yield was greater for afternoon grass allocation cows. This could be attributed to higher DM and WSC concentrations of the grass in the afternoon when there would have been proportionally greater grazing.

2.4.2.4 Trade-off: Intake vs. Parasite Avoidance

The heterogeneity of the sward due to faeces deposition creates patches of grass which have high nutrient and energy status. These tall patches have the potential to maximise the intake of the foraging ruminant (Hutchings *et al.*, 1999). However, helminth parasites are also associated with the faeces and migrate onto the surrounding sward (Sykes, 1987). This proves to be a dilemma for the grazer and must determine the trade-off between the consumption of high quality herbage as against avoidance of parasite ingestion, which would challenge the survival and reproductive ability of the herbivore (Hutchings *et al.*, 2001). In the light of the major challenges to the fitness and survival of the animal it would be expected that the herbivore minimises the detrimental effect of parasitism through faecal avoidance (Hutchings *et al.*, 1998). The trade-off is influenced by the physiological state and feeding motivation, immune status and current parasitic burden (Hutchings *et al.*, 1998; Kyriazakis *et al.*, 1998; Hutchings *et al.*, 2001b). It has been postulated that animals will trade-off where the benefits of nutritional advantage associated with the trade-off outweigh the costs of increased parasitism (Lafferty, 1992; Hutchings *et al.*, 1999).

2.4.3 Voluntary Food Intake

Voluntary food intake is a major factor influencing animal performance (Allen, 2000; Yearsley *et al.*, 2001). Large differences exist between feeds in the amount that an animal will consume and also between animals in the amount of a feed that they will consume (Beever *et al.*, 2000). It is regulated by physical and metabolic central mechanisms (Allen, 1996).

One of the problems with fibrous feeds, such as grass, is its bulky nature. The physical control of intake involves the capacity of the rumen and the rate of passage (Allen, 1996; Allen, 2000). The physical distension is monitored by epithelial receptors connected to the central nervous system, however it is not only volume or weight of rumen contents which limit intake but also the texture of the contents (Beever *et al.*, 2000). Texture rather than particle size has been shown to determine the outflow of the rumen and it is the time taken, through digestion and rumination, to process the fibre in forages which limit the intake (Beever *et al.*, 2000).

Voluntary DM intake increases with increasing digestibility of the diet with the NDF being the best predictor of intake because it passes through the rumen more slowly than other food constituents (Allen, 1996). Decreasing particle size through grinding or pelleting increases voluntary DM intake as a result of reduction of initial volume and retention time (Minson, 1981). Low quality, low digestibility forages are thought to constrain the intake due to a slow rate of passage. As digestibility increases voluntary DM intake is more likely to be constrained by metabolism and the animal's ability to utilise the digesta (Yearsley *et al.*, 2001). This will be related to the animal's physiological state and productivity.

2.5 SWARD MORPHOLOGY FACTORS AFFECTING GRAZING AND HERBAGE INTAKE

The major sward characteristics which affect grazing behaviour and herbage intake are sward surface height, sward bulk density and leaf/stem composition (Parga *et al.*, 2000; Peyraud & Gonzalez-Rodrigez, 2000). These factors interact to affect the ingestive behaviour: bite mass, bite rate and grazing time (Ungar, 1996). Many recent experiments have measured the effects of sward characteristics on grazing behaviour, herbage intake and milk production of dairy cows and are summarised in Table 2.5.

Table 2.5: The effect of sward characteristics on ingestive behaviour and milk production of dairy cows

Author	Sward Height (cm)	Sward Bulk Density (KgDM m^{-3})	Bite Mass (gDM)	Bite Rate (bites min^{-1})	Leaf Proportion	Herbage Intake (KgDM d^{-1})	Milk Yield (Kg d^{-1})	Comment
Gibb *et al* (2002)	7.3		0.30	60.7		10.2	20.8	Bite mass and herbage intake
	7.3		0.33	57.9		10.8	17.8	measured as
	7.1		0.32	56.8		11.4	10.5	OM not DM
Barrett *et al* (2001)	13.8#	1.3	0.74	45.0	0.80			
Exp 1	16.9#	1.66	0.70	42.3	0.76			
	13.6#	2.23	0.55	32.9	0.67			
	13.0#	2.16	0.62	45.2	0.67			
	18.5#	1.65	0.71	44.8	0.80			
Exp 2	17.4#	1.75	0.82	40.4	0.80			
	18.0#	1.85	0.86	41.1	0.74			
	17.9#	1.80	0.82	46.2	0.78			
Christie *et al* (2000)	25.7#	1.13	0.63		0.59	14.1	26.9	Leaf proportion
	28.7#	1.26	0.71		0.53	15.2	25.6	measured at
	33.8#	1.17	0.57		0.53	11.7	24.0	above 4 cm
	39.8#	1.53	0.65		0.43	14.4	21.9	sward surface height
McGilloway *et al*	21.2#	1.67	1.28	57.9	0.37			
(1999)	12.7#	2.19	1.17	55.1	0.28			
Exp 1	10.4#	2.49	0.93	57.5	0.24			
	8.9#	2.63	0.85	51.6	0.22			
	11.4#	2.45	1.00	65.4	0.39			
	8.7#	3.38	0.68	67.6	0.22			
Exp 2	6.4#	4.90	0.66	52.4	0.24			
Gibb *et al* (1997)	5.1		0.23	67.1		10.5		
	7.2		0.33	63.9		14.1		
	9.1		0.29	65.2		12.1		
Rook *et al* (1994)	4.0#					13.1	19.0	
	6.0#					14.6	22.9	
	8.0#					16.7	23.8	
	7.7					13.5	23.2	
	9.9					14.0	23.0	
Le Du *et al* (1981)	4.8	5.06				11.1	16.2	Bulk density
Exp 1	7.2	3.57				12.6	17.2	herbage intake
	8.6	3.79				12.9	18.5	measured as
	6.1	6.07				12.1	18.0	OM not DM
Exp 2	5.1	4.39				12.2	16.7	
	6.9	4.06				13.2	18.4	
Exp 3	5.0	3.94				12.4	14.5	
	7.2	4.51				15.2	19.5	

sward height using Rising Plate Meter

Care must be taken when comparing studies due to great variation in the methodologies used to measure the sward characteristics and grazing behaviour, the units used (e.g. SSH v compressed sward height and OM vs. DM) and the grazing management system.

Considering these data sets it can be generalised that bite mass is the main determinant of herbage intake and that bite rate declines slightly with increasing bite mass. A trend also is evident for increased bite mass with increasing sward height. The bulk density effect on bite mass is apparently very variable from the results in Table 2.5.

2.5.1 Sward Height

Potential intake from a given sward is positively related to sward surface height (Le Du *et al.*, 1981; Pulido & Leaver, 2001; Rook *et al.*, 1994; Griffiths *et al.*, 2003a). Gibb *et al.* (1997) reported a response of up to 1.7 kg DM d^{-1} increase in herbage intake with a 1cm increase in SSH. Pulido & Leaver (2001) and Le Du *et al.* (1981) showed a similar response in daily herbage intake with increasing sward height from 4 to 9 cm within a continuously stocked sward. However, McGilloway & Mayne (1996) and Laca *et al.* (1992) report a linear response in bite mass with increasing sward height between 8 and 20 cm and 8 cm and 30 cm hand constructed sward respectively. Bite mass and herbage intake has been shown to decline when cows are presented very tall swards of 30 cm under rotational grazing (Christie *et al.*, 2000). Gibb *et al.* (1997) also reported a reduction in herbage intake and intake per jaw movement when continuously stocked swards were maintained at 9 cm compared to 5 or 7 cm. This could be due to a reduction in herbage quality or sward components as the height increases (Hodgson, 1990; Christie *et al.*, 2000). Sward height has a marked effect on the distribution of leaf, stem and dead components as shown in Figure 2.11 and Figure 2.12.

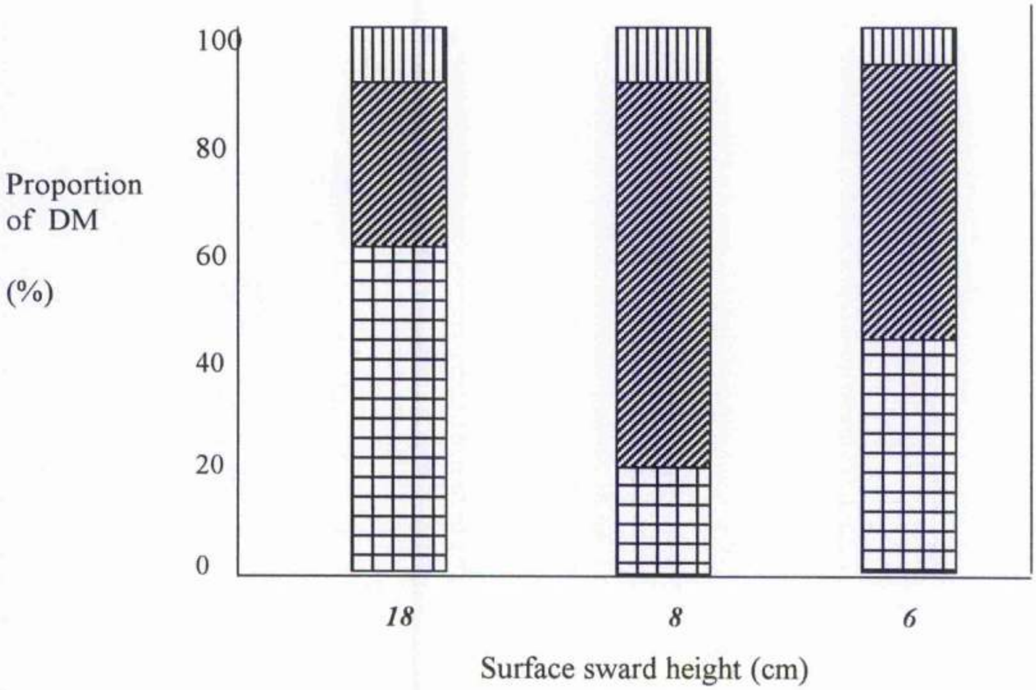


Figure 2.11: Effect of Grass Height on Components of Sward, Live stem ▦, Live leaf ▨ and Dead ||||| (Adapted from Hodgson, 1990)

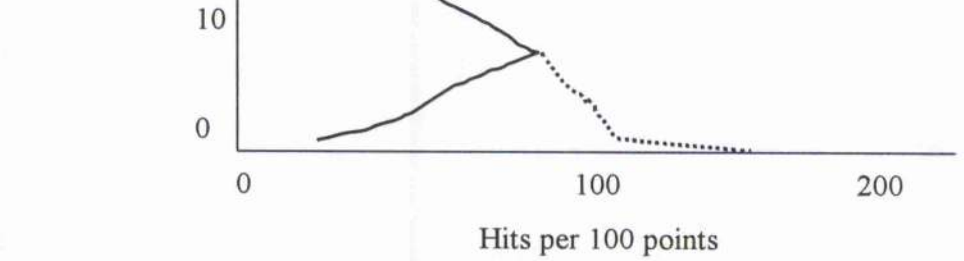


Figure 2.12: Sward profile through the horizons showing green contacts (——) and total contacts of dead and green (-------) using a point quadrat (Hodgson, 1981a)

Wade *et al.* (1989) showed dairy cows consistently removed around 34% of the tiller height over sward surface height range of 12-38 cm. However, Laca *et al.* (1992) report greater depths of up to 70%. These depth restrictions have been postulated to be due to a pseudo-stem barrier (Bao *et al.*, 1998) and the constraint on the animal due to a greater force required to sever the sward at the lower depth (Illius *et al.*, 1995; Rook, 2000).

2.5.2 Sward Bulk Density

The bulk density of the grazed horizon is an important factor in determining herbage intake through its effect on bite mass. For example, bite mass can be greater for legumes than grass despite a shallower bite depth, due to the vertical distribution of bulk density being greater near the ground for grass but near the top of the sward for legumes (Rook, 2000). There is a strong negative correlation between sward height and bulk density (Le Du *et al.*, 1987; Pulido & Leaver, 2001) and therefore the effect of each variable is difficult to ascertain. Laca *et al.* (1992; 1994a), using hand constructed swards, concluded that sward height and bulk density contributed 44% and 27% respectively to the variation in bite mass. They found animals obtained heavier bites on tall sparse swards compared to short dense swards. They also found that, at a given height, the bite area was reduced as density increased. This would reinforce the idea that bite area is limited by the force needed to sever the herbage (Illius *et al.*, 1995). Mayne *et al.* (1997) and McGilloway *et al.* (1999) concluded that bulk density becomes increasingly significant, with regards to herbage intake, as swards are grazed down and sward height declines within a rotational grazing system.

2.5.3 Leaf Mass

The leaf/stem ratio is an important characteristic of the sward, which due to its effect on both digestibility and rumen outflow rate, together with increased selectivity by grazing animal may strongly influence the herbage intake of the herbivore. Leaf is more digestible, however even at the same digestibility it has been shown that leaf is selected as a preference to stem with 20% higher voluntary intake than stems (Minson, 1981; Laredo & Minson, 1975). The leafiness of a sward declines as the sward is grazed down under rotational management (McGilloway *et al.*, 1999). While sward height can provide a good indication of sward state, it has been reported that green leaf mass can affect bite mass more so than height. The reduction in intake while animals are grazing deeper horizons is correlated with a reduction in the biomass of green leaves (Penning *et al.*, 1994). Parga *et al.* (2000) showed the positive effect of increasing the leafiness of the lower horizons within the sward. They found that increasing the leaf mass by 10% below 15 cm height, which was also accompanied by a greater tiller density, led on to higher herbage intake and produced greater milk yield in cows given a low herbage allowance. Increasing the leaf mass in the lower horizons could allow for lower herbage allowance without any detrimental effect on intake or milk yield.

Carrère *et al.* (2001) found that sheep while removing a constant 0.36 to 0.38 of a whole tiller, actually removed 0.57 of the leaf fraction of that tiller. Clover leaves were reported to have a more severe defoliation intensity of 0.7 and 0.8. Curll & Wilkins (1982) found that by reducing the leaf length, the proportion removed was increased. At leaf lengths of 161 mm and 53 mm, the proportion removed in a bite was 0.38 and 0.7 respectively.

2.5.4 Shear and Leaf Tensile Strength

While sward height and bulk density are considered to be the dominant factors affecting intake and grazing behaviour, it is important to remember that other factors play a role. Both shear strength and leaf tensile strength may contribute to bite mass variation. Shear strength of a leaf is the measure of resistance to breakage under a force applied at 90° to the length of the leaf while tensile strength is the resistance to breakage when 2 diverging forces are applied along the longitudinal axis of the leaf (Mackinnon *et al.*, 1988). Small differences in tensile strength occur between Perennial Ryegrass varieties in comparison to the difference in sheer strength (Mackinnon *et al.*, 1988). Evans (1967) showed that the leaf strength was correlated to the cellulose content, while Wright & Illius (1995) postulate that older leaves require greater force to fracture than young leaves due to the schlerenchyma content. The fine leaved species tend to produce swards of higher tiller density, which determines the higher forces and energy required to graze them (Illius *et al.*, 1995). Pseudostem and stem require greater force to sever owing to its complex structure, larger cross sectional area and higher fibre content, which may be the influencing factor in the animals active selection against pseudostem and stem (Illius *et* *al.*, 1995; Boudon *et al.*, 2002). Illius *et al.* (1995) concluded that the energy expenditure during grazing is greatest for chewing the ingestive material as opposed to the prehension of it and therefore could not be the limitation to the depth of grazing. They also report that large animals are able to graze lower in the canopy and were less constrained by the physical properties of the vegetation and the force requirement than small herbivores. Tharmaraj *et al.* (2003) measured bite fracture force and found it increased with depth in the sward for tall and short swards. However, the rate of increase down the profile was greater in tall swards. This was suggested to be due to difference in morphological structure of the tillers within the taller swards which had larger and thicker pseudostems. They also found the bite area was negatively related to bite fracture force.

2.5.5 Sward Heterogeneity

Within homogeneous grazing environments with no faecal contamination, the most important factor affecting daily intake and grazing behaviour is the sward structural distribution (Flores *et al.*, 1993). When bulk density and bite depth, as a proportion of tiller height, remain constant then the optimal sward height will maximise bite size and daily intake (Ungar, 1996). Taller swards with lower bulk density do not allow maximisation of bite size because of the constraint of bite depth (Parga *et al.*, 2000). When swards are heterogeneous, then plant/animal interactions occur at a higher level of spatial scale and choices between patches of height variation determine the daily intake. Varying the proportion of tall and short sward patches will affect the foraging efficiency (Parsons *et al.*, 2001). However, in a grazing sward the occurrence of tall patches often coincides with its association of faecal contamination and olfactory selection at the bite scale becomes the main constraint on intake (Hutchings *et al.*, 2001b). Griffiths *et al.* (2003) concluded that tall patches are selected over short only if both patches are in vegetative state. If tall is associated with stem and reproductive growth, then dairy cows will avoid these selecting instead the shorter patches. A large proportion of time is wasted on investigating potential favourable patches before rejecting due to faecal contamination and hence daily intake may be reduced if heterogeneous swards are as a result of faecal contamination.

2.6 ANIMAL FACTORS AFFECTING GRAZING BEHAVIOUR AND HERBAGE INTAKE

2.6.1 Genotype

Foldager & Haarbo (1994) showed that maximum feed intake capacity was determined by the breed of dairy cow. They reported the maximum feed intake capacity of stall fed cows for Danish red or black and white dairy cows was 20% greater than that of the Danish Jersey on a per animal basis. When this was expressed as per kg weight then their intake capacity was actually similar. Genetic selection within the dairy breeds has changed the type of animal and it's feeding requirements. Veerkamp *et al.* (1994) observed difference in DM intake of high genetic merit cows compared to cows of moderate genetic merit. Studies have shown a positive relationship between herbage intake and genetic merit (Patterson *et al.*, 1996; Buckley *et al.*, 2000 and Dillon *et al.*, 1999). Selection for milk yield and components of milk has resulted in larger animals which are more efficient in converting food energy and protein into milk (Veerkamp *et al.*, 1994). The effects of high genetic merit on grazing behaviour are not consistent and have been recorded as an increase in grazing time (Bao *et al.*, 1992), however, the difference was small compared to the greater milk production, which was suggested to be associated with a difference in grazing efficiency. O'Connell (2000) found no increase in grazing time but higher bite rates between high and medium genetic merit cows. Christie *et al.* (2000) found a trend of greater intake per bite with higher genetic merit cows and concluded that they increase their total intake through greater bite mass and not through greater grazing time and bite rate.

2.6.2 Liveweight

The size of the animal's muzzle determines the bite area, which will affect bite mass and total herbage intake. The breadth of the muzzle is proportional to body mass (Illius & Gordon, 1987). Digestion as well as ingestion constrain herbage intake and therefore the capacity of the alimentary tract can restrict intake (Allen, 2000). There is a close relationship between body size and alimentary tract capacity and therefore intake tends to increase with liveweight (Rook, 2000). Peyraud *et al.* (1996) reported increased herbage intake of between 1.0 and 1.5 kg OM (100 kg liveweight) $^{-1}$.

2.6.3 Milk Yield

Herbage intake varies according to production potential of the cow, which alter their intake in order to meet their requirements (McGilloway & Mayne, 1996). Higher yielding cows can absorb volatile fatty acids from the rumen faster as a result of their greater nutritional demands from the mammary gland compared to lower yielding cows (Illius & Jessop, 1996). Results from experiments show a positive relationship between milk yield and herbage intake (Le Du *et al.*, 1981; Rook *et al.*, 1994; Christie *et al.*, 2000; Gibb *et al.*, 2002). These studies cover a variation in management system, genetic potential and grazing system. However, in any system the ability of the animal to obtain its nutritional requirements from herbage will be greatly influenced by the sward structure and quality and indeed the whole plant-animal interaction comes into importance. Delaby *et al.* (1999) suggest a linear relationship between intake and milk yield up to 40 kg milk d^{-1} on ideal grazing conditions when herbage is not limiting. With less favourable grazing conditions a plateau in herbage intake would be expected and McGilloway & Mayne (1996) suggest such a plateau is reached above 30 kg milk d^{-1}.

The mechanism by which high yielding cows increase their herbage intake has been investigated with alterations in grazing time, bite rate and mass being considered.

Grazing time generally does not increase with increasing herbage intake (Christie *et al.*, 2000; O'Connell *et al.*, 2000). This could be due to the plateau of 9 to 10 hours which is reached by grazing animals and the diurnal control of grazing (see section 2.4.1.2).

Bite mass has been reported to be greater for the higher yielding cows with higher herbage intake (Christie *et al.*, 2000). Higher rates of intake up to 0.32 g DM minute $^{-1}$ per kg increase in milk yield have also been reported without determining how these are achieved (Rook & Huckle, 1996; Pulido & Leaver, 2001).

Bite rate has also been shown to be significantly higher in some studies for higher yielding dairy cows with greater intakes than lower yielding cows (Bao *et al.*, 1992; O'Connell, 2000).

2.6.4 Supplementation of Grazing

Supplements can be offered to cows at grass as a strategy to achieve higher nutrient intake than that possible from grazed herbage alone. The aim is to increase the production level, or to alleviate seasonal deficits in grazed grass. More specifically, supplementation can provide animals with nutrients thought to be deficit in the diet of the animal. Supplementary feeds fall into two main categories:

(i) Concentrate = ME >12.0 MJ kg^{-1}DM, DM >800g kg^{-1} DM and low fibre levels, e.g. barley or soya meal.

(ii) Forage supplements = high fibre, low DM and ME < 12.00 MJ kg^{-1}DM, eg grass silage, hay.

Substitution rate describes the reduction in grazed herbage intake per kg increase in supplement intake. Substitution rates of forage supplements are generally much higher than for concentrate supplements (Mayne *et al.*, 2000). This is thought to be the consequence of the higher fibre, lower DM content of the forage which add to the physical fill limit of the rumen. In grazing conditions of high herbage allowance, forage supplementing or buffer feeding has been shown to have high substitution rates over 1.0 (Leaver, 1985; Phillips, 1988, Peyraud & Gonzalez-Rodrigez, 2000). Accompanied by this, was also reduced milk yield or very low milk yield response to the supplement (Leaver, 1985; Phillips, 1988). It is generally recommended to offer forage supplements in situations where herbage availability is low and DM intake will be increased (Phillips, 1988). If herbage availability is high, then concentrate supplements are more appropriate to increase the nutrient intake of high yielding cows (McGilloway & Mayne, 1996).

Response to supplementation are extremely variable and dependent on the effects of the supplement on herbage intake (Mayne, 1991). Response is expressed as increase in milk output (kg) per kg of supplement fed. Early work has reported responses of 0.4 and 0.6 kg milk kg^{-1} concentrate DM (Journet & Demarquilly, 1979; Leaver, 1985). More recent studies have shown responses in excess of 1.0, which suggests an average increase in milk response of +0.1 kg per kg, concentrate DM with every 10 years (Table 2.6).

Table 2.6: Response and substitution rate to supplementation with concentrates of recent studies

Author	Concentrate fed (kg DM d^{-1})	Response (kg milk kg conc $^{-1}$)	Substitution rate (kg herbage kg conc $^{-1}$)
Gibb *et al.*, 2002	1.1/2.1/3.2/4.2/5.3	1.7/1.4/1.5/-1.1/3.7	-0.9/-0.3
Pulido& Leaver, 2001	0/5.2	0.57/0.84	0.99/1.11
Sayers *et al.*, 2000	5.0/9.9	0.64	0.57
Wales *et al.*, 1999	0/5.0	1.09	0.35
Dillon *et al.*, 1997	0/1.8/3.5	0.7/0.5	0.33/0.31

Leaver (1985) concluded, from a review of literature, that herbage availability was the major influence on the response to supplementation by dairy cows. Higher milk yield responses have been reported at lower levels of herbage allowance (Wales *et al.*, 1999). In periods of low herbage availability, provision of supplements results in low substitution rates and hence an increase in total nutrients leading to increased milk production. The response to concentrates is higher if the cow is in negative energy balance due to its high nutrient demand and/or low intake potential from the sward (Peyraud & Delaby, 2001). Herbage quality, especially digestibility, has an influence on the response to concentrate supplementation. Higher responses were observed in summer than spring when grass would be lower in digestibility (Stakelum, 1986a; Stakelum, 1986b). Wilkins *et al.* (1984) suggest a high proportion of clover in a sward may reduce the response of dairy cows to concentrate supplementation.

The evidence suggests that the response and efficiency of concentrate supplementation is not only affected by milk yield but also the interaction between the sward characteristics and morphology which influence the herbage intake and the cow's ability to obtain its nutrients from the grazed herbage alone.

2.6.5 Treading and Fouling

The pressure exerted by sheep and cattle is estimated to be 0.8-0.95 kg cm^{-2} and 1.2-1.6 kg cm^{-2} respectively (Spedding, 1971). It has also been estimated that grazing animals tread 0.01 ha per day although this is very dependent on grazing conditions, stocking rates and weather (Curll & Wilkins, 1982). The consequence of treading on the current and future grass production and utilisation is highly dependent on the soil moisture status at the time of grazing. Increase in soil bulk density and change to soil structure occur with treading, however, these are accentuated with increased soil moisture levels (Curll & Wilkins, 1982). Scholefield & Hall (1984) showed that, at or above a critical water content, treading causes soil compaction and poaching occurs with repeated treading, at least 3 times per single location, under wet conditions. The risk of poaching clearly varies seasonally, however it poses particular problems in spring and autumn when herbage growth is considerable at times when soils may be above field capacity for moisture (Wilkins & Garwood, 1986).

Brown & Evans (1973) studied the effect of treading on plant growth using sheep and different grass species. They concluded that perennial ryegrass was least susceptible, with a loss of dry matter yield of 10-20% through treading, while that for Cocksfoot was 60-80%. Swards in their first year from reseeding are much more susceptible to damage by treading than permanent swards (Wilkins & Garwood, 1986). Treading may directly damage or destroy growing-points, leaves, stems and roots which can result in reduced growth and botanical composition of the sward (Charles, 1979). Legumes are more susceptible to treading damage than grass, therefore treading within grass/legumes mixtures may cause a shift in botanical composition towards the grass component (Matches, 1992).

Stocking rate has a major influence on the extent of poaching damage and loss of production, therefore it is advised to avoid high stocking rates during periods of wet conditions on susceptible soils (Wilkins & Garwood, 1986). The evidence is therefore that the treading affect of the grazing animal can be detrimental to herbage production and sward composition which can ultimately result in reduced herbage intake and animal performance.

Fouling, through the deposition of faeces and urine by the grazing animal, directly affects the sward and ultimately grazing behaviour and herbage intake of those animals. Dung is deposited by a cow 7-13 times per day and urine 4-12 times per day (Marsh & Campling, 1970). Each dung pat covering an area of $0.02m^2$-$0.07m^2$ and urine patch 0.2-$0.7m^2$ (Bastiman & Van Dijk, 1975). The nutrient enhancement of the soil being mainly N from urine and P from dung has a beneficial effect on the growth of the grass immediately surrounding the dung pat or urine patch. The detrimental effect of the dung can be the smothering and killing of plants on which the dung pat directly lies. Urine can cause scorching and death in hot and dry conditions, however, this is less common than kill due to dung pats (Wolton, 1979). The adverse effect of faeces is much greater than those of urine with respect to the rejection of the herbage associated with the dung pat with up to 6-12 times the actual area of the pat itself, and an area of up to 45% of the whole sward being associated with dung pats (Marsh & Campling, 1970; Wolton, 1979). This rejection of herbage, through selective grazing caused by the offensive odour, can allow for a deterioration in quality through increased reproductive tillers producing stem and flowering inflorescence due to infrequent defoliation (Marsh & Campling, 1970; Wilkins & Garwood, 1986).

Herbage production due to faeces contamination of a sward is likely to be reduced because of reaching ceiling yield limit with high rates of senescence. Large & Tallowin (1979) observed 25% lower production in rejected areas of swards rotationally grazed with cattle compared to the grazed areas. The difficulty of meaningfully measuring the fouling effect on sward production has limited experimental work in this area.

Grazing behaviour relating to the heterogeneous swards created by dung pats has been investigated in a number of studies (Marten & Donker, 1964a, 1964b; Hodgson, 1981; Boa *et al.*, 1998; Hutchings *et al.*, 1998). There is agreement that patches associated with dung pats are not totally avoided or rejected, but rather a continuous sampling occurs in order to allow the animal to determine its value in relation to the diet being consumed. The height and colour differentiation of these patches may be used as a cue by the animal, which allows them to associate the offensive dung and that herbage patch (Edwards *et al.*, 1996).

When sampling these rejected patches, the bite rate was reduced and it was suggested that this was due to difficulty in handling the tall grass (Bao *et al.*, 1998). Bao *et al.* (1998) concluded that, under rotational grazing, the proportion of bites from the tall patches increased as the sward was grazed down and that the dairy cows initially grazed these patches from the edge furthest from the dung pat.

The effect of the change in grazing behaviour due to fouling on the herbage intake and animal production has also been investigated. The increase in herbage intake with clean, compared to fouled, pastures has been shown to be 10% (Greenhalgh & Reid, 1968; Sporndly, 1996) Grazing intensity will influence the intake on both clean and fouled swards. Wilkins & Garwood (1986) propose no effect if grazing intensity is low or high, however, over a middle range there would be a reduction in bite rate due to fouling. Animal performance was not significantly different, possibly due to the short time period of the experiment not allowing for the advantages to be recorded. Alternatively, over estimate of OMD intake could have been due to plucked samples being of lower digestibility than the diet selected by the dairy cows on the fouled pastures (Sporndly, 1996).

2.7 CRITICAL REVIEW OF LITERATURE AND RATIONAL FOR FURTHER WORK

The relationship between vegetation and grazing herbivore is dynamic: the structure and quality of vegetation affect not only the diet of the grazing animal but also the foraging behaviour it will exhibit, which in turn modify the structure and composition of the vegetation (Gordon & Lascano, 1994).

Grass plants, which are defoliated, show physiological and morphological responses. The physiological response to the removal of the photosynthetic area and carbohydrate source allows the plant in the short-term to survive and re-grow. Morphological response is long-term and is an important factor in 'avoidance' and 'tolerance' mechanism to grazing which allow for grazing resistance and survival with a grazed sward (Briske, 1996; Bullock & Marriott, 2000).

The defoliation management - cutting, grazing, grazing system, nitrogen use, stocking density and rates and animal species – have been shown to modify or change the sward morphology (Matches, 1992; Fisher & Roberts, 1995; Mayne *et al.*, 2000).

However, no sward is homogenous; there is always heterogeneity in both the horizontal and vertical plane due to patterns of grazing and faeces or urine deposition. This adds a further level to sward morphology and needs to be considered when trying to understand the plant/animal interactions of grazing. Heterogeneity of swards has been considered vertically with regards leaf mass, bulk density and pseudostem presence (Laca *et al.*, 1992; Flores *et al.*, 1993; Laca *et al.*, 1994; McGilloway *et al.*, 1999; Rook *et al.*, 2000; Dumont *et al.*, 2002). The horizontal heterogeneity in terms of patch distribution has been studied within the context of mixed species, e.g. grass/white clover swards or extensive grassland with a high variability of species content (Thorhallsdottir, 1990; Milne, 1991; Wallis de Vries, 1994; Garcia, 2002).

Spatial heterogeneity as a result of faeces deposition has been less well studied. Work some decades ago focussed on the effects of dung on production and growth and the associated dynamics of patch development (Marsh & Campling, 1970; Wolton, 1979). However, the dynamics of these patchy swards and the associated morphological differences have not been examined fully.

Morphology of the sward also has a major influence on grazing behaviour, with sward height, density and green leaf mass being shown to affect intake through modifications in grazing time, bite rate and bite mass (Rook *et al.*, 1994; Gibb *et al.*, 1997; Pulido & Leaver, 1997; Gibb *et al.*, 1999; McGilloway *et al.*, 1999). Foraging strategy adopted by the grazing animal is also influenced by sward structure (Ungar & Noy-Meir, 1988; Illius *et al.*, 1995, Laca *et al.*, 1994, Tharmaraj, 2003).

Diet selection by grazing animals has concentrated on the plant species preferences (Rutter *et al.*, 2001; Rook, 2000) with much work on understanding the basis of selection which is contentious (Black & Kenney, 1984; Provenza & Balph, 1990; Illius, 1992).

Studies of grazing behaviour associated with sward heterogeneity due to faecal contamination are very limited. Bao *et al.* (1998), showed that under rotational grazing, tall patches associated with dung pats are selectively grazed by dairy cows later in the grazing cycle, with the short patches being preferred. Hutchings *et al.* (1999) and Hutchings *et al.* (2001) investigated the grazing behaviour of sheep to tall patches associated with dung in relation to the trade-off with parasitism and postulated that grazing occurs if the trade-off outweighs the cost of potentially increased worm burden.

There remain many unanswered questions as to the interaction between the patchy sward and the grazing dairy cow. How, when and what encourages the cow to utilise the taller, infrequently grazed patches and what are the dynamics of the patches within the sward during mid season?

Bazeley (1990) and Griffiths (2003) showed that sheep and cattle select tall grass when given a chance of tall or short patches, uncontaminated with faeces, however if stem was associated with tall patches then the shorter patches were selected. Edwards *et al.* (1997) investigated the use of areas by sheep to associate a reward, using sight and smell. Illius & Gordon (1990) concluded that the taller patches associated with faeces are not totally avoided but continually sampled by the grazing animal in order for it to make an informed choice and to select its preferred diet. Is this true for dairy cows? What factors within the sward would cause the dairy cows to change their grazing behaviour and increase grazing of the previously infrequently grazed patches and thus significantly increase the utilisation of these patches within a heterogeneous sward? What effect would this have on milk yield?

Modelling foraging strategy has attracted much research with mechanistic models describing sward structure in two dimensions (Hutchings, 1991; Parsons *et al.*, 1994; Ungar & Noy-Meir, 1988). None of these models take into account the three dimensions of a sward and do not take account of spatial scale. Animal-based models have also been developed to varying degree of complexity of the foraging mechanics (Illius & Gordon, 1987; Demment & Laca, 1993; Brereton, 1996). Most of these animal based models do not incorporate sufficient sward variables. The lack of data on the dynamics of patches within a sward and the factors, which affect the animals grazing behaviour and intake from these patches, results in simplified models unrealistic to the field situation. An understanding of the sward and animal interactions associated with heterogeneous swards due to faecal contamination would allow for verification of developed models and allow for their improvement. It would also allow for the development of grazing systems and strategies, which would enhance the utilisation of the infrequently grazed patches and could improve animal performance.

Overall, there is a lack of understanding and knowledge on the plant and animal interactions involved with heterogeneous swards caused by faecal contamination. Increased utilisation of the whole sward and improved dairy cow performance could result from a better understanding of these interactions.

The aims of this study are:

1. To investigate the morphology of patches in a sward during the mid season.

   (a) To measure morphological characteristics of the frequently and infrequently grazed patches and the change of these over the mid season.

2. To investigate the foraging behaviour of dairy cows associated with the frequently and infrequently grazed patches of a faecal contaminated sward.

   (a) To explore the grazing behaviour of dairy cows associated with a heterogeneous sward and its effect on intake and milk production.

3. To determine the effect of grazing management on the dynamics of the patches and utilisation by dairy cows of infrequently grazed patches.

   (a) To study the effect of grazing pressure during mid season on the utilisation of infrequently grazed patches and its effect on intake and milk production.

   (b) To measure the effect of the frequently grazed patch height on the morphology of infrequently grazed patch and the grazing behaviour, intake and milk yield of the dairy cows.

   (c) To modify the morphological structure of the infrequently grazed patch through topping and to measure the effect of topping frequency on the grazing behaviour, intake and milk production of dairy cows.

CHAPTER 3. EXPERIMENT 1

THE EFFECT OF GRAZING PRESSURE IN MID SEASON ON THE INFREQUENTLY GRAZED PATCH MORPHOLOGY, UTILISATION AND DAIRY COW PERFORMANCE.

3.1 INTRODUCTION

Stocking rate, defined as the mean number of animals per area of land over a given period of time, or stocking density, which is defined as the number of animals per area of land at a given point in time, has the most direct influence on the efficiency of output of milk at both the per cow and per hectare level. For example, over thirteen stocking rate experiments Journet and Demarquilly (1979) observed an average reduction in milk yield of 10% per cow with an increase of 20% per hectare through increasing the stocking rate by one cow per hectare. Jones and Sandland (1974) reviewed grazing trials with beef cattle and concluded that, at a stocking rate giving maximum liveweight gain per hectare, individual animal performance was reduced by 24% relative to the maximum achievable at low stocking rate. The relationship between stocking rate and animal performance has been shown to be linear for growing animals from studies carried out by Hodgson (1975). Mathematical modelling, however, suggests a curvilinear decline in individual animal performance with increasing stocking rate, which has been shown by McFeely *et al.* (1977) using lactating dairy cows.

Neither of these measurements, stocking rate or stocking density, quantify herbage availability to the grazing animal. If we are to consider the supply of herbage relative to the animal's requirement, then account must be taken of the quantity of herbage available. Grazing pressure is used to define the number of grazing animals per weight of herbage at a given timepoint. Stocking density can therefore be used to manipulate the grazing pressure at any given time.

Grazing pressure in early season has been shown to affect the sward morphology in mid and late season (Korte, 1981; Baker and Leaver, 1986; Dillon and Stakelum, 1988; Stakelum and Dillon, 1990 and Fisher and Roberts, 1995). The evidence indicates that the greater the grazing pressure in early season the higher quality is the sward for mid season grazing i.e. less infrequently grazed areas, higher tiller density and greater proportion of leaf. The effect of a high stocking rate resulting in a high grazing pressure during the early season on milk production during mid season was studied by Chalmers *et al.* (1981), Stakelum and Dillon (1990) and Fisher and Roberts (1995). The results of Chalmers *et al.* (1981) under continuous stocking and Dillon and Stakelum (1990) under rotational grazing, both showed greater dry matter intake and milk yield per cow in the mid season with those cows on the swards which had been managed under high grazing pressure during the Spring, compared to those under low grazing pressure in Spring. Fisher and Roberts (1995), however, under continuous stocking, observed different results. Cows grazing on swards which were grazed hard in Spring showed lower dry matter intake and less milk per cow than those on swards grazed laxly in Spring. These contrary results to those of Chalmers *et a.* (1981) could be attributed to the poor growing conditions during the mid season for the experiment of Fisher and Roberts (1995), when supplementary forage and concentrate were offered and could have substituted for grazed grass intake.

Early season management has been shown to be useful in manipulating the sward for reduced infrequent grazed patches in mid season, however, there is no work on the utilisation of these patches during the mid season.

Too high a grazing pressure applied directly during the mid season has been shown to be detrimental to milk production under rotational grazing (Stakelum, 1993). There is no work to examine the effect of high grazing pressure during the mid season on the sward morphology and utilisation of the otherwise infrequently grazed areas within a sward under continuous stocking management.

This chapter describes an experiment designed and carried out to investigate the effect of manipulating grazing pressure during the mid season on the sward morphology and utilisation of infrequently grazed patches within the sward, under continuous stocking. Grazed grass intake and animal performance of lactating dairy cows was measured to help understand the plant - animal interactions associated with this utilisation.

3.2 MATERIALS AND METHODS

The experiment was designed to examine how two grazing pressures applied during the mid season, by manipulating the stocking density of lactating dairy cows, affected the dynamics of infrequently grazed patches within the sward. Treatment 1 applied a high grazing pressure (HP) by manipulating the stocking rate to reduce the grazed grass height to 6 cm. Treatment 2 applied moderate grazing pressure (MP) by maintaining grazed sward height of 7.5 cm. These heights were chosen to represent high and moderate grazing pressure in accordance with the recommended sward surface heights for dairy cows under continuous grazing (Hodgson, 1981).

The experiment was managed as a continuous stocking system carried out between 7 July and 19 August 1997. The design was randomised complete block. Six plots, which were approximately equal by size at 1.7ha each, were blocked into replicates on 7 July when there was no significant difference in grazed height or proportion of infrequently grazed patches within blocks. Plots were randomly allocated to treatments at this time. The sward was predominantly perennial ryegrass, *Lolium perenne* of intermediate and late heading varieties originally sown in September 1996. All plots received a total fertiliser application of 360 kg N, 45 kg P_2O_5 and 45 kg K_20 per ha during the whole grazing season with Nitrogen applied at monthly intervals.

The management of the swards was carried out from turnout on 21 April. Stocking was continuous and surface sward heights, SSH maintained at around 7.5 cm by put and take of animals. This conditioning period ensured all plots had similar levels of infrequently grazed patches at the end of June. A rest period of 7 days was necessary due to very low growth rates prior to the experimental period, which commenced 7 July. The first two weeks of the experimental period were used to allow cows to adjust to the experimental system and also to provide covariate data for animal parameters. Treatments were imposed on 21 July until 19 August, when the trial finished. Stocking density was used to maintain target SSH, which was used as a tool to determine grazing pressure. The low rainfall and relatively high temperatures during July and August, see appendix 1, resulted in the MP treatment falling below the target SSH of 7.5 cm, even at the lowest stocking density dictated by the minimal number of animals required for reliable intake data.

Thirty six multiparous Holstein/Friesian cows calving between 3 February and 24 June were paired according to calving date, milk yield at the end of June and lactation number. One cow per pair was randomly allocated to a treatment within a replicate on 7 July. Each treatment had a total of 18 cows with six cows per plot on which all measurement were made. Additional cows from the main dairy herd were added and removed to manage the grazing pressure. During the experiment cows were milked at 06.30h and 15.30h. Throughout the experimental period the core cows received 2.9kg DM day^{-1} of a 200g kg^{-1} DM Crude Protein concentrate.

3.3 MEASUREMENTS

Sward surface height was recorded Monday, Wednesday and Friday of every week during the experimental phase using a HFRO sward stick (Hill Farming Organisation, 1986). This tool allowed the prescribed grazing pressures to be maintained through target sward heights. Stocking densities were adjusted according to the trend in SSH, with the object of maintaining SSH at 7.5 cm in MP treatment while reducing the SSH gradually to 6 cm under the HP treatment. Minimal stocking rate of 3.5 cows/ha were maintained irrespective of SSH due to the requirement for sufficient individual cow data for intake estimation which resulted in the SSH dropping below the target of 6 cm.

Sixty SSH measurements were taken in a 'W' pattern across each plot. If the sward stick landed in an infrequently grazed patch, subjectively determined, then this fact was recorded and a height in the nearest grazed area was also measured. This provided 60 grazed heights together with the proportion and height of infrequent grazed patches within the sward. A criticism of this method is the high variability of subjective measurements between operators. This potential source of variability and bias was avoided by the use of a single operator who made all measurements.

Defoliation of tillers was recorded Monday, Wednesday and Friday each week by marking individual tillers with plastic covered wire at 20cm intervals along a 4m transect which traversed both frequent and infrequently grazed areas. The youngest leaf tip of each tiller was split to aid the determination of defoliation between recording occasions. Ninety tillers within both areas of the sward were marked per treatment.

Weekly herbage samples were collected from the frequently and infrequently grazed areas separately by mowing to 2 cm above ground level using an Alpino Motor Scythe on average 5 strips (1.5m x 0.33m) located at random. These samples were used to determine herbage mass and also sub-samples were taken for sward component analysis. Samples for herbage mass were dried at 80°C for 12hrs to determine dry matter content. Sub-samples for component analysis were separated into leaf and stem, living and dead prior to drying to determine proportions of components on a dry matter basis. Samples from herbage mass were also used for NIR (near infra-red spectroscopy) to estimate Digestible Organic matter in the dry matter (DOMD), Metabolisable energy (ME), crude protein (CP), water soluble carbohydrate (WSC) and neutral-detergent fibre (NDF) of both frequently and infrequently grazed areas within the swards. The calibration set for NIR used fresh grass samples from the fields at SAC Auchincruive and Crichton Royal Farm (Offer, N.W. personal communication) with the methodology for scanning and prediction being that published by Barber *et al.* (1990)

Tiller density was measured every 14 days during the experimental phase. Twenty random cores (19.6cm^2) were collected per plot, sixty per treatment, from frequently and infrequently grazed areas. Living tillers i.e. those with no sign of senescence on the last emerging leaf sheath were identified allowing for perennial ryegrass (*Lolium perenne*) and a total live tiller count to be recorded.

Detailed height data, using the sward stick, of infrequently grazed patches associated around dung pats was recorded using a quadrat (1.5m x 1.5m) with a 100-square grid, each square 15 cm x 15 cm. Undisturbed SSH was recorded Tuesday and Friday of each week throughout the 7 week experimental period. Maximum height recorded was the maximum height of the sward stick, 30cm. Three dung pat areas were recorded per plot.

Intake of grazed herbage by individual cows was estimated using the n-alkane technique, starting at week 1 and continuing consecutively for 5 weeks. Animals were dosed twice a day with pellets containing 640mg in total of dotriactane (C32) impregnated into shredded paper. After the initial seven day period, when the concentration of alkane reaches a constant level, faeces were sampled from individual animals at each morning or afternoon milking. These were then bulked for 5 consecutive days. Hand plucked herbage samples were also taken separately from the frequently and infrequently grazed patches daily. Samples were obtained randomly throughout the whole plot. These herbage samples were bulked every 3 days for both frequently and infrequently grazed patches. Both faeces and herbage samples were stored at -20°C initially prior to freeze drying. Milled samples were analysed for n-alkanes as described by Mayes et al (1986). The alkane profiles (especially the odd chain C27-C35) of the frequently and infrequently grazed patches differed due to the presence of stem and flower in infrequently grazed patches. The difference was used to estimate the proportion of herbage from frequently and infrequently grazed patches in the diet. The technique involved the use of Microsoft Solver to calculate the dietary proportions, which would yield the best fit between predicted and measured C27-C35 ratios in faecal samples. Total intakes were estimated using the formula of Hameleers and Mayes (1998), using C33 and C32 alkane concentrations of the complete diet of individual animals and the using C27-C35 alkane recoveries as reported by Dillon (1993).

Milk yield was recorded daily for the 36 core cows with samples taken mid week for consecutive am and pm milking for analysis of fat, protein and lactose content (Biggs, 1979). Cows were weighed and condition scored (Mulvany, 1977) every seven days following afternoon milking.

The grazing behaviour of core cows was recorded as time spent grazing, ruminating or other activities during a continuous 24 hour period. These observations commenced one week prior to the treatments being imposed and continued at weekly intervals thereafter for four consecutive weeks. Cows were observed every 15mins with activity recorded. Night recordings were aided by torch and coloured collars for core cows.

In addition, bite rate and the area of grazing within the sward were recorded on the day prior to 24 hour observations for each week. Bite rate was recorded as the natural bite rate, including the time spent searching for and manipulating herbage. The time for 20 bites was recorded for 10 observations on one core cow per plot after morning and afternoon milking. The core cow in each plot was from the same initial cow grouping with all cows being observed over the four week period. Concurrently, the grazing area was observed and determined as either frequently or infrequently grazed patch. The time spent within the infrequently grazed patches during two 5 minute periods, after morning and afternoon milking, was recorded.

3.4 STATISTICAL ANALYSIS

The statistical comparison between treatments was estimated using statistical package Genstat 5 release 4.1 (Lawes Agricultural Trust, 1990). Animal performance data were analysed by analysis of covariance, in order to take into account the between-animal variation. Those animal variables measured over the whole experimental period were analysed by repeated measures, with each cow treated as one unit, in order to account for the dependence on time for those variables. Animal performance data were also evaluated by calculating the slope for each animal as a summary measure of response over time. A comparison of slopes between treatment groups was made by one way ANOVA. Sward data were analysed at specific timepoints throughout the experiment by analysis of variance with two treatments, each with three replicates. Using time as a factor within the ANOVA, these results were compared over the experimental period, since the same unit was not sampled at each timepoint and therefore repeated measures could not be imposed.

3.5 RESULTS

3.5.1 SWARD

3.5.1.1 Sward Surface Height (SSH) and Proportion of Infrequently grazed areas

The frequently grazed patches were reduced from 7.5 cm at week 1 to 5.1 cm and 6.6 cm at week 5 under the HP and MP treatment respectively, with a significant difference between treatments ($P \leq 0.001$) evident over all weeks and at weeks 2, 3 and 4 (Table 3.1; Figure 3.1). The HP treatment showing significantly lower sward height on these occasions ($P \leq 0.001$).

The height of the infrequently grazed patches showed a trend for gradual reduction over the first four weeks under the HP treatment while under the MP treatment this decline was much less until week 4 (Fig. 3.2). There was a significant ($P \leq 0.001$) difference between treatments ($P \leq 0.001$), with the HP treatment showing lower height of 2 cm, when compared over all weeks during experiment and at weeks 3 and 4. (Table 3.2)

The proportion of infrequent patches followed a similar trend to the height of these patches with a steady decline over the five weeks under the HP treatment, while under the MP treatment it remained fairly constant until week 4, after which there was a decline (Fig.3.3). The HP treatment had significantly lower proportion, by 6% compared to MP over the whole experiment with 11% and 12% significantly less at weeks 4 and 5 ($P \leq 0.001$) (Table 3.3).

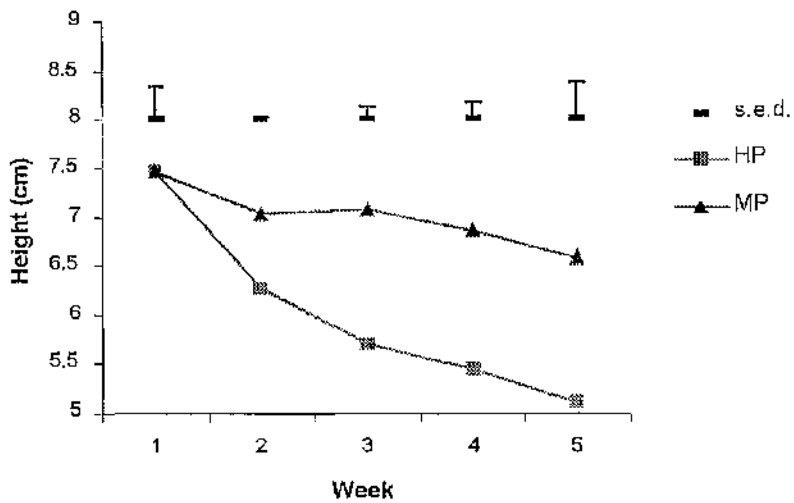


Figure 3.1: Height (cm) of the frequently grazed patches within the sward for HP (■) and MP (▲) treatments during the five week experimental period.

Table 3.1: The effect of HP and MP treatments on the height (cm) of the frequently grazed patches within the sward during the week prior to the start (week 0) and during the experiment (week 1,2,3,4).

	Mean over all weeks	Treatment x Week interaction				
		Week				
		0	1	2	3	4
HP	6.6	8.1	7.5	6.2	5.7	5.5
MP	7.3	8.1	7.5	7.0	7.1	6.9
s.e.d	0.09			0.2		
P	***			***		

***=$P \leq 0.001$

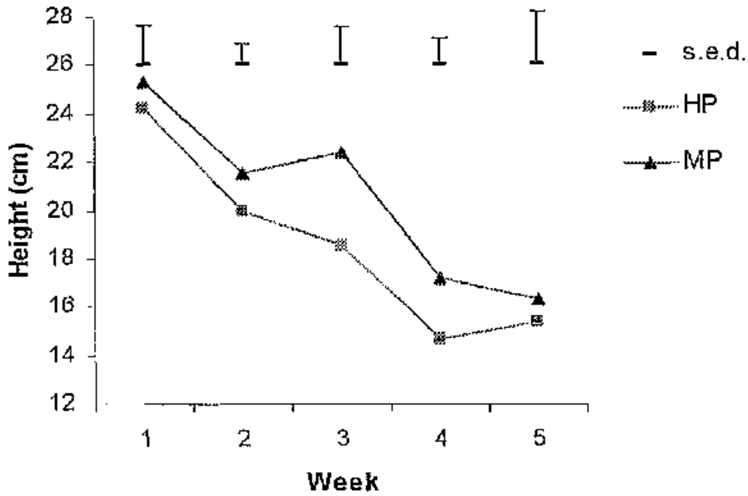


Figure 3.2: Height (cm) of the infrequently grazed patches within the sward for HP HP (■) and MP (▲) treatments during the five week experimental period.

Table 3.2: The effect of HP and MP treatments on the height (cm) of the infrequently grazed patches within the sward during the week prior to the start (week 0) and during the experiment (week 1,2,3,4).

	Mean over all weeks	Treatment x Week interaction				
		Week				
		0	1	2	3	4
HP	21.0	27.5	24.2	20.0	18.6	14.7
MP	23.0	28.5	25.3	21.5	22.4	17.2
s.e.d	0.55			1.23		
P	***			ns		

***=$P \leq$ 0.001, ns= non significant

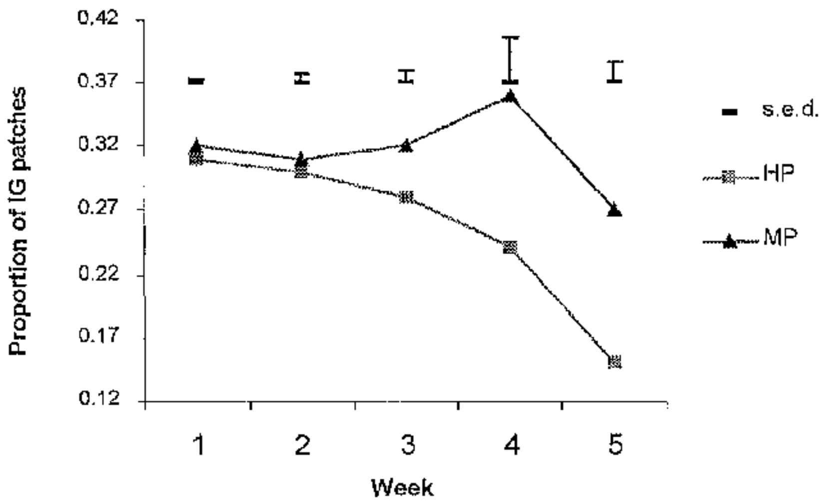


Figure 3.3: Proportion of infrequently grazed patches within the sward for HP (■) and MP (▲) treatments during the five week experimental period.

Table 3.3: The effect of HP and MP treatments on the proportion of the infrequently grazed patches within the sward during the week prior to the start (week 0) and during the experiment (week 1,2,3,4).

	Mean over all weeks	Treatment x Week interaction				
		Week				
		0	1	2	3	4
HP	0.26	0.31	0.30	0.29	0.24	0.15
MP	0.32	0.33	0.31	0.32	0.36	0.27
s.e.d	0.009			0.021		
P	***			***		

***=$P \leq 0.001$

3.5.1.2 Sward mapping

There was no significant difference between treatments at any sward height range during week 0 and 1. For week 2, treatment HP gave a significantly greater proportion ($P \leq 0.05$)of the infrequently grazed patch for the sward height ranges of 0-5 and 5-10 cm compared to MP (Table 3.4). However, treatment HP gave significantly lower proportion of the patch within the tallest sward range of >20 cm ($P \leq 0.01$). This difference was maintained throughout the following weeks together with a significantly lower proportion within the height range >10-20 cm from week 3 onwards under the HP treatment.

Appendix 2 shows these results as contour maps, using the software Mapinfo, which visually describes the reduction of height at the outer edges of the infrequently grazed patch together with a reduction of the tallest height associated in the centre of the patch. This was significantly greater from week 2 onwards under the high grazing pressure, HP compared to the moderate grazing pressure, MP ($P \leq 0.001$ wk 3 and 4, $P \leq 0.05$ wk 5; $P \leq 0.001$ wk 2 and 3, $P \leq 0.05$ wk 4).

Table 3.4: Proportion of the infrequently grazed patch falling within the height ranges 0-5 cm, >5-10 cm, >10-15 cm, >15-20 cm and >20 cm (as determined by Map Info) during the week prior to the start (week 0) and during experimental period (week 1,2,3,4,5) within HP and MP treatments.

		Sward surface height range (cm)				
Week	Treatment	0-5	>5-10	>10-15	>15-20	>20
	HP	0.0017	0.20	0.28	0.24	0.27
0	MP	0.0015	0.15	0.30	0.23	0.31
	s.e.d	0.0018	0.07	0.06	0.05	0.05
	HP	0.003	0.26	0.31	0.22	0.21
1	MP	0.005	0.23	0.33	0.22	0.21
	s.e.d	0.003	0.09	0.03	0.04	0.07
	HP	0.036	0.47	0.29	0.16	0.04
2	MP	0.007	0.32	0.34	0.21	0.13
	s.e.d	0.11*	0.07*	0.03	0.03	0.03**
	HP	0.117	0.52	0.28	0.07	0.012
3	MP	0.003	0.28	0.35	0.22	0.14
	s.e.d	0.04*	0.04***	0.05	0.03***	0.03**
	HP	0.19	0.56	0.21	0.04	0.003
4	MP	0.01	0.35	0.36	0.18	0.1
	s.e.d	0.06*	0.04***	0.04**	0.03**	0.04*
	HP	0.20	0.64	0.14	0.008	0.0007
5	MP	0.02	0.43	0.41	0.13	0.019
	s.e.d	0.06*	0.08*	0.08**	0.04*	0.009

*=$P \leq 0.05$ **=$P \leq 0.01$ ***=$P \leq 0.001$

3.5.1.3 Herbage mass

The herbage mass of the frequently grazed patches showed a steady decline in both treatments during the experiment, reaching very low levels by week 5. Herbage mass of the infrequently grazed patches was much greater, in the region of three or four fold, compared to frequently grazed patches. Under MP treatment, the herbage mass remained high up to and including week 4 but thereafter declined. The HP treatment showed a decline in herbage mass from week 4 onwards. There was significantly less herbage mass for the infrequently grazed patches under the high grazing pressure, HP compared to moderate grazing pressure, MP treatment at week 5 ($P \leq 0.05$). When all weeks are considered, there was significantly lower herbage mass within the infrequently grazed patches under HP than under MP treatment ($P \leq 0.05$) (Table 3.5).

Table 3.5: Herbage mass (t DM/ha) of the frequently and infrequently grazed patches within the HP and MP treatments prior to the start of (week 0) and during the experimental period (week 1,2,3,4,5).

	Week						
Treatment	0	1	2	3	4	5	Mean over all weeks
Frequently grazed patches							
HP	1.56	1.73	1.07	1.12	0.57	0.55	1.10
MP	1.75	1.84	1.34	0.98	0.68	0.63	1.20
s.e.d.	0.23	0.28	0.23	0.23	0.19	0.18	0.09
Infrequently grazed patches							
HP	4.63	3.73	3.70	3.77	2.74	1.16	3.29
MP	4.22	4.38	4.20	4.43	4.10	2.91	3.81
s.e.d.	0.6	0.18	0.43	0.12 *	0.62	0.39*	0.21*

*= $P \leq 0.05$

3.5.1.4 Tiller density

There was little difference between treatments for both total tiller and perennial ryegrass tiller density for samples taken randomly throughout the plots. As there was no distinction of samples taken from frequently and infrequently grazed patches the samples are not representative of either patch alone. (Table 3.6).

Table 3.6: Tiller density (number/m^2) of random samples from HP and MP treatments (both frequently and infrequently grazed patches bulk sampled) prior to the start of (week 0) and during the experimental period (week 2,4,5).

	Week				
Treatment	0	2	4	5	Mean over all weeks
Perennial Ryegrass tillers					
HP	5574	5545	5441	6086	5661
MP	4664	6322	4939	5912	5459
s.e.d.	1123	403	142	774	509
Total tillers					
HP	9846	8669	7825	8532	8718
MP	8312	9280	7608	8631	8458
s.e.d.	311*	133 *	392	757	349

*=$P \leq 0.05$

3.5.1.5 Leaf:Stem

Leaf:Stem ratio did not change significantly (P>0.05) between the start and end of the experiment. There were no significant differences between treatments at any week or over all ($P > 0.05$). The infrequently grazed patches in both treatments commenced with lower ratios than the frequently grazed patches, reflecting the higher proportion of stem within the former. The initially higher leaf:stem ratio within MP treatment was maintained throughout the experiment with no significant difference at any timepoint ($P > 0.05$). Both treatments showed a gradually decreasing leaf:stem ratio over the 5 week experimental period (Table 3.7).

Table 3.7: The leaf:stem ratio of frequently and infrequently grazed patches within the swards of HP and MP treatments prior to the start of (week 0) and during the experimental period (week 1,2,3,45).

	Week						
Treatment	0	1	2	3	4	5	Mean over all weeks
Frequently grazed patches							
HP	1.23	0.69	1.62	1.21	1.24	1.29	1.21
MP	1.24	0.85	1.11	1.26	1.65	1.33	1.24
s.e.d.	0.1	0.07	0.49	0.2	0.35	0.37	0.13
Infrequently grazed patches							
HP	0.82	0.73	0.7	0.46	0.6	0.49	0.63
MP	1.02	0.89	0.8	0.54	0.76	0.57	0.76
s.e.d.	0.2	0.47	0.16	0.22	0.18	0.08	0.10

3.5.1.6 Live:Dead

The live:dead ratio was very variable between weeks, with a trend towards a lower ratio under the HP treatment from week 2 onwards within both the frequently and infrequently grazed patches (Table 3.8). The only significant difference was found at week 4 for the frequently grazed patches, when the HP treatment had significantly lower proportion of live material ($P \leq 0.05$).

Table 3.8: The live:dead ratio of frequently and infrequently grazed patches within the swards of HP and MP treatments prior to the start of (week 0) and during the experimental period (week 1,2,3,45).

	Week						
Treatment	0	1	2	3	4	5	Mean over all weeks
Frequently grazed patches							
HP	9.8	2.2	5.2	2.7	1.3	0.8	3.7
MP	5.0	1.5	12.0	3.2	2.3	2.1	4.4
s.e.d.	6.5	0.34	3.4	0.31	0.2 *	0.9	1.26
Infrequently grazed patches							
HP	28.8	6.8	9.8	5.4	2.9	0.9	9.1
MP	26.1	3.8	11.1	4.1	4.3	2.9	8.7
s.e.d.	12.1	1.97	3.8	1.48	1.48	1.15	2.44

*=$P \leq 0.05$

3.5.1.7 Tiller defoliation: Proportion and Interval

The proportion of the marked tillers within both the frequently and infrequently grazed patches that were defoliated was greater in all weeks under the HP treatment. This was significant for the frequently grazed tillers at week 2,3 and 4 ($P \leq 0.01$ week 2 and 3, $P \leq 0.05$ week 4) and infrequently grazed tillers at week 2 and 3 ($P \leq 0.01$ week 2, $P \leq 0.001$ week 3). This greater proportion was directly related to the higher stocking density.

Infrequently grazed tillers defoliated, as a proportion of total tillers defoliated, was constant both within and between HP and MP treatments over the experimental period (Table 3.9; Figure 3.4).

The defoliation interval, or days between tiller defoliations, was greater within the infrequently grazed patch than frequently grazed patch for both treatments, with significant difference at week 4 ($P \leq 0.05$). This interval was less under the HP than MP for the frequently grazed patches. However, only in week 3 and 4 was the defoliation interval less for the infrequently grazed patches under HP compared to MP (Table 3.10; Figure 3.5).

Table 3.9: Proportion of marked tillers defoliated within the frequently grazed patches, infrequently grazed patches and tillers defoliated within the infrequently grazed patches as the proportion of total defoliations prior to the start of (week 0) and during the experimental period (week 1,2,3,45).

	Week				
Treatment	0	1	2	3	4
Stocking density (cows ha^{-1})	HP=6.3 MP=6.3	HP=4.7 MP=3.5	HP=5.9 MP=3.5	HP=7.0 MP=3.5	HP=5.7 MP=3.5
Defoliated tillers marked within frequently grazed patches only					
HP	0.18	0.24	0.30	0.33	0.28
MP	0.19	0.17	0.21	0.16	0.15
s.e.d.	0.025	0.039	0.03 **	0.052 **	0.052 *
Defoliated tillers marked within infrequently grazed patches only					
HP	0.013	0.15	0.25	0.27	0.15
MP	0.11	0.18	0.14	0.15	0.11
# *P*			**	***	
Defoliations within infrequently grazed patches as proportion of all marked tillers					
HP	0.19	0.41	0.43	0.45	0.40
MP	0.36	0.43	0.55	0.42	0.43
s.e.d.	0.08	0.05	0.07	0.05	0.06

*=$P \leq 0.05$ **=$P \leq 0.01$ ***=$P \leq 0.001$ # = repeated measures analysis carried out due to a dependence of time and therefore only *P* reported

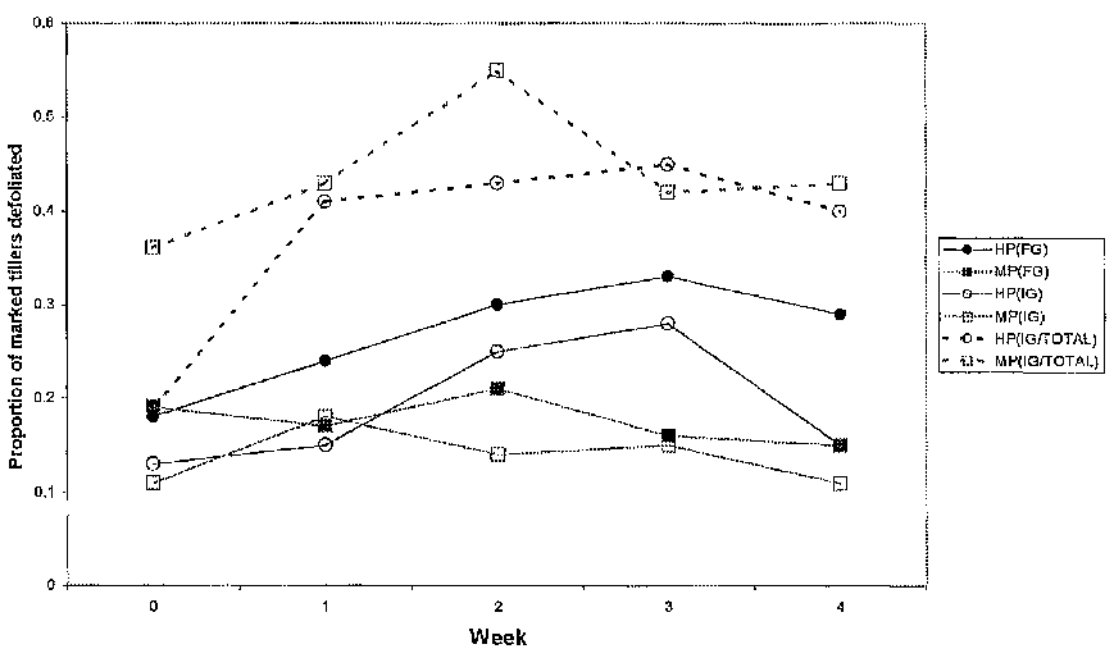


Figure 3.4: The proportion of marked tillers defoliated within, Frequently grazed, Infrequently grazed and Total tillers within HP and MP treatments.

Table 3.10: Defoliation interval (days) within Frequently grazed (FG) and Infrequently grazed (IG) patches and between HP and MP treatments prior to the start (week 0) and during the experimental period (week 1,2,3,4).

	Week				
Treatment/Patch	0	1	2	3	4
HP/ FG	9.4	10.9	9.0	7.7	7.8
HP/IG	19.0	20.8	12.0	8.4	14.4
MP/FG	15.5	13.8	12.3	16.6	15.2
MP/IG	16.8	21.4	13.8	15.3	20.2
s.e.d					
Treatment	3.34	3.98	1.925	2.07 **	1.76 **
Patch	3.34	3.98	1.925	2.07	1.76 *
Interaction	4.72	5.63	2.72	2.92	2.49

*=$P \leq 0.05$ **=$P \leq 0.01$

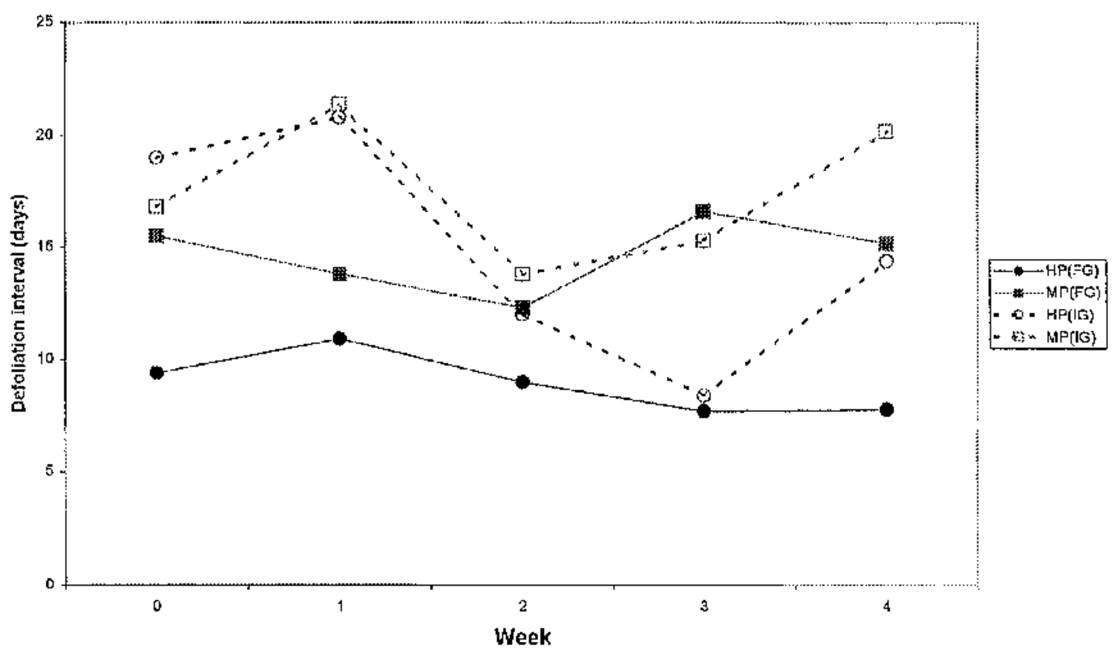


Figure 3.5: Defoliation interval of Frequently grazed (—) and Infrequently grazed (-----) tillers within HP (○/●) and MP (□/■) treatments.

3.5.1.8 Herbage quality

The D value and ME values showed little difference between treatments. Values for the infrequent patches tended to be slightly higher than for the corresponding frequently grazed patch (Table 3.11).

The NDF content was variable within and between treatments throughout the experimental period. There was a general trend for increasing NDF from week 3 onwards for both treatments.

Crude protein and Water soluble carbohydrate levels fluctuated greatly over time and within treatments.

Table 3.11: Chemical analysis of FG and IG patches of HP and MP treatments prior to the start (week 0) and during (week 1,2,3,4,5) of experimental period.

			Week					
	Patch	Treatment	0	1	2	3	4	5
D-value (%)	FG	HP	63.3	60.7	65.7	66.3	61.7	62.0
		MP	65.3	64.3	65.3	65.7	66.7	65.0
		s.e.d.	0.33	1.76	0.33	1.33	3.2	2.5
	IG	HP	70.0	67.3	67.0	64.3	65.0	64.0
		MP	68.7	66.7	67.3	63.7	65.7	67.3
		s.e.d.	0.7	0.67	0.33	0.88	0.67	2.4
ME MJ/kgDM	FG	HP	9.47	9.07	9.86	9.97	9.30	9.37
		MP	9.77	9.63	9.83	9.87	9.97	9.7
		s.e.d.	0.41	0.233	0.033	0.2	0.52	0.37
	IG	HP	10.5	10.1	10.1	9.6	9.7	9.6
		MP	10.3	10.0	10.1	9.6	9.8	10.1
		s.e.d.	0.067	0.09	0.06	0.15	0.1	0.33
CP g/kgDM	FG	HP	147	123	167	175	145	117
		MP	147	133	141	170	159	151
		s.e.d.	10.5	9.6	10.2	5.0	14.4	17.1
	IG	HP	173	142	156	134	136	131
		MP	181	161	114	156	150	127
		s.e.d.	7.6	8.7	30.4	21.2	3.9	9.7
WSC g/kgDM	FG	HP	59.7	57.5	50.3	52.3	40.0	55.0
		MP	70.3	66.0	67.7	44.3	64.0	53.6
		s.e.d.	7.06	11.0	9.5	11.5	23.5	18.6
	IG	HP	62.0	65.3	61.3	57.0	51.3	44.7
		MP	60.0	53.7	86.0	26.7	40.7	80.7
		s.e.d.	20.1	8.1	17.6	3.18 *	5.46	15.5
NDF g/kgDM	FG	HP	567	594	588	590	618	619
		MP	568	584	558	599	586	612
		s.e.d.	6.1	11.0	13.2	11.7	23.1	32.5
	IG	HP	594	593	588	616	629	655
		MP	583	593	591	624	629	605
		s.e.d.	17.2	12.6	7.2	21.0	6.4	33.0
OM g/kgDM	FG	HP	830	809	882	882	831	862
		MP	859	880	885	888	898	888
		s.e.d.	5.0 *	47.0	7.9	29.1	54.1	18.8
	IG	HP	975	953	935	895	942	941
		MP	938	934	977	891	953	982
		s.e.d.	3.9	12.4	32.0	19.4	12.4	7.2

*=$P \leq 0.05$

3.5.2 ANIMAL

3.5.2.1 Herbage Intake

Ante dependence modelling was used to analyse the data in order to take into account the effect of time for each cow. During the experimental period, there was significant difference in daily total organic matter intake from week 3 ($P \leq 0.001$), when intake under HP was significantly lower than MP treatment by between 1.5 and 4kg/d (Table 3.12; Figure 3.6). Treatment MP gave a significantly higher organic matter intake from infrequently grazed patches at all weeks ($P \leq 0.01$). There was a trend in both treatments for a decline of intake from infrequently grazed areas over weeks (Figure 3.7). There was a significant effect of time on the intake from the infrequently grazed areas with greater intake under the HP treatment at week 3 and 4 ($P \leq 0.001$) (Table 3.12).

Table 3.12. Estimated herbage organic matter intake (kg OM day^{-1}) as total daily intake and daily intake from IG patch using the n-alkane technique

		Week				
	Treatment	0	1	2	3	4
Total intake (kg OM day^{-1})	HP	22.5	22.5	22.0	20.1	22.5
	MP	21.4	21.8	23.6	23.9	23.9
	P at week	ns	ns	ns	***	ns
	P up to week	ns	ns	ns	***	***
Intake from IG patches (kg OM day^{-1})	HP	3.5	2.3	1.0	0.6	0.3
	MP	6.0	2.0	1.2	0.1	0.0
	P at week	**	ns	ns	*	ns
	P up to week	**	**	*	**	**

*=$P \leq 0.05$ **=$P \leq 0.01$ ***=$P \leq 0.001$ ns= non significant

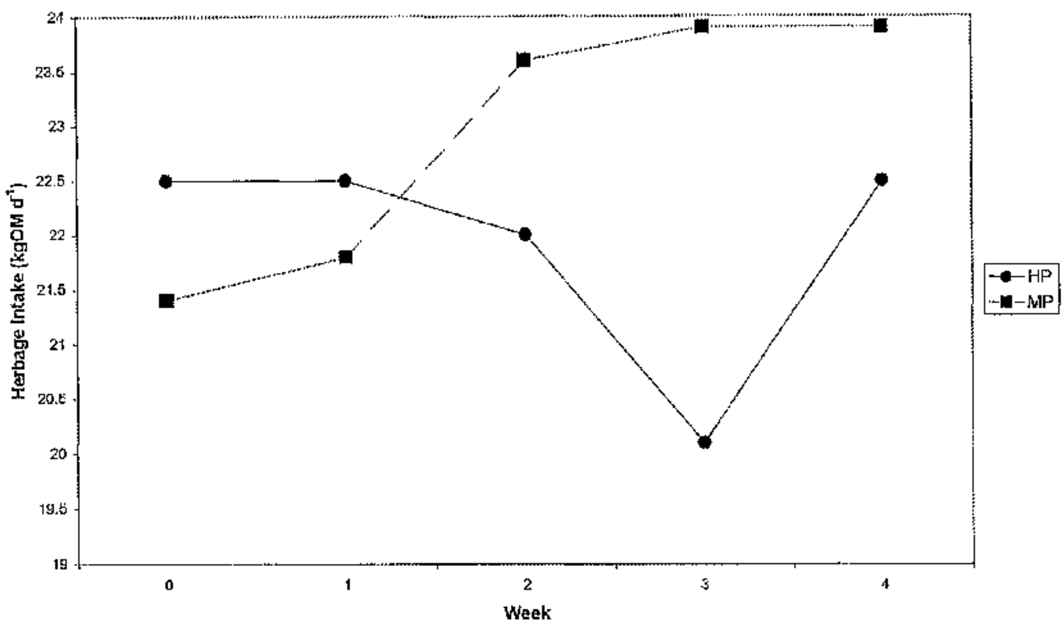


Figure 3.6 : The effect of grazing pressure treatment HP (•) and MP(■) on the total Organic matter intake (kgd^{-1}) of dairy cows during the week prior to starting the experiment (week 0) and during the four experimental weeks (week 1,2,3,4).

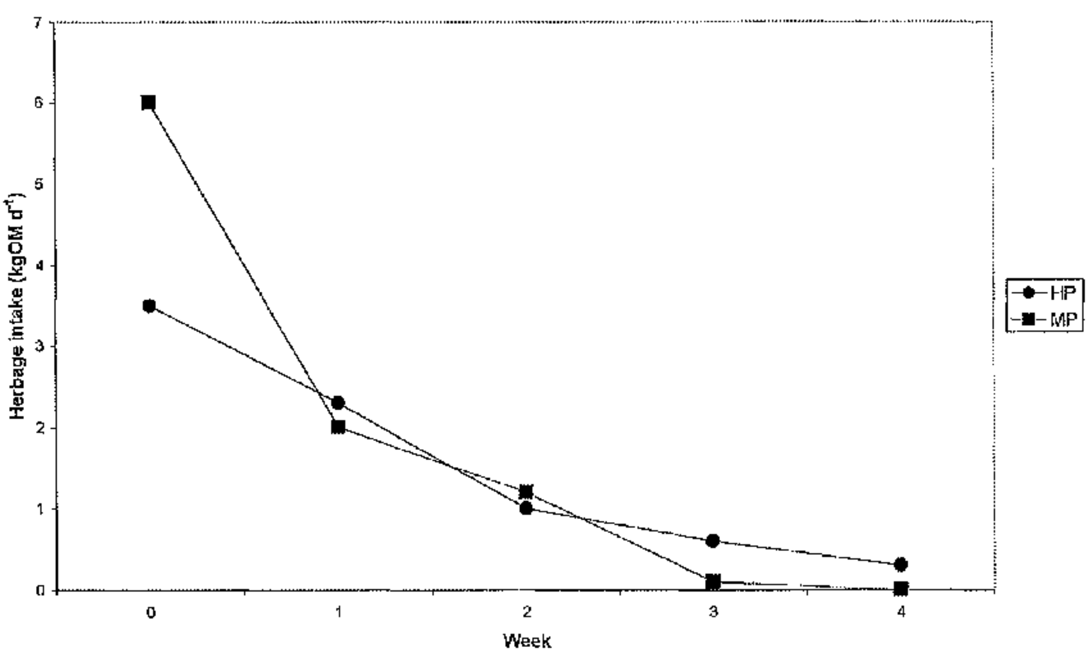


Figure 3.7: The effect of grazing pressure treatment HP (•) and MP(■) on the Organic matter intake of dairy cows (kgd^{-1}) from the infrequently grazed patches during the week prior to starting the experiment (week 0) and during the four experimental weeks (week 1,2,3,4).

3.5.2.2 Milk Yield and Composition

Daily milk yield corrected to standard fat and protein was significantly greater at week 3 and 4 for the MP treatment compared to the HP treatment by 1.4 and 3.2 kg/d respectively ($P \leq 0.05$) (Table 3.13; Figure 3.8). Over all the experimental period there was an accumulated effect, which was significant by week 5 with higher yields for treatment MP compared to HP ($P \leq 0.05$).

There was no significant difference ($P > 0.05$) in the percentage composition of fat between the two treatments at any week or over weeks (Table 3.13). Protein percentage was significantly lower at week 5 for the HP treatment ($P \leq 0.05$), however this was not true when compared throughout all weeks. Lactose percentage was significantly higher at week 2 ($P \leq 0.05$) then significantly lower at week 3 and 4 under the HP treatment ($P \leq 0.01$ week 3, $P \leq 0.05$ week 4). There was also a significant effect of time on treatments from week 3 onwards ($P \leq 0.01$).

Fat yield was significantly lower under the HP treatment at week 4 and 5 ($P \leq 0.05$). The effect over time was significant by week 5 ($P \leq 0.05$) (Figure 3.9).

At week 0 the protein yield was significantly less under the MP treatment ($P \leq 0.01$), however, this did not continue and by week 3 and 4 had significantly greater yield ($P \leq 0.05$ week 3, $P \leq 0.01$ week 4) (Figure 3.9). This was significant throughout all weeks when taking account of the effect over weeks ($P \leq 0.001$).

The change of FPCM, Fat yield and Protein yield over time when analysed by linear regression was not significantly different between treatments ($P > 0.05$) (Table 3.14).

Table 3.13: Milk Yield (kg cow^{-1} day^{-1}), Fat and Protein corrected milk yield, FPCM (kg cow^{-1} day^{-1} corrected to fat and protein content of 40 g kg^{-1} and 30g kg^{-1} respectively), milk composition (fat, protein and lactose g kg^{-1}) and yield of fat and protein (g day^{-1}) for cows prior to the start of the experiment (week 0) and during the experimental period (week 1,2,3,4) on HP and MP treatments.

			Week				
		Treatment	0	1	2	3	4
Milk yield		HP	27.6	25.3	23.8	21.6	19.4
		MP	27.1	25.9	24.3	23.7	22.1
		P at week	ns	ns	ns	ns	*
		P up to week	ns	ns	ns	*	***
FPCM		HP	27.4	23.0	22.6	20.5	17.8
		MP	27.0	23.4	22.6	21.9	21.0
		P at week	ns	ns	ns	*	*
		P up to week	ns	ns	ns	ns	*
	Fat	HP	41.7	37.3	40.2	39.5	38.3
		MP	41.5	37.2	38.2	40.2	38.6
		P at week	ns	ns	ns	ns	ns
Milk		*P up to week*	ns	ns	ns	ns	ns
Composition	Protein	HP	31.1	29.7	30.2	29.2	28.9
		MP	31.3	30.3	30.6	30.5	30.3
		P at week	ns	ns	ns	ns	*
		P up to week	ns	ns	ns	ns	ns
	Lactose	HP	45.6	44.3	45.0	44.2	43.3
		MP	45.7	45.0	44.8	44.6	44.4
		P at week	ns	ns	*	**	*
		P up to week	ns	ns	*	**	***
Fat yield		HP	1230	1170	930	850	732
		MP	1243	1055	940	913	862
		P at week	ns	ns	ns	*	*
		P up to week	ns	ns	ns	ns	*
Protein yield		HP	864	734	717	628	548
		MP	854	768	738	696	667
		P at week	**	ns	ns	*	**
		P up to week	**	**	**	**	***

*=$P\leq$ 0.05 **=$P\leq$ 0.01 ***=$P\leq$ 0.001, ns = non significant

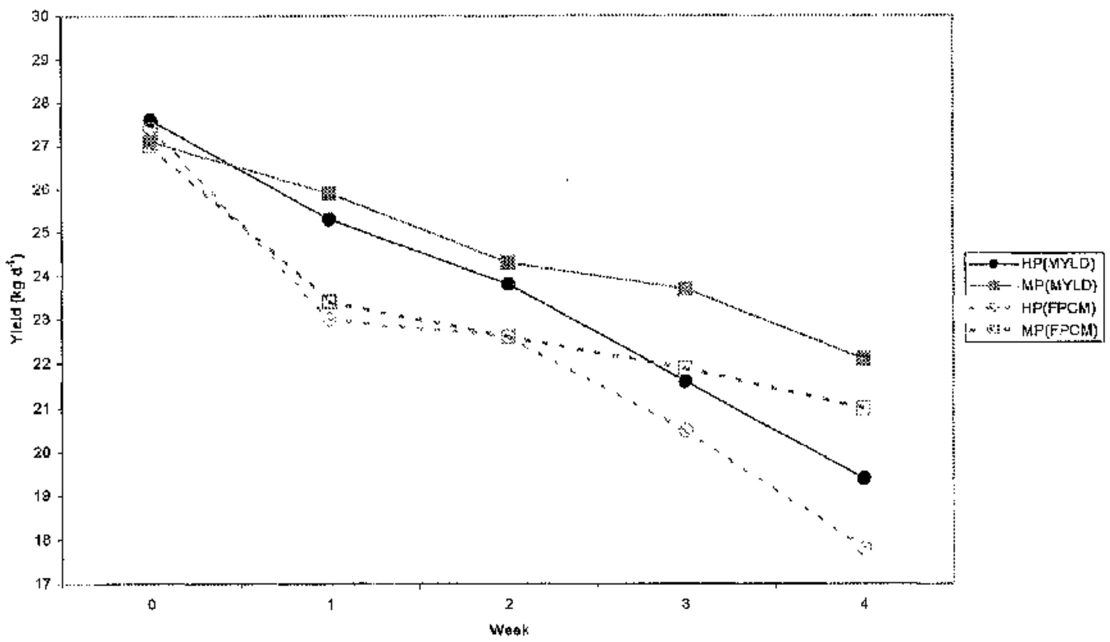


Figure 3.8: The effect of HP (•) and MP(■) treatment on daily milk yield (—) and FPCM (----) (kg/d) during the week prior to starting the experiment (week 0) and during the four experimental weeks (week 1,2,3,4).

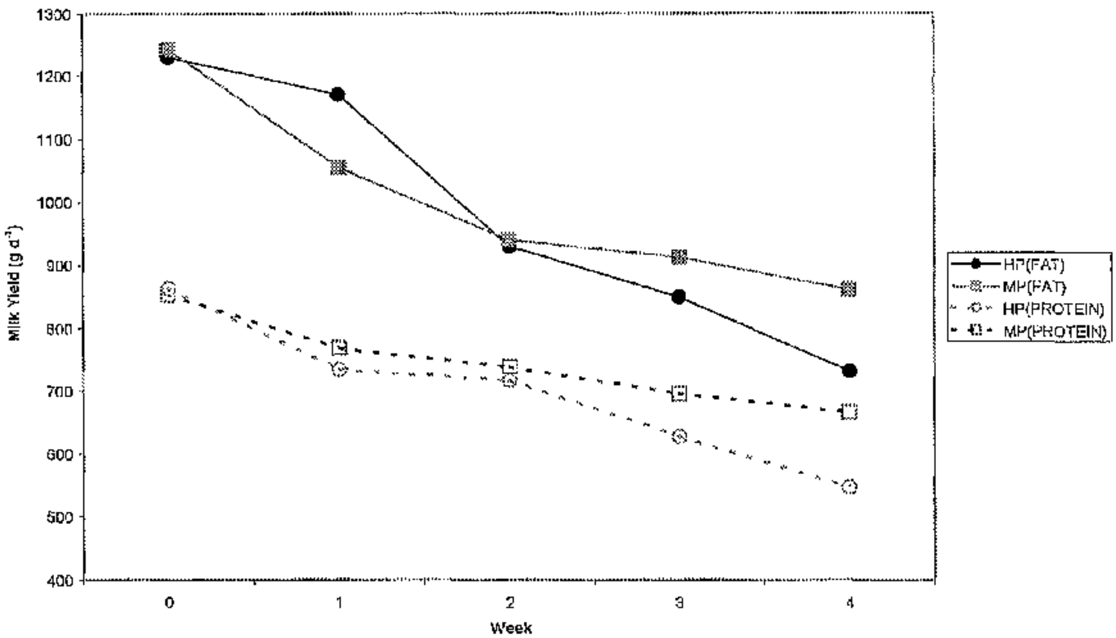


Figure 3.9: The effect of HP (•) and MP(■) treatment on Fat (—) and Protein (----) yield (g d^{-1}) during the week prior to starting the experiment (week 0) and during the four experimental weeks (week 1,2,3,4).

Table 3.14: The effect of treatment on the change of FPCM (kg/week), Fat yield (g/week) and Protein yield (g/week) by linear regression over the four week experimental period for HP and MP treatments.

	Treatment		
	HP	MP	s.e.d /*P*
FPCM (kg/week)	-2.03	-1.8	0.27/ns
Fat Yield (g/week)	-89.4	-74.4	15.4/ns
Protein Yield (g/week)	-59.5	-54.6	8.1/ns

ns= non significant

3.5.2.3 Grazing Behaviour

Manual observation of the time spent grazing, ruminating and idling during a 24 hour period within each week showed no significant difference between treatments at any week ($P > 0.05$) (Table 3.15). However, there was a trend towards an increase in grazing time, which was also associated with a reduction in ruminating time during week 4 under the HP treatment.

Table 3.15: Time spent grazing and ruminating (min d^{-1}) prior to the start of experiment (week 0) and during the experimental period (week 1,2,3,4) within HP and MP treatment.

Activity	Treatment	Week				
		0	1	2	3	4
Grazing	HP	520	490	531	513	516
(min d^{-1})	MP	510	500	560	508	491
		s.e.d. treatment x week = 23				
Ruminating	HP	426	519	455	499	455
(min d^{-1})	MP	411	529	408	476	467
		s.e.d. treatment x week = 22				

Natural bite rate, which includes the time spent searching and handling material, was not significantly different between treatments at any week ($P > 0.05$) (Table 3.16). The proportion of grazing time spent within the infrequently grazed areas fluctuated between treatment and weeks with no significant difference. However, the selection ratio was calculated to take into account the proportion of infrequently grazed patches within the sward and the proportion of time spent grazing within these patches. This showed a trend for positive selection (i.e. >1.0) within the HP treatment from week 1 onwards, with very active selection of infrequently grazed patches in week 4. This positive selection was also evident within the MP treatment from week 3 onwards. There was no significant difference of selection ratio between treatments at any week.

Table 3.16: Natural Biting rate (bites min^{-1}), proportion of time spent grazing and selection ratio (1= neutral, >1= positive selection, <1= negative selection) of infrequently grazed areas within HP and MP treatments prior to the start of the experiment (week 0) and during the experimental period (week 1,2,3,4).

		Week				
	Treatment	0	1	2	3	4
	HP	62.4	63.4	61.9	64.1	59.7
Natural bite rate	MP	66.7	67.7	62.1	59.9	65.6
(bites min^{-1})	s.e.d	4.1	2.3	3.81	4.6	6.5
Proportion of time	HP	0.39	0.41	0.50	0.30	0.43
grazing infrequent grazed	MP	0.32	0.27	0.56	0.38	0.39
areas	s.e.d.	0.78	0.63	0.17	0.68	0.89
Selection ratio	HP	1.2	1.3	1.6	1.1	1.8
	MP	1.0	0.9	1.7	1.1	1.1
	s.e.d.	0.34	0.20	0.52	0.35	0.34

3.5.2.4 Live weight and Condition score

Live weight between the cows prior to the start of the treatments was significantly different with the HP treatment showing a lower live weight. This was not evident again until at week 5 at the end of the experiment. Both treatments saw a gradual decline in live weight over time, which was not significant over the experimental period ($P > 0.05$) (Table 3.17).

Condition score remained fairly constant, with only a fluctuation of less 0.25 of a unit over the experiment. There was no difference between treatments (Table 3.17).
The change of live weight and condition score when analysed over time by linear regression showed no significant difference between treatments ($P > 0.05$) (Table 3.18).

Table 3.17: Live weight (kg) and condition score (0-5 scale) of cows on HP and MP treatments prior too the start of the experiment (week 0) and during the experimental period (week1,2,3,4,5).

		Week					
	Treatment	0	1	2	3	4	5
Live weight (kg)	HP	594	590	579	570	573	571
	MP	615	612	599	592	593	600
	P at week	*	ns	ns	ns	ns	**
	P up to week	ns	ns	ns	ns	ns	ns
Condition score	HP	2.11	2.08	2.25	2.17	2.06	1.9
	MP	2.14	2.06	2.28	2.27	2.14	2.0
	P at week	ns	ns	ns	ns	ns	ns
	P up to week	ns	ns	ns	ns	ns	ns

*=$P\leq 0.05$ **=$P\leq 0.01$ ns = non significant

Table 3.18: Change of live weight (kg week^{-1}) and condition score (units week^{-1}) by linear regression over the 5 week experimental period for HP and MP treatments.

	Treatment	Change during Experiment
Liveweight (kg week^{-1})	HP	-4.1
	MP	-2.7
	s.e.d	0.95
Condition score (units week^{-1})	HP	-0.03
	MP	-0.02
	s.e.d	0.019

3.6 DISCUSSION

The SSH of frequently grazed patches fell to heights below the target due to low growth rate associated with the low rainfall and relatively high temperature experienced during the 5 weeks of the experiment (Appendix 1). The enforced high grazing pressure under HP treatment, through high stocking density together with a sward surface height (SSH) of frequently grazed patches below 6 cm, caused a steady decline of height and area of infrequently grazed patches during the first 3 weeks. Both treatments saw a greater reduction in the fourth week, of which some could be attributed to the rainfall during that week which caused the tall, heavily seeded patches to lodge. Since SSH rather than extended height was measured, lodging would be recorded as a reduction in overall height of the infrequently grazed patch. When the area or proportion of these infrequently grazed patches is considered, then it is evident that, under the HP treatment, their area progressively declined. In contrast, under the MP treatment their area was continuing to increase.

The mapped areas associated with a dung pat were divided into discrete height categories. The categories of 0-5 cm and >5-10 cm represent the frequently grazed area of the sward. The >15-20 cm and >20 cm categories represent the infrequently grazed areas. The remaining category of >10–15 cm falls somewhere between the two. The contour maps (Appendix 2), together with the proportion of these height categories within the area (Table 3.4), also indicate that, under the HP treatment, the infrequently grazed areas were grazed from the edge of the patch and also initially from the top of the tallest height area. This pattern of grazing resulted in an overall reduction of height and a lower proportion of the mapped area lying within the infrequently grazed height categories, with only 1% compared to 15% recorded as greater than 15 cm for HP and MP respectively. The lower grazing pressure resulted in a mapped area with much greater variation of height by week 4 and 5. The high grazing pressure produced a map area of much greater uniformity (80% falling within 0-10 cm categories) with the grazing initiated from the edges. This is in agreement with Fitzgerald and Crosse (1989) and Bao *et al.* (1998) who suggested grazing of tall grass around dung pats appeared to be concentrated around the edge together with a height reduction of approximately 30% after 8 cycles of rotational grazing. The area of the infrequently grazed patches was reduced by 7%. The current experiment under continuous grazing showed a reduction of approximately 30% of the height and 5% infrequently grazed patch area under moderate grazing pressure. Under high grazing pressure the height reduction remained similar to that under moderate grazing pressure, however the area was reduced by approximately 15%. This would suggest that forced grazing is more concentrated around the edge of the patch than the tallest, more central area.

Herbage mass was on average three-fold greater for the infrequently grazed areas than the frequently grazed area. Fitzgerald and Crosse (1989) reported up to 70% greater herbage mass within the tall grass area of the sward and Stakelum and Dillon (1990) reported the yield of grass was four times greater for the tall compared to short phase within a sward. The difference in the reported results could be due to the time over which measurements were made. Fitzgerald and Crosse (1989) measured over the whole season, while Stakelum and Dillon (1990) concentrated on the mid season. Since the area of the infrequently grazed patches increases dramatically in mid season (Marsh and Campling, 1970) herbage mass values for the current experiment (averaged between July and August) would be expected to be greater or similar to that of Stakelum and Dillon (1990). Herbage mass of the infrequently grazed patches remained unchanged during the first two weeks, thereafter it declined to become significantly less under HP treatment in the third and fifth week ($P \leq 0.05$). Herbage mass of the infrequently grazed patches within the MP treatment remained constant until the fifth week when there was a decline but still remaining significantly greater than the HP treatment ($P \leq 0.05$). When averaged over all weeks, there was significantly lower herbage mass within the infrequently grazed patches of the HP treatment compared to MP treatment ($P \leq 0.05$). This would be expected to accompany the height and area reduction within these patches, supporting the evidence of greater utilisation of the infrequently grazed patches under the high grazing pressure treatment.

Baker and Leaver (1986) showed for a stocking rate of 6.4 cows ha^{-1} in early season, that the sward height was decreased, tiller density was increased and interval of defoliation was reduced compared to a stocking rate of 4.7 cows ha^{-1}. The swards under high stocking rate in early season had less rejection, higher tiller density and higher digestibility during the mid season than those swards under the lower stocking rate in early season. In comparison to the work of Baker and Leaver (1986), the current experiment had an average stocking rate of 5.8 cows ha^{-1} under the high grazing pressure treatment during the mid season. This gave rise to a sward with significantly ($P \leq 0.001$) lower sward height of the frequently grazed patches together with a significantly ($P \leq 0.001$) lower proportion of infrequently grazed patches by mid-August than the moderate grazing pressure. The measurement of tiller density was taken as a random sample throughout the whole plot; therefore it represented a mixture of frequently and infrequently grazed patches. The treatments resulted in similar tiller density; however, the lower stocking rate did commence at a much lower density. This may have been due to sampling error leading to an unrepresentative proportion of the cores being taken from the lower tillering infrequently grazed patches. The total tiller density in absolute terms was relatively low compared to that reported by Fisher and Roberts (1995) and Fisher and Dowdeswell (1995). This could be attributed to the management in the early season when the plots within the current experiment were grazed leniently to ensure a high level of infrequently grazed patches. This would reduce the mid-season tiller density than if tight grazing was applied (Baker and Leaver, 1986). The greater reduction in total tiller density over the 5 weeks within the high grazing pressure treatment could be the result of the combination of the low rainfall together with the higher stocking density resulting in greater sod pulling of the rather shallow rooting *Poa annua*. Since the sampling of cores for tiller density measurement was random throughout the sward, then it is not possible to determine if the change in density was a result of changes of one or both of the patches within the sward of the two treatments.

The tiller defoliation data suggests that the utilisation of the infrequently grazed patches under HP was the result of the greater number of defoliations due to the greater stocking density. The interval between defoliations was also less under HP during week 3 and 4. Both stocking densities showed a constant proportion of all defoliated tillers being within the infrequently grazed patch. This suggests that the greater utilisation of infrequently grazed patches under HP was not a result of changed grazing behaviour of cows, in terms of the proportion of defoliations. However, it is possible that the depth of grazing of the infrequently grazed tillers may have altered over the weeks. This was not

measured in the current experiment. Multiple defoliations between recordings may also have occurred. Again, this was not recorded and therefore the assumption of one defoliation between recording dates (2 days) would underestimate both the interval and number of defoliations occurring. The data for time spent grazing within infrequently grazed areas suggests that, in week 4 the cows were grazing the infrequently grazed patches to a greater extent than expected from the area of these patches within the sward. These data however may reflect the variation of grazing behaviour between cows, since different core cows were observed each week. The observations were made over a short period of their daily grazing time directly after milking when their hunger drive may have been high and therefore not truly representative of their average grazing process.
Bao *et al.* (1998) over two experiments within a rotational paddock system, found a variation in the defoliation pattern of grass by cows around a dung pat area. The cows in experiment 1 grazed tall patches in proportion to the area they occupied, which then increased as the sward was grazed down. In experiment 2, the cows selected short patches at the initial encounter, but then increased the proportion of bites on tall grass as the sward was grazed down. The difference between these two patterns within the two experiments was thought to be due to the difference in grazing pressure. The retention time within paddocks was 1 day within the experiment 1 and 2 days within experiment 2 creating a variation in grazing pressure. The results of the current experiment, under continuous stocking suggest a continual sampling of the tall, infrequently grazed area. However, it is only when the grazing pressure becomes sufficiently high, that the defoliation of these patches becomes more frequent leading to the reduction of height, herbage mass and area within the sward.

Illius and Gordon (1990) suggest that herbivores may not remember detail about a food while eating another and a continual sampling of patches is required. Cattle graze heterogeneous swards in a pattern of sampling with the frequency of patches partially influencing their encounter, (Illius *et al.*, 1987). This need for continual sampling, rather than relying on visual assessment, may explain the apparent selection for the infrequently grazed patches under both treatments at a similar frequency.

The natural bite rate, which includes time spent selecting and manipulating material was found by Bao *et al.*, (1998) to be significantly reduced as the sward was grazed down. It was suggested that this might be attributed to the increased proportion of bites from the tall patches. Within the current experiment there is evidence to suggest that the natural biting rate declined within both treatments whenever there was a greater time spent within infrequently grazed patches. This could to be as a result of a greater time spent selecting and manipulating the material rather than directly biting for the infrequently grazed patches.

Plant components within the infrequently grazed patches of both treatments showed a trend for a reduction in leaf content, on a weight basis over the 5 weeks. This was due to the development of stem and flower heads. The net herbage production is reduced within rejected herbage, due to the high senescence rates within the lower canopy of the patch (Large and Tallowin, 1979), reducing the weight of leaf in comparison to stem. There is also some evidence to suggest that the proportion of dead material was greater within the infrequently grazed patch of the HP treatment compared to the MP treatment, especially in weeks 4 and 5. Stakelum and Dillon (1990) concluded that material of higher digestibility and green leaf content was selected when cows entered a paddock. Their results showed an increase in the proportion of stem and dead material from day 1 to day 3 within a paddock grazing system. This is in agreement with the results of the current experiment, with the increased defoliation within the infrequently grazed patches of the HP treatment together with the selection for live leaf material reduced the total mass and hence increased the proportion of stem and dead material.

The quality of herbage was measured by various chemical attributes. Samples for such analyses were obtained by cutting to ground level therefore the sample may not entirely be representative of that selected by the grazing animal. Measurements from the total material available within the sward was of lower D value for frequently grazed patches under the HP treatment compared to MP treatment at week 4 and 5 by 5 and 3 units respectively, although this was not statistically significant ($P \leq 0.05$). This could be due to the higher stem and dead material present under the HP treatment at these weeks. The high grazing pressure resulted in very low grazed height with the leaf being grazed and a greater proportion of the remaining sward being stem.

Infrequently grazed patches within both treatments had the same D value for the first four weeks with week 5 measuring 3 units lower under HP treatment than MP treatment. This again could be due to the higher proportion of stem and dead material within these patches under HP compared to the MP treatment. Stakelum and Dillon (1990) compared grass quality within short and tall grass patches in the mid season showing the tall patches to have a higher proportion of dead and stem with lower leaf content than short patches. Their experiment was carried out under rotational grazing system and over a range of early season grazing pressures.

Herbage intake was expressed in organic matter terms to allow for the greater soil contamination of herbage samples from the HP treatment when under very low SSH. The absolute values for total herbage organic matter intake is high at an average 22kgOM/cow/day. In comparison Le Du *et al.* (1981) and Sporndly (1996) estimated intakes within the range 11 to 15 kgOM/cow/day with cows yielding 18-22kg milk per day. Stakelum and Dillon (1990) have reported dry matter intakes of 13- 27kg/day for late lactating cows. Energy balance calculation (AFRC, 1993) gives much lower predicted intakes, within the range 11-17 kgDM/day (Table 3.19), however, the trend and comparative values are similar to those of the n-alkane estimates.

Table 3.19: Comparison of estimated intakes of grazed grass using the energy balance calculations and n-alkane methods for cows on HP and MP treatments prior to starting the experiment (week 0) and during the experiment (week 1,2,3,4).

	Week/Treatment									
	0		1		2		3		4	
	HP	MP	HP	MP	HP	MP	HP	MP	HP	MP
ME required (MJ/d)										
Maintenance	60.2	62.3	60.4	62.0	59.7	61.2	59.3	60.7	59.3	60.7
Milk Production	139.4	139.4	118.8	118.8	116.7	116.7	105.9	113.1	91.9	108.4
ME supply (MJ/d)										
Concentrate	30	30	30	30	30	30	30	30	30	30
Liveweight loss	0	0	30.4	7.6	30.4	36.1	24.7	19	7.6	0
Energy Balance (MJ/d)	169.6	171.7	118.8	143.2	116.0	111.8	110.5	124.8	113.6	139.1
ME grass (MJ/kg)	10.0	10.0	9.6	9.8	9.9	9.9	9.8	9.7	9.5	9.9
Intake -energy balance calculation (kgDM/d)	17.0	17.1	12.3	14.6	11.7	11.3	11.2	12.9	11.6	14.0
Intake - n-alkane (kg/DM/d) *	25.0	23.5	25.0	23.6	24.2	26.0	22.1	27.0	25.0	26.3

*Dry matter intake = Organic matter intake +10%

The high estimates of intake from the n-alkane technique could be attributed to errors within a number of areas within the procedure:

Sampling of faeces and herbage

The diurnal variation of dosed C_{32} alkane and naturally occurring alkane could potentially affect the absolute concentrations within the faeces at different times of the day, however the ratio of the concentration for the pair of alkanes would not be affected (Dove and Mayes, 1991). Dillon (1993) extensively investigated feeding pattern and temporal sampling in dairy cattle. He found that errors from such effects would be small as long as the dosed pellets were administered twice daily. Controlled release devices would also help in minimising temporal variation of alkane recovery within the faeces. Within the current experiment, the sampling of faeces from individual cows was not always at the same time of day, due to missed sampling at morning milking. However, the dosing procedure employed was twice-daily dosing of a paper C_{32} impregnated pellet, which would minimise error due to variation in faecal recovery of the alkane pair. The faeces sampling procedure, although not ideal, is unlikely to have caused the discrepancy in estimated intake between alkane and energy balance methods.

Herbage sampling is much more likely to cause errors in the intake estimations (Dove, 1995; Newman *et al.* 1995; Dove and Mayes, 1996; Newman *et al.* 1998). It is critical that herbage sampled is as close to that consumed by the grazing animal as possible. This is difficult in practice, unless fistulated animals are used to collect extrusa. Plant parts vary in their alkane concentrations, with leaf showing approximately ten fold increase in C_{33} compared to sheath, stem or flowerheads (Dove *et al.*, 1996). Therefore, if the diet selected by the animal contains greater leaf content than that sampled by hand plucking, this would led to over estimation of calculated intake. A sensitivity analysis of the equation used to estimate intake has shown that an increase in the concentration of C_{33} within the herbage sampled reduces the intake estimate by similar proportions (Table 3.20). It has been shown that grazing animals select higher digestible diets and greater leaf, than a random sample of that on offer, by up to 20% (Le Du *et al.* 1981; Loredo and Minson, 1975). The error caused by sampling herbage of lower leaf content would be similar for all animals assuming each cow selects for a similar leafiness. If we assume 10-20% greater leaf content in the diet this would increase the C_{33} concentrations and reduce the estimated intake by 3-3.5 kg OM (Table 3.20). In order to achieve similar intakes to that predicted by the energy balance method, the concentration of C_{33} would need to increase by 100%. However, the energy balance method is not without potential error. Fisher et al. (1995) also found alkane estimated intake to exceed those of the energy balance method. The greatest potential error within energy balance method is the ability to accurately weigh the animals and attribute accurate composition of tissue lost. It is worth mentioning that on very hot days during this experiment the cows tended to graze less during the mid afternoon, seeking shade or idling, and as a result this may have a large effect on rumen fill and hence liveweight on the day of weighing. This may have incorrectly increased liveweight loss of the cows on some occasions, and hence reduced the estimate of grazed grass intake by the energy balance method. The ME content of the grazed diet may vary from that sampled for chemical analysis, which is further error in the calculation.

Both alkane and energy balance technique have errors within their estimates of grass intake. With milk production levels of between 19-27 kg/cow/d it is likely the true intakes would fall somewhere between the estimates from the 2 methods. Although the absolute values of intakes may be high for the alkane method, the treatment effect and change over time can be compared on a relative basis, if we assume the errors to be equal between cows and treatments.

Table 3.20: The sensitivity of leaf content on the estimated DM intake using the alkane technique.

C_{33} concentration in herbage (mg/kg)	63	70	77	84	88	91	105
% C_{33} change to average concentration #	-10	0	+10	+20	+25	+30	+50
% DM intake	113	100	87	84	79	74	64
Change of intake (kg OM/d) from average #	+2.8	0	-3.0	-3.6	-4.7	-5.7	-7.9

average intake being 22kgOM with 70 mg/kg C_{33}

The intake, as estimated by the n-alkane technique, over the 4 week experimental period was similar in week 1 and 2, approximately 22-23 kg OM/day. At week 3, cows on the HP treatment had a significantly lower intake compared to the MP treatment, dropping by 2 kg OM day^{-1} from the previous week ($P \leq 0.001$). There was a significant effect of time by week 3 and this continued to the end, with lower OM intake under the HP treatment ($P \leq 0.001$). This is in agreement with Le Du *et al.* (1981) who reported a range of 1-3 kg OM cow^{-1} day^{-1} less for those cows grazing a sward at 5 cm SSH compared to 7.5 cm.

The proportion of the total intake from the infrequently grazed area was significantly higher within the MP treatment compared to HP at week 0, prior to the treatments commencing ($P \leq 0.01$). However, during week 1 and 2 of the experimental period, there was no difference between treatments for the estimated intake from the infrequently grazed area. At week 3, there was significantly greater intake from infrequently grazed area under the HP treatment, by 0.5 kg OM day^{-1} ($P \leq 0.05$). There was a significant effect of time ($P \leq 0.01$), with both treatments showing a gradual decline of the proportion of intake from the infrequently grazed area under both treatments, however that of the HP treatment was significantly greater than MP at the end ($P \leq 0.001$).

This conflicts with the data for grazing behaviour and defoliation within this experiment. These indicate at least a constant intake from the infrequently grazed patches. A possible explanation of the discrepancy may have been due to the n-alkane pattern within the herbage changing over the weeks. Both C_{27} and C_{29} were reduced greatly during week 3 and 4 within the infrequently grazed herbage samples. This narrowed the difference of the n-alkane profiles between the two diet components, which lowered the accuracy of the least square optimisation procedure. Newman *et al.* (1998) reviewed the sensitivity of the n-alkane analysis and has shown that, when sampling or measurement error exists, then one of the diet components will be under-estimated and the other over-estimated.

Increasing the stocking rate is also commonly accompanied by a reduction in milk production per cow (Gordon, 1973,1976, King and Stockdale, 1980). Mayne *et al.* (1987) concluded that grazing pressure, which resulted in residual SSH under rotational grazing below 80 mm, reduced individual milk yield per cow, although, milk yield per hectare and utilised metabolisable energy was greater than if SSH was above 80 mm. Stakelum and Dillon (1990) summarised the results from 7 years of grazing research which showed milk depression of 2% per cow when stocking rates were increased from 5.0 cows ha^{-1} to 6.4 cows ha^{-1} under rotational grazing system. This depression increased under more adverse grass growing conditions. Le Du *et al.* (1981) concluded that, under continuous stocked swards, a SSH of 7-9 cm had little effect on intake and milk production. However, at 5 cm there was significant depression in both herbage intake and milk yield of 2 kg OM cow^{-1} d^{-1} and 3 kg cow^{-1} d^{-1} respectively. Mayne *et al.*, 1987 also found 3 kg less milk per cow per day when sward height was 5 cm (plate meter height) compared to 6 or 8 cm and intake reduced by 1 kg OM per cow per day. When they compared high and low yielding cows, the severity of grazing had a greater impact on milk yield, due to a restriction on intake, for the high yielding dairy cows.

Within the current experiment, herbage intake and milk yield was consistently similar between treatments over the first 2 weeks within this experiment. On the third week herbage intake and milk yield were depressed by 4 and 1.5 kg per day respectively for cows under HP treatment. At this time, the SSH of the frequently grazed patches was 5.75 cm compared to 7 cm under MP, which could be responsible for the reduced intake and milk yield. During the fourth week, the milk yield continued to fall by a further 3 kg, however, the herbage intake appeared to increase by 2 kg. The ME (MJ/kgDM) of the frequently grazed areas fell to 9.3 from 10 under the HP treatment, possibly due to an increase in dead and stem material within these patches compared to those under the MP treatment. This may have lead to a reduced milk yield while the herbage intake increased. Milk per hectare increases with stocking rate, but not linearly, as often other interactions can reduce herbage production per hectare (Mayne *et al.*, 1987). Milk yield per hectare was not recorded within the experiment, however, it would be likely that the increase in stocking rate per hectare over the 5 weeks would more than compensate for the sum overall reduction in yield/cow observed for the HP treatment.

Milk composition was significantly different for lactose, being higher at week 2 ($P \leq 0.05$) and then lower at week 3 and 4 under the HP treatment ($P \leq 0.01$). Protein was significantly lower for HP at week 4 ($P \leq 0.05$). This suggests a reduction in the energy level from week 3 onwards which could be attributed to a lower intake during week 3 and a reduction in the ME value of the frequently grazed patches of the HP treatment in week 4. This is agreement with Gordon, 1973, McFeely *et al.* (1975) and Mayne *et al.* (1987) who concluded that milk composition is fairly insensitive to grazing pressure.
Yield of constituents in the current experiment was significantly less under HP treatment for fat and protein on week 3 and 4 ($P \leq 0.05$). Le Du *et al.* (1987) in two different experiments investigating grazing severity found contrasting results; significantly less fat and lactose under severe grazing severity within one experiment while there was no significant difference of any constituent yield in the second.

Increasing the severity of grazing resulted in greater live weight loss or less gain (Le Du *et al.*, 1981). Dillon *et al.* (1995) found cows under a low stocking rate system were significantly heavier at the end of their lactation. King and Stockdale (1980) found increasing the stocking rate from 4.4 cows ha^{-1} to 8.6 cows ha^{-1} reduced the live weight of cows at all times during their lactation and when drying off. The 4 week duration of the current experiment means that live weight and condition scores are of limited value, however the reduction of live weight was slightly greater for cows under the HP treatment which had a higher stocking rate. Condition score gradually declined by on average 0.25 of a unit over the 5 weeks for both treatments.

3.7 CONCLUSION

Increasing the grazing pressure during the mid season:

1) Significantly reduced the height of the frequently grazed patches within the sward to below 6 cm after 3 weeks ($P \leq 0.001$).
2) Significantly reduced the height of the infrequently grazed patches but only when SSH of the frequently grazed patches was reduced to below 6 cm ($P \leq 0.001$).
3) Significantly reduced proportion and mass of the infrequently grazed patches by 10% and 0.7 t DM ha^{-1} respectively by the third week ($P \leq 0.001$ and $P \leq 0.05$ respectively).
4) Increased the utilisation of the infrequently grazed patches by significantly increasing the total defoliations ($P \leq 0.01$). There was some evidence to show reduced interval of defoliation towards the end of the experimental period.
5) Significantly reduced the total intakes of grazed grass at week 3 and 4 ($P \leq 0.001$), with significantly higher proportion from the infrequently grazed patches ($P \leq 0.01$).
6) Significantly reduced milk yield ($P \leq 0.001$), fat and protein yield per cow by week 3 ($P \leq 0.001$ and $P \leq 0.001$ respectively). The higher stocking rate would probably have increased yield/ha compared to MP.
7) Significantly increased liveweight loss ($P \leq 0.01$).
8) Reduced the bite rate as the proportion of time in the infrequently grazed areas increased.

CHAPTER 4. EXPERIMENT 2

THE EFFECT OF THE FREQUENTLY GRAZED PATCH HEIGHT ON THE INFREQUENTLY GRAZED PATCH MORPHOLOGY, UTILISATION AND DAIRY COW PERFORMANCE.

4.1 INTRODUCTION

The previous experiment within the current series suggested that the partition of the cow's grazing time between frequently grazed (FG) and infrequently grazed (IG) patches is influenced by the availability of grass within the FG patches. It was apparent that, as the height of the FG patch fell to levels, which would restrict intake, (at approximately 6 cm or below), cows would spend more time grazing and eat proportionally more from the IG patch within the sward.

The optimal foraging strategy suggests that animals graze so as to maximise their instantaneous intake rate and, in doing so, select for large bites which give high bite weight (Ungar and Noy-Meir, 1988). This can be greatly affected by the sward heterogeneity especially if availability is limited. Under these conditions, animals might be expected to have evolved behaviour, which maximises the intake rate through greater selection within a horizontally heterogeneous sward (Kenney and Black, 1984). Daily intake can be less sensitive to availability than the instantaneous intake rate due to the compensatory effect of grazing time (Chacon and Stobbs, 1976, Gibb *et al.*, 1997). However, due to the largely diurnal grazing behaviour and requirement for rumination this too has limitations. Diet quality therefore may also become important in these situations where daily intake may be further limited by digestion rate (Belovsky, 1981), therefore in order to maximise the daily intake a high quality diet must also be selected by the grazing animal.

On continuously stocked swards, the mean sward surface height (SSH) can significantly affect the daily organic matter intake. Gibb *et al.* (1997) found that 5 cm and 9 cm mean SSH resulted in significantly less intake for lactating cows than a SSH of 7 cm. They also found that these swards all showed the characteristic patchiness of short FG patches and tall IG patches. However, it was the taller swards of 7 and 9cm SSH that showed a reduction in the height and proportion of the short FG patches over time, whilst those for the short SSH swards remained constant. At the 5 cm SSH, it was assumed that there was some grazing of the taller areas surrounding the fouled patches causing their proportion of the sward to remain static. However, under the low grazing pressure (SSH 7 or 9 cm) the taller areas were persistent and increased in proportion through the season. Their studies were unable to determine the time spent grazing or intake from within the FG or IG patch populations. This is crucial in understanding the dynamics of the patches within the sward, their interactions with the grazing animal and indeed how it relates to sward management.

Griffiths *et al.* (1997) concluded that when height and bulk density was the only variation between patches, cattle grazing activity was strongly and positively related to height. However, if this was accompanied by increased plant maturity, the animals concentrated their grazing on the shorter leafier patches rather than the tall stemmier patches. Therefore heterogeneity, both horizontally and vertically within a sward, interacts with the grazing animal and vice versa causing patches to change dynamically through the season.

It is therefore important to understand the relationship between the FG patch height and the dynamics of the IG patch within a sward. The aim of this experiment was to determine how the sward height of the FG patches affected the utilisation of the IG patches by lactating dairy cows. The hypothesis being tested was that the utilisation of the IG patch is greater when the height of the FG patch is 6 cm compare to either 8 or 10 cm.

4.2 MATERIALS AND METHODS

The experiment was designed to examine the effect of the FG patch height on the morphology, grazing and utilisation of the IG patches within a sward grazed by dairy cows during the mid season.

Three treatments were applied; target sward surface height of the FG area of 6, 8 or 10 cm maintained over a four week continuous period commencing mid July. The swards were maintained prior to the experiment by stocking with non lactating dairy cows to a target sward surface height of 7 cm during May and June rising to 8 cm in early July.

The experimental design was randomised complete block with three replicates per treatment. The plots were randomly allocated to treatments within blocks during the week prior to the start of the experimental period. Each plot was approximately 1.1 ha and were predominantly *Lolium perenne* receiving a total fertiliser application of 50 kgN/ha during the four week experimental period and a total of 360 kgN/ha, 45 kg/ha of both P_2O_5 and K_2O over the whole grazing season.

On the 5th July 1999, 36 Holstein/Freisian cows were grouped into threes according to calving date, milk yield at 30th June and lactation number. One cow from each triplet group was randomly allocated to a treatment within a replicate. Each treatment had a total of 12 cows on which all animal measurements were made. During the experiment cows were milked at 6.30 and 15.30 daily. A concentrate supplement (200g kg^{-1} DM Crude protein) of 2.9 kg DM day^{-1} was fed, split over the two milkings.

4.3 MEASUREMENTS

Sward surface height (SSH) was measured Monday, Wednesday and Friday every week using a HFRO sward stick (Hill Farming Research Organisation, 1986). This enabled the treatment SSH to be maintained by altering stocking densities accordingly if SSH were changing. Forty height measurements were taken in a zig zag pattern across each plot, except on the Wednesday of each week when 250 measurements were taken in a systematic grid pattern throughout the plots in order to get detailed records of the two patch populations. The height and proportion of the infrequently grazed patches were obtained from the SSH measurements. The person recording the height subjectively determined when a hit landed within an infrequently grazed patch and this, together with an adjacent frequently grazed patch height was measured. From these records it was then possible to determine the height of both the frequently and infrequently grazed patch and the proportion of the infrequently grazed patches within the sward.

Herbage mass was measured within both the frequently and infrequently grazed patches once per week by cutting five random strips (1.5m x 0.33m) to 2cm above ground level using an Alpino motor scythe. Sub samples were dried at 80°C for 12 hours to determine dry matter content. A sub-sample from the fresh material was also taken for sward component analysis at week 1, the beginning and week 4, the end of the experiment. This allowed the leaf, stem, live and dead components of the patches to be determined.
A further sub-sample of the fresh material sampled for herbage mass was taken for Digestible Organic Matter in dry matter (DOMD), Metabolisable Energy (ME), Crude Protein (CP), Neutral detergent Fibre (NDF) and water soluble carbohydrate (WSC) using Near infra-red spectroscopy (NIR). The calibration set for NIR used fresh grass samples from the fields at SAC Auchincruive and Crichton Royal Farm (Offer, N.W. personal communication) with the methodology for scanning and prediction being that published by Barber *et al.* (1990)

Tiller defoliation was also recorded every Monday, Wednesday and Friday by marking individual tillers with plastic coated wire. Three 5m transects were randomly placed within the plots to initially mark the tillers. Each transect traversed both the frequently and infrequently grazed patch with a tiller being marked at 20 cm intervals with approximately 30 tillers within both the frequently and infrequently grazed patches being marked per plot. The extended height of each tiller was measured at each occasion, together with the presence or absence of a defoliation, by tearing the leaf apex vertically for approximately 1 cm length and inspecting for its presence or absence at the next visit. This allowed the proportion of marked tillers defoliated within both the frequently grazed and infrequently grazed patches together with the depth of biting to be measured.

The animal parameters measured were grazed grass intake, grazing behaviour, milk yield, milk composition, live-weight and condition score.

The intake of grazed grass was estimated using the n-alkane technique. All 36 cows were dosed twice daily with pellets containing 600mg of dotriachane (C32) impregnated onto shredded paper. This started on 28th June to allow an initial 7 day period when the concentration of C32 reached a constant level before the sampling of faeces occurred. On the 5th July faeces was collected daily and bulked for the week. Herbage was sampled by hand plucking grass from the frequently grazed and infrequently grazed patches separately. These samples were also bulked per plot per week keeping the patches separate. This procedure was carried out for each of the four experimental weeks. Both faeces and herbage samples were freeze dried prior to milling. Analyses for the n-alkane content was carried out as described by Mayes *et al* (1986). Dry matter intake of grazed grass was estimated using the equation of Dove and Mayes (1991).

The grazing behaviour of the cows was manually observed over a continuous 12 hour period in which the time spent grazing, ruminating or idling was recorded. This was carried out on each of the 4 experimental weeks. Detailed recording of the area was also carried out weekly when one of the four cows per plot was observed for a 30 minute period directly after the pm milking. The recorder subjectively decided when the cow was grazing within a frequently or an infrequently grazed patch. This allowed for a proportion of the total observed time that was spent within the two patches of the sward to be determined. This was carried out on Monday, Wednesday and Friday each week with the core cows being allocated to a day within a week according to a latin square design of 4 weeks and 4 cows per plot, therefore each cow was observed for 3 occasions over the weeks.

Milk yield was recorded twice daily for each of the core 36 cows. A milk sample was taken mid week from two consecutive milkings and analysed for fat, protein and lactose content as described by Biggs (1979).

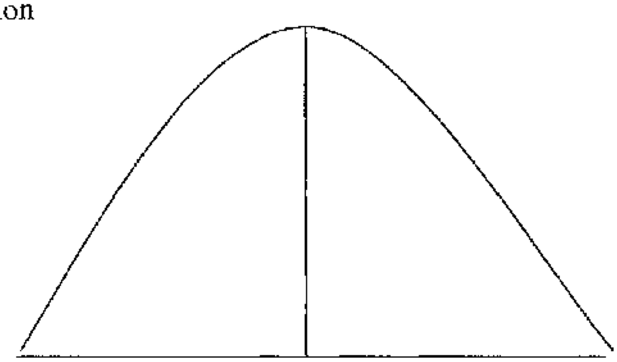
The cows were weighed and condition scored weekly, as described by Mulvany (1977).

4.4 STATISTICAL ANALYSIS

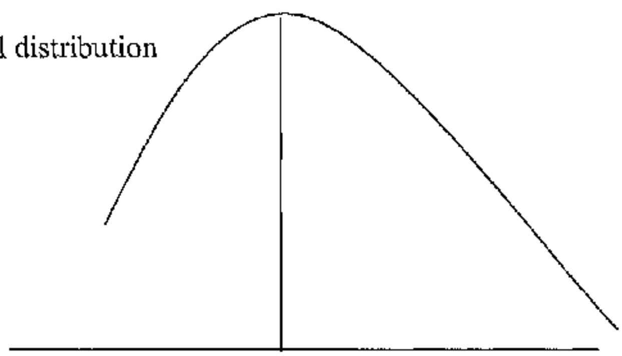
Data were analysed using statistical package Genstat 5 release 4.1 (Lawes Agricultural Trust, 1990). Animal variables measured over the whole experimental period were analysed by repeated measures, with each cow treated as one unit, in order to account for the dependence on time for those variables. Sward data were analysed at specific separate timepoints throughout the experiment by analysis of variance with three treatments, each with three replicates.

Gibb and Ridout (1986, 1988) were able to fit two normal distributions to their data for sward surface height. Hence they estimated the relative proportions falling in each distribution (frequently and infrequently grazed patches) and both a mean and a variance for each distribution. The methodology for fitting multiple distributions to the SSH data of this study has required modification (and hence greater complexity) for two main reasons. Firstly, sward heights greater than 30 cm were recorded as 30 cm. This is termed "censoring". Secondly, after allowance for the impact of censoring, plots of the observed data indicated that two normal distributions would, in general, not provide a good fit to the data. The distribution of the frequently grazed patch data was truncated due to controlling the height and also the physical limitation of grazing below 5 cm. A truncated normal distribution differs from a standard normal distribution in that the left tail of the distribution is removed as visually described in Figure 4.1.

Normal distribution



Truncated normal distribution



A censored distribution

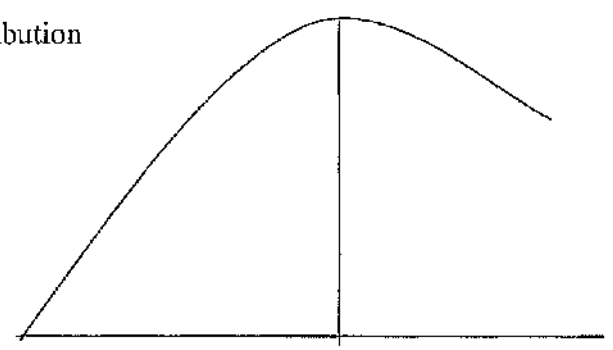


Figure 4.1: Graphical representation of normal, truncated and censored distributions.

It was necessary to postulate likely distributions that would fit the data adequately. A mixture of a truncated normal distribution for the frequently grazed areas and a truncated censored normal distribution for the infrequently grazed areas was considered. Secondly, a mixture of a truncated lognormal distribution for frequently grazed areas and a truncated censored normal distribution for the infrequently grazed areas was considered. It was assumed that all censored data belonged to the distribution for infrequently grazed areas. This is a reasonable assumption, as the treatments imposed would prevent uncontaminated areas approaching 30 cm in height. A lognormal distribution is appropriate for data, which, although skewed with a long tail on the original scale, follow a normal distribution on the log scale.

For each of the nine plots at the four dates, a separate fit was obtained for both models. The fitting process for the chosen distributions is iterative. In essence, maximum likelihood gives height and proportion estimates for the FG and IG patches each that give the largest probability of observing the collected data. Parameter estimates for the 36 (plot x date) sets of sward heights (chosen from the better fitting of the two models for each of the 36 datasets separately) can be regarded as summary statistics for the 36 datasets. As such, it is valid to compare the effect of the three treatments by analysing each of the summary statistics. This can be done by univariate split-plot ANOVA in time for the height and proportion of the two distributions.

4.5 RESULTS

4.5.1 SWARD

4.5.1.1 Sward Surface Height

The conditioning period immediately prior to the start of the experiment aimed to produce a sward of differing FG patch height, 6, 8 or 10 cm, while maintaining equal proportion and height of IG patches. This proved to be very difficult and required a period of rest immediately prior to the start of the experiment to ensure the IG areas were not over-grazed. As a result, the mean height of the FG patches was 9, 10 and 11 cm rather than the target 6, 8 and 10 respectively. The target heights were achieved within $\pm$ 0.5 cm range for weeks 2, 3 and 4 for all but the 10 cm treatment at week 4. The growing conditions did not allow for the maintenance of the 10 cm height using only the core cows and as a result the height fell to 9 cm during week 4. The proportion of the IG patches did vary at the start of the experiment (0.32, 0.37 and 0.41 for 6, 8 and 10 treatment respectively), however this was not a significant difference ($P > 0.05$).

Tables 4.1, 4.2 and 4.3 show the mean height of FG and IG patches together with the proportion of IG patches analysed using ANOVA using (a) data collected and subjectively determined as to FG and IG categories meaned over the whole week and also those means produced by (b) best fit distribution using maximum likelihood using data from the Wednesday collection of 250 data per plot only.

There was a significant effect of treatment on the height of the FG patches within the sward ($P \leq 0.001$) (Table 4.1). There was no significant interaction of the treatments over the 4 weeks ($P \leq 0.001$). The IG patch height also showed significant difference between treatments with those within the 6 cm treatment being approximately 4 cm shorter than either the 8 or 10 cm treatment, when averaged over all weeks ($P \leq 0.001$) (Table 4.2). However, there was no significant week and treatment interaction for the model fitted data, all showing the same trend albeit at a reduced height for the 6 cm treatment ($P > 0.05$). The measured data did show a significant week and treatment interaction ($P \leq 0.001$); the 6 cm treatment showed a reduction at each week, compared to the 8 and 10 treatment maintaining the height until week 3 followed by gradual reduction.

Table 4.1: Height (cm) of the frequently grazed patches throughout the experimental period within treatments 6, 8 and 10, obtained by (a) subjective measuring and (b) best fit model.

	Treatment (cm)					
	6		8	10	s.e.d	*p*
Mean over weeks	(a) 7.0		(a)8.6	(a)9.8	(a)0.06	***
	(b)6.7		(b)8.6	(b)9.8	(b)0.24	***
	Week					
	1	2	3	4		
Mean over treatments	(a)10.1	(a)8.2	(a)7.9	(a)7.6	(a)0.16	***
	(b)9.9	(b)8.0	(b)7.8	(b)7.7	(b)0.21	***
Week x Treatment Interaction	Treatment					
Week	6		8	10		
1	(a)9.0		(a)10.0	(a)11.2	(a)0.25	ns
	(b)8.4		(b)9.9	(b)11.3	(b)0.43	ns
2	a)6.9		(a)8.3	(a)9.5		
	(b)6.4		(b)8.2	(b)9.5		
3	(a)6.4		(a)8.1	(a)9.2		
	(b)6.1		(b)8.1	(b)9.3		
4	(a)5.7		(a)7.9	(a)9.1		
	(b)5.7		(b)8.1	(b)9.2		

***=$P \leq 0.001$, ns = non significant

Table 4.2: Height (cm) of the infrequently grazed patches throughout the experimental period within treatments 6, 8 and 10, obtained by (a) subjective measuring and (b) best fit model.

	Treatment (cm)					
	6		8	10	s.e.d	*p*
Mean over weeks	(a) 22.5		(a)26.9	(a)26.7	(a)0.38	***
	(b)21.8		(b)27.7	(b)27.1	(b)2.5	**
	Week					
	1	2	3	4		
Mean over treatments	(a)28.1	(a)26.6	(a)24.4	(a)22.3	(a)0.44	***
	(b)31.7	(b)27.9	(b)23.8	(b)18.8	(b)1.0	***
Week x Treatment Interaction	Treatment					
Week	6		8	10		
1	(a)27.3		(a)28.5	(a)28.5	(a)0.76	***
	(b)29.3		(b)32.7	(b)33.1	(b)2.9	ns
2	a)24.1		(a)28.0	(a)27.6		
	(b)23.3		(b)31.1	(b)29.4		
3	(a)20.4		(a)26.4	(a)26.4		
	(b)20.5		(b)25.6	(b)25.2		
4	(a)18.0		(a)24.6	(a)24.4		
	(b)14.3		(b)21.2	(b)20.8		

**=$P \leq 0.01$, ***=$P \leq 0.001$, ns = non significant

Regression of this data over time showed significant difference between treatments with the 6 cm treatment being reduced significantly greater than either 8 or 10 cm treatments ($P \leq 0.001$) (Table 4.3). There was no difference in the change of height over time between the 8 or 10 cm treatments.

Table 4.3: Change of height (cm/week) within infrequently grazed patch by linear regression over the experiment and between treatments 6, 8 and 10.

	Treatment (cm)				
	6	8	10	s.e.d	P
Change in height (cm/week)	-3.2	-1.3	-1.4	0.12	***

***=$P \leq 0.001$

4.5.1.2 Proportion of infrequently grazed patches

Both the subjectively determined and fitted data show significance of treatment effect over all weeks ($P \leq 0.01$ and $P \leq 0.05$ respectively), with no significant interaction between treatments over the four weeks ($P > 0.05$) (Table 4.4). There was approximately 7% less infrequently grazed patches within the 6 cm treatment sward than both the 8 and 10 cm swards. The greatest change was seen in week 4 when under the 6 cm treatment the proportion fell by 5% whereas it rose by 7% and 2% under the 8 and 10 cm treatments respectively to levels similar or higher than those at week 1 of the experiment.

Table 4.4: Proportion of the infrequently grazed patches throughout the experimental period within treatments 6, 8 and 10, obtained by (a) subjective measuring and (b) best fit model.

	Treatment (cm)					
	6	8		10	s.e.d	*p*
Mean over weeks	(a) 0.27	(a)0.39		(a)0.40	(a)0.016	**
	(b)0.30	(b)0.37		(b)0.37	(b)0.017	*
	Week					
	1	2	3	4		
Mean over treatments	(a)0.37	(a)0.36	(a)0.35	(a)0.35	(a)0.017	ns
	(b)0.35	(b)0.34	(b)0.33	(b)0.35	(b)0.022	ns
Week x Treatment Interaction	Treatment					
Week	6	8		10		
1	(a)0.32	(a)0.38		(a)0.41	(a)0.03	ns
	(b)0.31	(b)0.37		(b)0.38	(b)0.04	ns
2	a)0.30	(a)0.39		(a)0.38		
	(b)0.32	(b)0.34		(b)0.36		
3	(a)0.30	(a)0.39		(a)0.41		
	(b)0.32	(b)0.34		(b)0.36		
4	(a)0.23	(a)0.39		(a)0.42		
	(b)0.25	(b)0.41		(b)0.38		

*=$P \leq 0.05$, **=$P \leq 0.01$, ns = non significant

4.5.1.3 Herbage mass

Treatment significantly affected the herbage mass within both FG and IG patches when considered throughout the whole experimental period ($P \leq 0.05$). The herbage mass of the FG patches increased with increasing sward height, in contrast to the IG patches which showed the 6 cm treatment having significantly less than either 8 or 10 cm ($P \leq 0.05$), which were similar (Table 4.5, 4.6; Figure 4.2,4.3).

Table 4.5: Herbage mass (tDM/ha) of the frequently grazed patches within the sward of treatments 6,8 and 10 during the experimental period.

	Treatment (cm)					
	6	8		10	s.e.d	*p*
Mean over Weeks	0.88	1.19		1.42	0.15	*
	Week					
	1	2	3	4		
Mean over Treatments	1.52	1.10	1.05	0.98	0.12	***

*=$P \leq 0.05$, ***=$P \leq 0.001$,

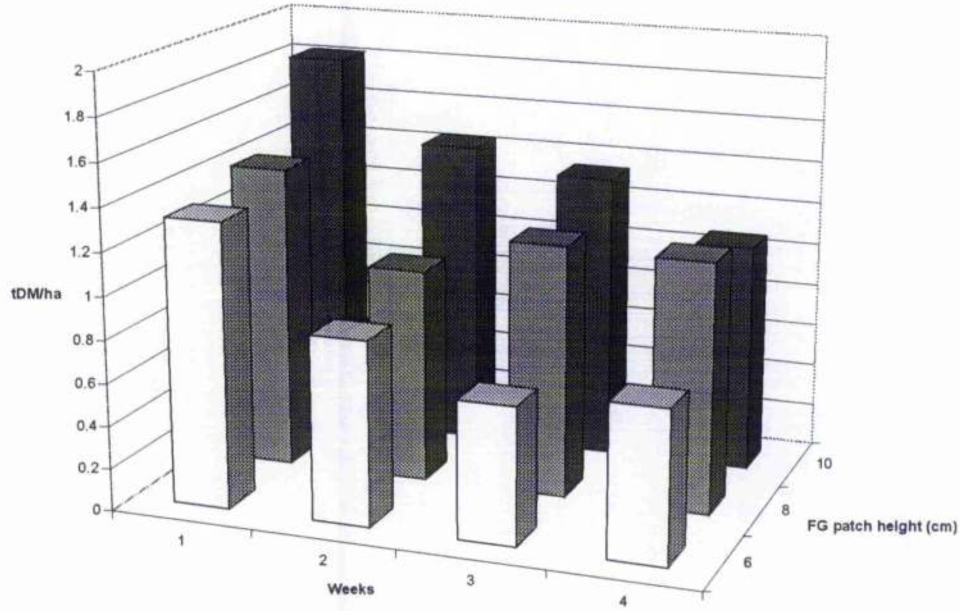


Figure 4.2: The effect of treatments 6, 8 and 10 FG patch height (cm) on the herbage mass (t DM/ha) of the FG patches over the four experimental weeks.

Table 4.6: Herbage mass (tDM/ha) of the infrequently grazed patches within the sward of treatments 6, 8 and 10 during the experimental period.

	Treatment (cm)				
	6	8	10	s.e.d	*p*
Mean over Weeks	4.05	5.44	5.53	0.54	*

	Week					
	1	2	3	4		
Mean over Treatments	5.31	5.19	4.67	4.86	0.5	ns

*=$P \leq 0.05$, ns = non significant

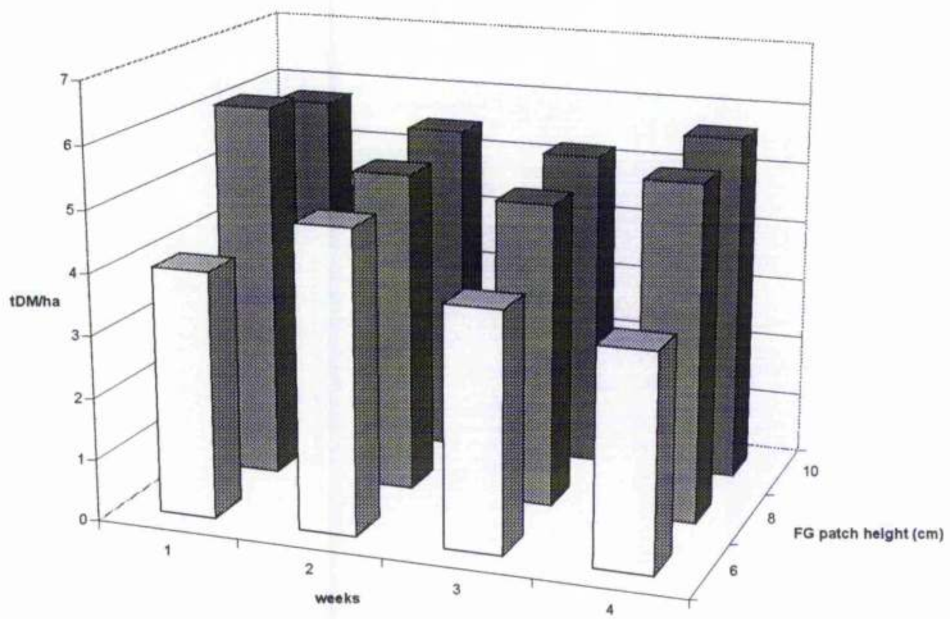


Figure 4.3: The effect of treatments 6, 8 and 10 FG patch height (cm) on the herbage mass (t DM/ha) of the IG patches over the four experimental weeks.

4.5.1.4 Tiller Defoliation: Proportion and Depth

When averaged over all weeks, there was no significant difference between treatments in tiller defoliation within the FG patches (P >0.05) (Table 4.7). When averaged over all treatments, there was a significant effect of week with a significantly greater defoliation of tillers in week 2 than any other week ($P \leq 0.001$).

There was a significant week and treatment interaction ($P \leq 0.01$). Initially, a low proportion of marked tillers within the FG patches of the 6 cm treatment were defoliated. However, by week 2 through to week 4 there was a greater proportion of tillers were defoliated within this treatment compared to both the 8 and 10 cm treatments.

Table 4.7: Proportion of the frequently grazed tillers defoliated within treatments 6, 8 and 10 during the experimental period.

	Treatment (cm)					
	6		8	10	s.e.d	*p*
Mean over weeks	0.27		0.21	0.24	0.043	ns
	Week					
	1	2	3	4		
Mean over treatments	0.19	0.33	0.20	0.23	0.023	***
Week x Treatment Interaction	Treatment					
Week	6		8	10		
1	0.14		0.23	0.22	0.055	**
2	0.40		0.27	0.33		
3	0.26		0.16	0.20		
4	0.31		0.17	0.22		

*=$P\leq0.05$, **=$P\leq0.01$, ns = non significant

There was no significant difference between treatments when averaged over all weeks or between weeks when averaged over treatments within the IG patch ($P > 0.05$) (Table 4.8.). There was a trend for a greater proportion of defoliated IG tillers at 6 cm over the weeks, however this was not significant at any time ($P > 0.05$) (Figure 4.4).

Table 4.8: Proportion of the infrequently grazed tillers defoliated within treatments 6, 8 and 10 during the experimental period.

	Treatment (cm)				
	6	8	10	s.e.d	*p*
Mean over Weeks	0.13	0.15	0.09	0.035	ns

	Week					
	1	2	3	4		
Mean over Treatments	0.10	0.13	0.13	0.13	0.031	ns

ns = non significant

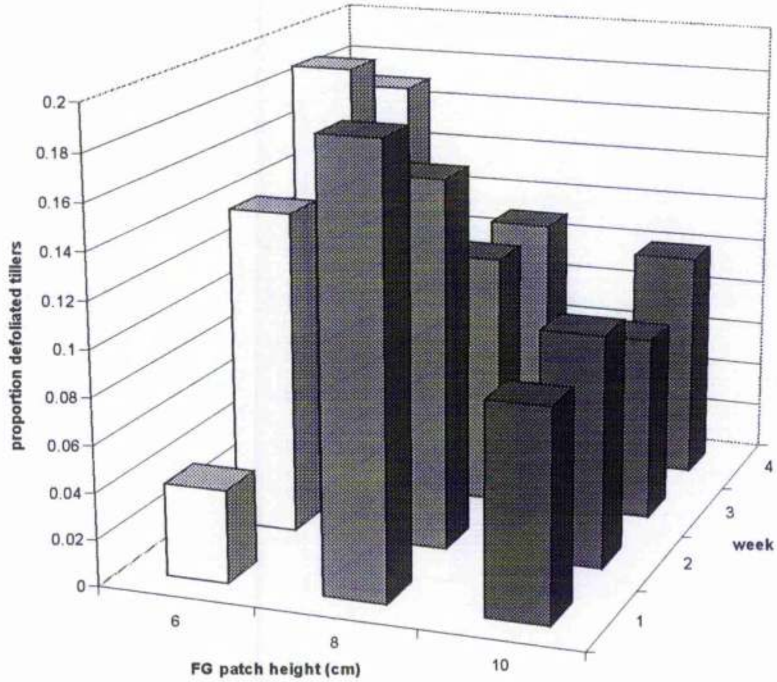


Figure 4.4: The effect of treatments 6, 8 and 10 FG patch height (cm) on the proportion of IG tillers defoliated over the four experimental weeks.

Treatment effect on the depth of defoliation of tillers within the FG patches was not significantly different between treatments ($P > 0.05$), however there was a significant decrease over the weeks ($P \leq 0.01$) (Table 4.9). There was a trend for a shallower depth of bite for the 6 cm treatment at week 2 and 3 than either of the other two treatments. The week and treatment interaction was not significantly different($P > 0.05$)(Figure 4.5).

Table 4.9: The depth of defoliation (cm) of tillers within frequently grazed patches of treatments 6, 8 and 10 during the experimental period.

	Treatment (cm)					
	6		8	10	s.e.d	*p*
Mean over Weeks	3.7		4.1	3.8	0.37	ns
	Week					
	1	2	3	4		
Mean over Treatments	5.4	4.1	3.4	2.7	0.69	**

**=$P \leq 0.01$, ns = non significant

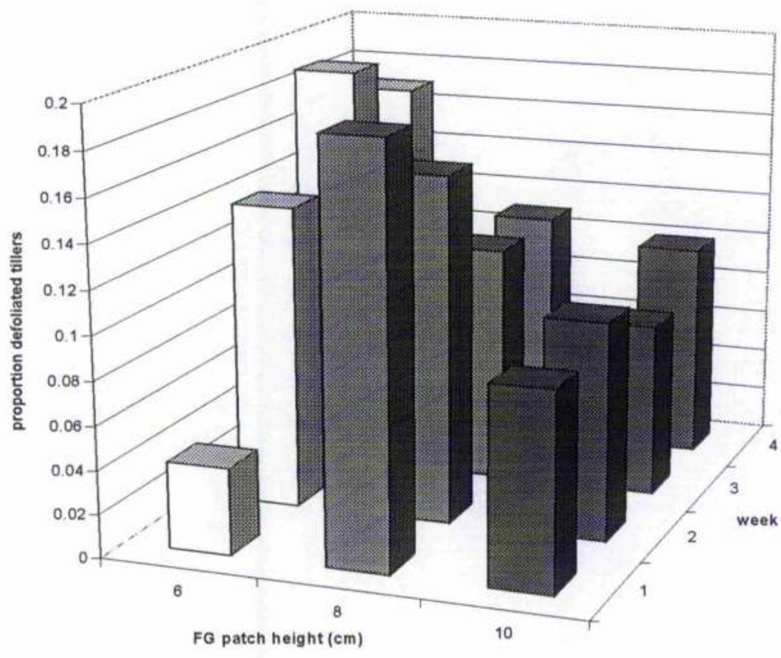


Figure 4.5: The effect of treatments 6, 8 and 10 FG patch height (cm) on the depth of defoliation of FG tillers over the four experimental

The depth of defoliation within the IG patches was not significant when averaged over all weeks ($P > 0.05$), however there was a significant interaction between weeks and treatments ($P \leq 0.05$) (Table 4.10). The bite depth gradually declined over weeks 2 to 4 within the 6 cm treatment, whilst within the 8 cm treatment it fluctuated, rising at week 3 and dropping again at week 4. Under the 10 cm treatment bite depth started high, reducing and remaining constant for weeks 2 and 3, then a massive reduction at week 4.

Table 4.10: The depth of defoliation (cm) of tillers within infrequently grazed patches of treatments 6, 8 and 10 during the experimental period.

	Treatment (cm)					
	6		8	10	s.e.d	*p*
Mean over weeks	7.9		8.9	6.8	1.91	ns
	Week					
	1	2	3	4		
Mean over treatments	8.5	9.4	7.9	5.8	1.47	ns
Week x Treatment Interaction	Treatment					
Week	6		8	10		
1	5.7		8.1	11.7	2.92	*
2	10.6		9.3	8.2		
3	8.5		10.4	7.9		
4	7.0		7.9	2.6		

*=$P \leq 0.05$, ns = non significant

The depth of defoliation, described as the proportion of the extended tiller height, of FG tillers shows a significant treatment effect, with the cows within the 10 cm treatment removing a significantly lower proportion of the tiller height, by approximately 10% ($P \leq 0.05$) (Table 4.11). There was no significant difference at any week over all treatments and neither was there any significant week and treatment interaction ($P > 0.05$). There was a trend for a reduction in the proportion removed to around 30% or below for the 8 and 10 cm treatment at week 3 and week 4, however the 6 cm treatment maintained the 50% removal for most weeks (Figure 4.7).

The depth of defoliation as a proportion of the IG tillers was not significantly different between treatments ($P > 0.05$), however it did show the same trend as the FG tillers with the 10 cm treatment approximately 10% less than either 8 or 6 cm treatment (Table 4.12). On average, the proportion removed for treatments was 12 – 15% lower for a IG tiller compared to the equivalent treatment for a FG tiller. There was a significant interaction between weeks and treatment with the 6 cm treatment maintaining 40% removal at week 2-4 compared to that within the 10 cm treatment declining from 29% to 11% during weeks 2-4 ($P \leq 0.05$).

Table 4.11: The depth of defoliation as a proportion of the extended frequently grazed tiller height within treatments 6, 8 and 10 during the experimental period.

	Treatment (cm)					
	6	8		10	s.e.d	*p*
Mean over Weeks	0.48	0.47		0.36	0.04	*
	Week					
	1	2	3	4		
Mean over Treatments	0.48	0.50	0.39	0.38	0.07	ns

*=$P \leq 0.05$, ns = non significant

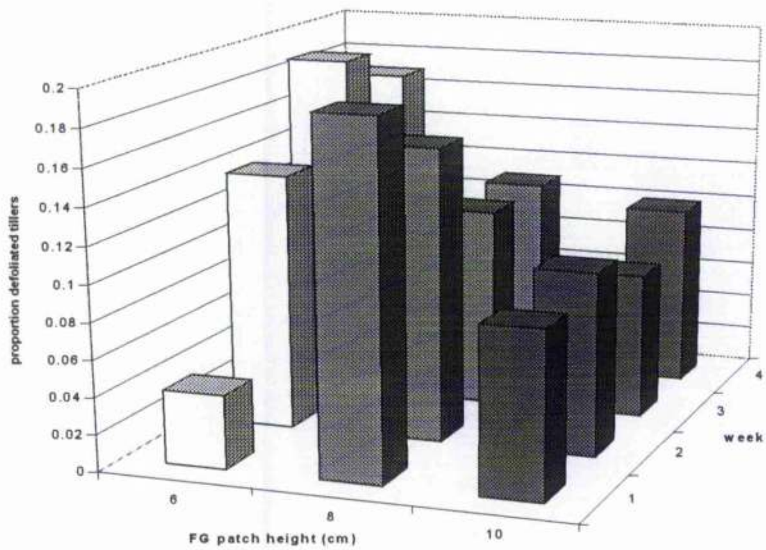


Figure 4.6: The effect of treatments 6, 8 and 10 FG patch height (cm) on the depth of defoliation of FG tillers, as a proportion of tiller removed over the four experimental weeks.

Table 4.12: The depth of defoliation as a proportion of the extended infrequently grazed tiller height within treatments 6, 8 and 10 during the experimental period.

	Treatment (cm)					
	6		8	10	s.e.d	p
Mean over weeks	0.35		0.32	0.24	0.68	ns
	Week					
	1	2	3	4		
Mean over treatments	0.29	0.34	0.31	0.26	0.05	ns
Week x Treatment Interaction	Treatment					
Week	6		8	10		
1	0.20		0.27	0.40	0.11	*
2	0.42		0.33	0.29		
3	0.40		0.38	0.17		
4	0.38		0.30	0.11		

*=$P \leq 0.05$, ns = non significant

4.5.1.5 Leaf : Stem ratio

There was no significant difference in the leaf:stem ratio within either the FG or IG patches at the beginning and end of the experiment(P >0.05) (Table 4.13). The effect of the treatments and time was to generally reduce the content of leaf within both FG and IG patches, however, there was predominantly less leaf in an IG patch compared to a FG patch on both occasions for any treatment.

Table 4.13: Leaf : Stem ratio of (a) frequently grazed patches and (b) infrequently grazed patches within 6, 8 and 10 treatment at the beginning (week 1) and end (week 4) of the experimental period

	Treatment (cm)				
Week	6	8	10	s.e.d.	p
1	(a)2.5	(a)2.0	(a)1.9	(a)0.6	ns
	(b)1.4	(b)0.7	(b)0.8	(b)0.33	ns
4	(a)1.5	(a)1.5	(a)2.2	(a)0.5	ns
	(b)1.0	(b)0.6	(b)0.5	(b)0.25	ns

ns = non significant

4.5.1.6 Live : Dead

The live:dead ratio within the frequently grazed patches was very variable between the treatments at the beginning of the experiment, with both the 6 and 8 cm treatments showing nearly twice the ratio than for the 10 cm treatment (Table 4.14). By the end of the 4 week experiment the ratios had fallen so that the 6 cm treatment showed a much smaller ratio than either the 8 or 10 cm treatment, which were very similar. However none of these differences were significant (P >0.05). The live:dead ratio within the infrequently grazed patches all showed a similar ratio at week 1 (Table 4.14). By week 4, these were reduced with the 10 cm treatment being significantly less than both 8 and 6 cm, while the 6 cm treatment had a significantly lower ratio than the 8 cm treatment ($P \leq 0.05$).

Table 4.14: Live : Dead ratio of (a)frequently grazed patches and (b) infrequently grazed patches within 6, 8 and 10 treatment at the beginning (week 1) and end (week 4) of the experimental period.

	Treatment (cm)			s.e.d.	*p*
Week	6	8	10		
1	(a)19.5	(a)17.4	(a)9.1	(a)3.5	ns
	(b)10.9	(b)11.7	(b)13.1	(b)3.6	ns
4	(a)4.2	(a)7.3	(a)7.1	(a)1.9	ns
	(b)4.0	(b)5.6	(b)0.6	(b)0.3	*

*=$P \leq 0.05$, ns = non significant

4.5.1.7 Herbage quality

None of the quality characteristics differed significantly between treatments at week 1 (P >0.05) (Appendix 3). There was no effect of treatment on ME, D-value, CP or WSC on the two occasions sampled. By week 4, the greatest changes in each of the treatments was in CP and WSC with all treatments showing a reduction and increase respectively. The only significant difference at week 4 was the NDF content, with the 8cm treatment being significantly greater than both the 6 and 10 cm ($P \leq 0.01$).

4.5.2 ANIMAL

4.5.2.1 Herbage Intake

The estimated total dry matter intake was not significantly different between treatments at week 1 (P >0.05), however thereafter increasing FG patch height led to significantly greater intake and this effect increased with time ($P \leq 0.001$) (Table 4.15).

Table 4.15: Estimated total herbage dry matter intake (kg dm day^{-1}) using the n-alkane technique for cows on treatments 6, 8 and 10 during the experimental period.

	Treatment (cm)			P	P
Week	6	8	10	at week	accumulated to week
1	15.5	17.9	17.0	ns	ns
2	14.7	15.8	17.9	**	**
3	12.5	15.2	16.1	**	***
4	14.6	18.9	20.0	*	***

*=$P \leq 0.05$, **=$P \leq 0.01$, ***=$P \leq 0.001$, ns = non significant

The estimated dry matter intake from the IG patches was not significantly different between treatments at week 1(P >0.05), however this was significant at weeks 2,3 and 4 ($P \leq 0.001$). The 6 cm treatment showed the least intake at week 2 and the greatest at weeks 1,3 and 4 (Table 4.16). The proportion of the total intake which came from the infrequently grazed patches was significantly different at all weeks with the 6 cm treatment having the highest proportion and the 10 cm the lowest at weeks 1,3 and 4 ($P \leq 0.001$) (Table 4.17).

Table 4.16: Estimated herbage dry matter intake (kg dm day^{-1}) from the infrequently grazed patches using the n-alkane technique for cows on 6 , 8 and 10 treatment during the experimental period

Week	Treatment (cm)			P at week	P accumulated to week
	6	8	10		
1	6.0	5.3	3.9	ns	ns
2	3.3	4.7	3.9	**	*
3	2.6	1.9	1.6	***	***
4	2.2	1.8	1.6	*	***

*=$P \leq 0.05$, **=$P \leq 0.01$, ***=$P \leq 0.001$, ns = non significant

Table 4.17: The proportion of the total herbage dry matter intake from the infrequently grazed patches for cows within 6, 8 and 10 treatments during the experimental period.

Week	Treatment (cm)			P at week	P accumulated to week
	6	8	10		
1	0.37	0.29	0.21	**	**
2	0.21	0.28	0.22	*	***
3	0.20	0.12	0.10	***	***
4	0.14	0.09	0.08	***	***

*=$P\leq0.05$, **=$P\leq0.01$, ***=$P\leq0.001$, ns = non significant

4.5.2.2 Milk yield and composition

The milk yield was significantly different between treatments at week 3 and 4 with the milk yields increasing with increasing treatment sward height ($P > 0.05$) (Table 4.18). By the fourth week the differences had accumulated to a significant level ($P \leq 0.05$). When these yields were corrected to the same protein and fat content, the only significant difference between treatments was at week 3, which showed the same trend between the treatments as the non corrected milk yields ($P \leq 0.05$). The regression of milk yield and FPCM over the four weeks showed both to be significant, both showing the same trend ($P \leq 0.05$, $P \leq 0.01$ respectively) (Table 4.19). All treatments showed a declining yield over time with the greatest decline being the 6 cm treatment, while 8 and 10 cm treatment declined at a similar rate.

Table 4.18: Milk Yield (kg cow^{-1} day^{-1}) and Fat and Protein corrected milk yield, FPCM (kg cow^{-1} day^{-1} corrected to fat and protein content of 40g kg^{-1} and 30 g kg^{-1} respectively) for cows on treatment 6, 8 and 10 during the experimental period.

MILK YIELD						FPCM				
Treatment						Treatment				
Week	6	8	10	*P* at week	*P* accumulated up to week	6	8	10	*P* at week	*P* accumulated up to week
1	28.5	28.8	29.8	ns	ns	28.8	27.0	29.0	ns	ns
2	27.4	27.3	29.6	ns	ns	27.1	24.8	27.7	ns	ns
3	24.3	25.8	27.5	*	ns	21.0	23.6	25.3	*	ns
4	22.5	25.4	27.1	*	*	20.0	22.8	24.8	ns	ns

*=$P \leq 0.05$, ns = non significant

Table 4.19: Linear regression (slopes) of milk yield (kg cow^{-1} $week^{-1}$) and FPCM (kg cow^{-1} $week^{-1}$) (corrected to fat and protein content of 40g kg^{-1} and 30 g kg^{-1} respectively) for cows on treatments 6, 8 and 10 over the four week experimental period.

	Treatment				
Linear regression	6	8	10	s.e.d	*P*
Milk Yield (kg cow^{-1} $week^{-1}$)	-2.16	-1.16	-1.02	0.432	*
FPCM (kg cow^{-1} $week^{-1}$)	-3.25	-1.37	-1.47	0.60	**

*=$P \leq 0.05$, **=$P \leq 0.01$

There was no significant difference between treatments for fat, protein and lactose composition at any week or accumulated over the weeks ($P > 0.05$) (Appendix 4,5 and 6).

The yield of fat was not significantly different between treatments at any week or over the weeks ($P > 0.05$). Protein yield was significantly different at week 3 when the yield increased with increasing sward height treatment ($P \leq 0.05$) (Table 4.20). Although this trend was also seen in week 4 these differences were not significant ($P > 0.05$). However, the linear regression of fat and protein yield over time showed the 6 cm treatment to have a significantly greater reduction than the 8 and 10 cm treatments ($P \leq 0.05$, $P \leq 0.01$ respectively) (Table 4.21).

Table 4.20: Fat and Protein yield (g cow^{-1} day^{-1}) for cows on treatments 6, 8 and 10 during the experimental period.

	FAT YIELD (g cow^{-1} day^{-1})					PROTEIN YIELD (g cow^{-1} day^{-1})				
	Treatment					Treatment				
Week	6	8	10	*P* at week	*P* accumulated up to week	6	8	10	*P* at week	*P* accumulated up to week
1	1237	1088	1249	ns	ns	931	891	914	ns	ns
2	1122	980	1143	ns	ns	884	837	897	ns	ns
3	931	939	1161	ns	ns	725	788	844	*	ns
4	825	917	1000	ns	ns	645	722	828	ns	ns

*=$P \leq 0.05$, ns = non significant

Table 4.21: Linear regression (slopes) of Fat and protein yield (kg cow^{-1} day^{-1}) for cows on treatments 6, 8 and 10 over the four week experimental period.

	Treatment				
Linear regression	6	8	10	s.e.d	*P*
Fat Yield (kg cow^{-1} $week^{-1}$)	-142	-55	-73	32.6	*
Protein Yield	-102	-56	-31	21.3	**

(kg cow^{-1} week^{-1})

*=$P\leq0.05$, **=$P\leq0.01$

4.5.2.3 Grazing Behaviour

The general trend over weeks 2, 3 and 4 was for the least time spent grazing and the greatest time spent ruminating to be within the 10 cm treatment, with those animals within the 6 cm treatment grazed for the greatest time and ruminated for the least (Table 4.22).

The only significant difference between treatments was measured at week 4 when those animals on the 6 cm treatment grazed for an extra 55 minutes and ruminated for 40 minutes less, approximately compared to those on either the 8 or 10 cm treatments ($P \leq 0.05$). Idling time makes up the remainder of the 24 hour period, therefore it was relatively constant between treatments at each week.

Table 4.22: Time spent grazing and ruminating (minutes) during a 24 hour observation period for cows on treatments 6 , 8 and 10 during the experimental period

	Grazing time (min) Treatment				Ruminating Time (min) Treatment			
Week	6	8	10	s.e.d / P	6	8	10	s.e.d / P
1	416	450	427	15.6/ns	242	217	228	12.2/ns
2	481	463	443	31.0/ns	195	205	213	21.6/ns
3	528	526	491	21.6/ns	167	166	203	17.2/ns
4	500	442	447	13.7/*	168	200	218	9.4/*

*=$P\leq0.05$, ns = non significant

There were no significant differences due to treatments in the time grazing the IG patches, with a high variability over the weeks and between the treatments ($P > 0.05$) (Table 4.23). When the proportion of time spent grazing the infrequently grazed patches is combined with their proportion in the sward, in the form of the selection ratio, then a trend appears. Those animals within the 6 cm treatment stopped avoiding the infrequently grazed patches at week 2. At this time they had a neutral selection ratio being significantly greater than those for either the 8 or 10 cm treatment which both show lower ratios indicating continued avoidance ($P \leq 0.05$) (Table 48.). At week 3, those in the 6 cm treatment also avoided grazing the infrequently grazed patches. However, by week 4 this had reversed and the animals were very positively selecting these patches when grazing the sward, while animals on the other two treatments continued to avoid them.

Table 4.23: Proportion of time spent grazing and selection ratio (1= neutral, >1= positive selection, <1= negative selection) of infrequently grazed patches by cows on treatments 6, 8 and 10 during the experimental period.

	Proportion of time grazing				Selection ratio			
	Treatment				Treatment			
Week	6	8	10	s.e.d / P	6	8	10	s.e.d / P
1	0.15	0.20	0.15	0.04/ns	0.48	0.50	0.35	0.09/ns
2	0.3	0.24	0.25	0.04/ns	1.0	0.60	0.66	0.08/*
3	0.24	0.34	0.27	0.07/ns	0.67	0.79	1.0	0.07/ns
4	0.37	0.31	0.33	0.04/ns	1.7	0.9	0.8	0.09/ns

*=$P \leq 0.05$, ns = non significant

4.5.2.4 Live weight and Condition score

Both live weight and condition score showed no significant differences between treatments at any week or accumulated over weeks ($P > 0.05$) (Appendix 7).

4.6 DISCUSSION

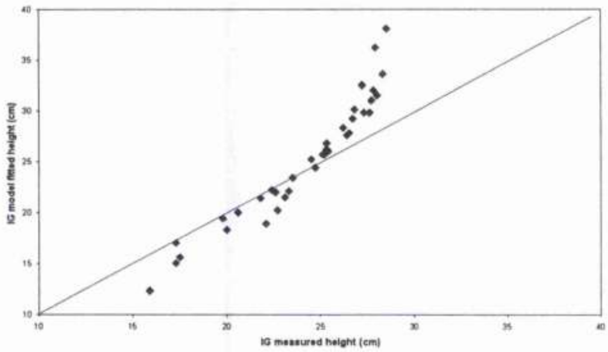
The aim of this experiment was to determine how the sward height of the FG patches affected the utilisation of the IG patches by lactating dairy cows.

Perhaps the greatest difficulty with grazing experiments is being able to manage the grazing to obtain the required sward for investigation. This study was no exception. Attempts to achieve the different FG mean patch heights, without affecting the IG patch proportion, resulted in mean heights for the FG patches during the first week of the experiment that were substantially higher than the target. There was a small difference in the proportion of IG patch between treatments at the start of the experiment due to the conditioning grazing needed to achieve the required treatment heights. These differences were not significant ($P > 0.05$), however it does highlight the complex association between the sward and animal when using this as a conditioning tool for experimental swards.

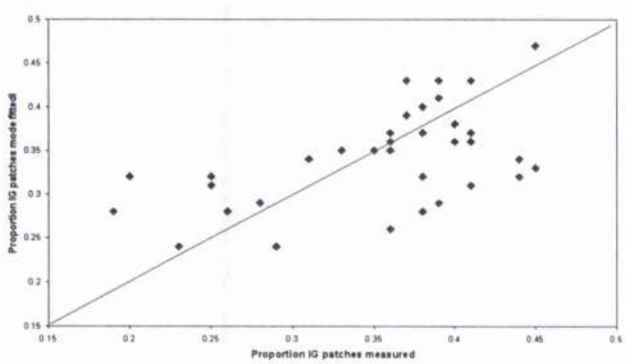
4.6.1 Sward structure

Comparing the mean height of FG and IG patches and the proportion of IG patches within the sward, as measured subjectively and fitted by the model, there is good agreement, especially for the FG patch height and IG proportions (Figure 4.7). However, there would appear to be some significant discrepancy between height means for the IG patches at the higher heights due to the censoring of measured data (Figure 4.7). The subjective method of assessing patches and the "grey" area of overlap between the two patches appears to be valid as the fitted model yielded very similar means. The difference in the mean height of the IG patches may be attributed to the model adjusting for the censoring of the distribution which was not present for the FG patches.

(a)



(b)



(c)

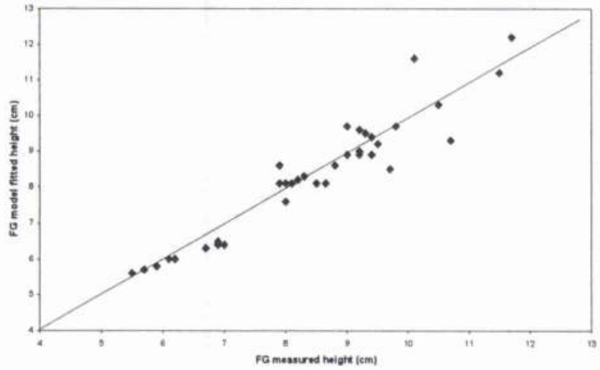


Figure 4.7: Comparison of model fitted data to that measured, with the straight line showing variation from the an exact fit for a) IG height b) Proportion of IG patches in sward and c) FG height.

The height of the IG patch was significantly lower at the 6 cm treatment, while that of the 8 and 10 cm treatment was similar($P \leq 0.001$). An exponential relationship was fitted to the data, with an r^2 of 0.83 and 0.56 for measured and model fitted data respectively (Figure 4.8).

This is also true for the proportion of the IG patches within the swards. An exponential curve was fitted to both the measured and model fitted data of proportion of IG patch against the height of the FG patch (Figure 4.9). Correlation coefficients of 0.6 and 0.3 were obtained for the curves fitted to the measured and best fit model data respectively.

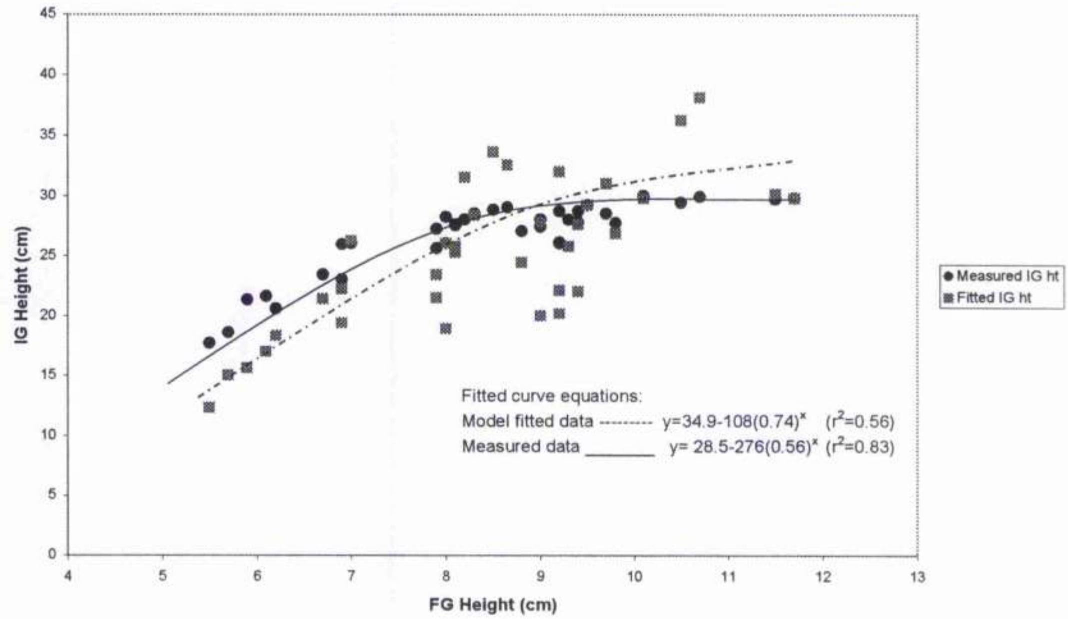


Figure 4.8: The relationship between FG and IG mean patch height (cm) for measured (•) and model fitted (■) data

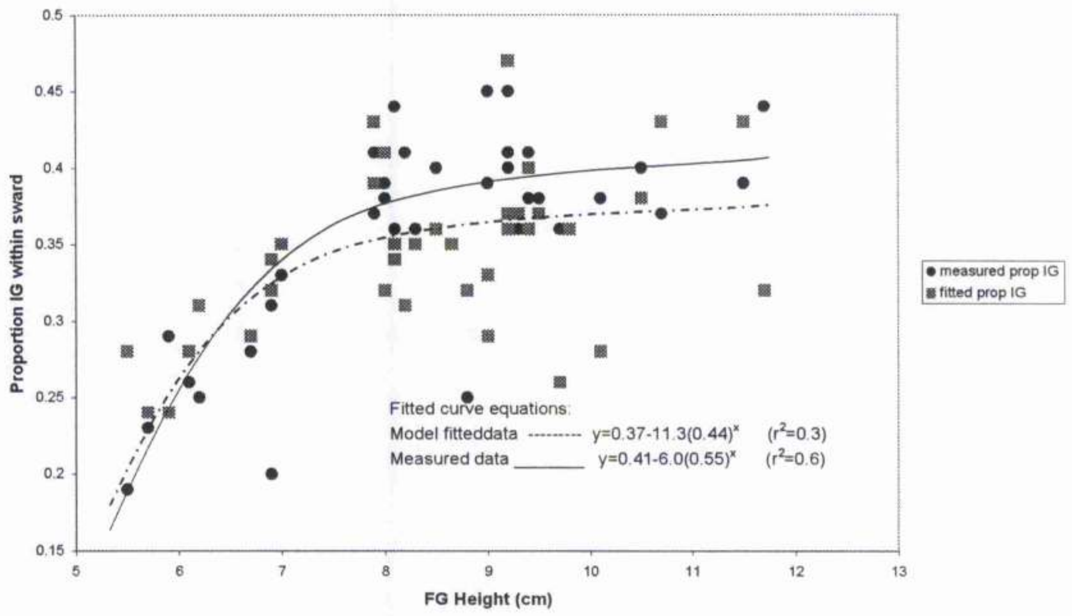


Figure 4.9: The relationship between the FG mean patch height (cm) and proportion of IG patches within the sward for measured (•) and model fitted (■) data.

The proportion of the IG patches within the sward was consistently at around 35-40% for both the 8 and 10 cm treatment and 25-32% for the 6 cm treatment. Gibb *et al.* (1997) also found a similar order of difference in the proportion of IG patches albeit at lower levels for a 5, 7 and 9 cm mean sward height of 18, 34 and 32 % respectively. Within the present study, the proportion of the IG patches within the 6 cm treatment declined at week 3 together with a reduction in the mean height of these patches. This indicates that these patches were being grazed from the top and the edge. Within the FG patch sward height treatments of 8 and 10 cm, the mean height of the IG patches declined gradually over the weeks which indicates a constant sampling of these patches from the top rather than total rejection. It must be stated that these mean heights were not extended height and therefore a decline may be attributed to trampling or heavy rainfall. However, since rainfall was minimal during the whole experimental period and the grazing pressure low, then it is unlikely that either of these factors contributed to the fall in the mean patch height within any treatment. Grazing from both the top and the edge of the IG patch within the 6 cm treatment would initially conflict with that reported by Bao *et al.* (1998). They concluded that under rotational grazing, dung patch areas were grazed from the edge during early grazing stages and only later grazing showed a reduction in the height. These differences could be attributed to the great variation in the sward as it is presented to a grazing animal under rotational and continuously stocked grazing. Swards within rotational grazing become more similar to that encountered by a grazing animal within a continuously stocked sward as the difference between the frequently and infrequently grazed patches and the heterogeneity of the whole sward increases as the grazing progresses. Therefore considering this, the results of Bao *et al.* (1998) do actually agree with those of this study.

The content of leaf was lower within a IG patch compared to the FG patch, however there was no effect of treatment on leaf content within either patch type. The content of dead material within a patch was significantly greater for the IG patch under the 10 cm treatment by the end of the experiment ($P \leq 0.05$). Disappointingly, the chemical analysis results did not show any difference in ME or D value between treatments or patches which may be due to sampling error of patches due to the great variation of IG patch maturity within a plot. Milne and Fisher (1994) state an ME of tall rejected areas having developed seed heads as 8.O MJ ME/ kg DM , which is 30% lower than the short grazed area of a sward. Griffiths *et al.* (1997) measured OM digestibility of tall mature swards and found it to only be 2% lower than short immature swards. The comparison of such results is difficult due to the great variation in plant species and structure together with sampling method, which can greatly affect the ME obtained.

4.6.2 Grazing Behaviour

The continual sampling of the IG patch to reduce the height gradually over the four weeks within the 8 and 10 cm treatment is also supported by the estimated herbage intake of 10-20% of total diet being obtained from these patches. This agrees with Griffiths *et al.* (1997) and Illius and Gordon (1990) who proposed that grazing animals need to sample continually alternative areas to gain information of what is located there. The observations of grazing behaviour shows some 15-30% of the grazing time spent within these IG which suggests a greater time than the diet proportion. The time within the patches includes time for searching, selecting and grazing. Laws *et al.* (1996) observed cattle to olfactory examine (moving nose into herbage while inhaling deeply) and graze slurried areas of a sward for up to 20% of total grazing period.

When the area of the sward classified as IG patch, together with the grazing behaviour is considered we see that the selection ratio (i.e. neutral, positive or negative towards the IG patches) initially is similar and negative for all treatments. This was also reported by Bao *et al.* (1998) when cows initially entered a paddock within rotational grazing. Avoidance continued into the second week of the present study except for the 6 cm treatment when the cows were grazing the IG patches as often as expected from their proportion within the sward (i.e. neither selecting or avoiding). Active selection of these patches was only evident at week 4 under the 6 cm treatment. Animals within the 8 and 10 cm FG patch height treatments showed avoidance of IF patches over all weeks. The combination of reduced leaf, greater dead content and declining herbage mass of the FG patches within the 6 cm may well have resulted in the grazing animal positively selecting the IG patches during the fourth week of the experiment. However, the total intake from within the IG patches remained at a similar level to the previous week despite spending longer grazing within the patches. The proportion of tiller removed, together with the number of defoliations, remained similar to previous weeks which indicates that the extra time spent within these patches was for non grazing activities i.e. searching, selecting and manipulating material. Total intake within the 6 cm treatment during week 4 was increased from the previous week through increasing the number and depth of defoliations within the FG patches. The quality of these patches at week 4, in terms of leaf and dead content was poorer than at week 1 and hence the increased intake was insufficient to maintain the previous level of production at week 2 for the same total dry matter intake.

The depth of defoliation as a proportion of the extended tiller height within both FG and IG patches varied between 11 – 58%. This is within the range reported by Hodgson *et al.* (1985), Wade *et al.* (1989), Ungar *et al.* (1991) and Laca *et al.* (1992). The proportion of both the FG and IG tiller being defoliated at each bite remained relatively constant after week 1 (week 1 heights were high and stocked in order to achieve target sward surface heights). A higher proportion, by approximately 10%, being removed from the FG compared to the IG grazed tillers. Wade *et al.* (1989) report a constant 34% removed when under a grass height of 12-38 cm. A 30-40% removal is reported in the present study when averaged over both FG and IG tillers for all treatments. The higher proportion within this range was within the 6 and 8 cm treatment, which may be due to the lower sward height restricting intake. There was a significantly greater proportion removed from the IG tillers within 6 cm treatment at weeks 3 and 4 compared to either 8 or 10 cm, with the 10 cm having least removed ($P \leq 0.05$). The depth of defoliation of any IG tiller did not exceed 40% of the extended tiller height while that of the FG were reaching nearly 60% depth. This could have been due to the extended tiller height in excess of 25 cm within the infrequently grazed patches being too difficult to manipulate the quantity of material removed. A stem barrier below which grazing was inhibited may restrict the grazing to the upper lamina horizons of the IG tillers (Barthram and Grant, 1984; Arias *et al.* 1990; Flores *et al.* 1993)

Generally, a greater number of FG tillers were defoliated by approximately two- fold than IG tillers within all treatments. The 6 cm treatment showed greatest defoliation of both IG and FG tillers during week 3 and 4 compared to either the 8 and 10 cm treatment.

This data shows that those animals grazing within the 6 cm treatment utilised the IG patches by increasing the number of tillers defoliated within this patch. This was achieved through less avoidance and by active selection of these patches during grazing, which was also modified by an increase in grazing time of up to 45 minutes daily. The overall effect was to reduce both the height and area of IG patches within the 6 cm treatment to a greater extent than that within the 8 or 10 cm treatment.

4.6.3 Grazed grass intake

Sward surface height on a continuously stocked sward has been shown to significantly affect the daily organic matter intake, Gibb *et al.* (1997). Hodgson (1986) showed the main limitation of potential intake by a grazing animal is bite size, which itself is determined by sward surface height (SSH) and bulk density. Laca (1992) and Brereton and McGilloway (1998) both showed that increasing sward height increases bite depth and consequently bite size. Grazing time was shown to be increased at low SSH (Gibb *et al.*, 1997). This was similar for a sward height of either 7 or 9 cm, however the total dry matter intake was actually lower under the 9 cm sward. This is in contrast to the results of the present study. Daily dry matter intake estimated using the n-alkane technique showed a significantly increasing intake with increasing mean height of the FG patches of 6, 8 and 10 cm ($P \leq 0.001$). These conflicting results may be due to the different methods used to estimate dry matter intake and their interaction with sward morphology. Short-term intake as measured using the weighing techniques, accounting for insensible weight loss, described by Penning and Hooper (1985) may disadvantage the taller more heterogeneous sward by allowing for greater selecting and searching compared to the more uniform short sward. This could result in reduced intake over a relatively short time period of one hour, although if measured over a longer period of a day, as in the present study, may not cause a significant effect. The energy balance calculations for estimating intake for the present study are generally in good agreement with the n-alkane estimates (Table 4.24)

Table 4.24: Comparison of estimated daily intakes of grazed grass (kgDM/day) for cows on treatments 6, 8 and 10 during the experimental period, using the energy balance calculations and n-alkane methods.

	Week/Treatment											
	1			2			3			4		
	6	8	10	6	8	10	6	8	10	6	8	10
ME required (MJ/d)												
Maintenance	59.8	60.2	60.2	59.3	60.0	59.8	59.5	60.1	59.3	59.8	60.9	60.5
Milk Prod.	149.8	139.4	149.8	139.4	129.1	144.6	108.4	123.9	129.1	103.2	118.8	129.1
ME supply (MJ/d)												
Concentrate	30	30	30	30	30	30	30	30	30	30	30	30
Lwt change	0	0	0	19	8	13.5	-8	-5.5	-16.3	-10.8	-24.5	-40.7
Energy Balance (MJ/d)	179.6	169.6	180.0	149.7	151.1	160.9	145.9	159.5	174.7	143.8	174.2	200.3
ME grass (MJ/kg)	10.4	10.6	10.3	10.3	10.0	10.0	10.1	10.1	10.1	10.4	10.2	10.1
Intake - energy balance (kg/d)	17.2	16.0	17.5	14.5	15.1	16.1	14.4	15.7	17.2	13.8	17.0	19.8
Intake - n-alkane (kg/d)	15.5	17.9	17.0	14.7	15.8	17.9	12.5	15.2	16.1	14.6	18.9	20.0

4.6.4 Milk Production

Milk yield was significantly different between treatments by weeks 3 and 4 when it increased with increasing FG height ($P \leq 0.05$), which would be expected since the total daily dry matter intake also showed the same trend. The composition of the milk showed a trend for a higher fat concentration for those cows within the 6 cm treatment. This may be attributed to the higher proportion of their diet coming from the IG patches, which contain a higher stem, and hence fibre content than the FG patches.

4.7 CONCLUSION

From this study we can conclude that the height of the FG patches does affect the dynamics of the infrequently grazed patch through the modification of the grazing behaviour of the dairy cow.

In summary:

1) Only at the lowest FG patch height of 6 cm, did the animals consume a significantly greater intake from the IG patches ($P \leq 0.05$).
2) The overall effect within the 6 cm treatment was a significant reduction in height and area of the IG patches within the sward compared to those swards with FG patches at a mean height of 8 or 10 cm ($P \leq 0.001$, $P \leq 0.01$ respectively).
3) Increased intake from IG patch within 6 cm treatment was brought about by increased grazing and less avoidance of the patches.
4) There was a continual sampling of the IG patches even at the 10 cm FG patch height which contributed to between 10 -20% of their total dry matter intake.
5) The total dry matter intake at each week and milk yield by week 3 was significantly greater with increasing FG patch height ($P \leq 0.05$).

Dairy cows which are continuously stocked in the mid season at the recommended 8 – 10 cm sward surface height are unlikely to be effectively utilising the IG patches. In order to increase their utilisation, the sward needs to be grazed at mean heights of 6 cm and below, however this would compromise the milk yield per cow.

CHAPTER 5. EXPERIMENT 3

THE EFFECT OF TOPPING THROUGHOUT THE SEASON AND FREQUENCY OF TOPPING ON SWARD MORPHOLOGY, UTILISATION OF INFREQUENTLY GRAZED PATCHES AND MILK PRODUCTION WITHIN A SWARD GRAZED BY DAIRY COWS IN THE MID SEASON.

5.1 INTRODUCTION

The production of milk from grass is not only dependent on the quantity of herbage available but also the quality of that herbage. Leaf has a higher nutritive value than stem due to a lower proportion of cell wall compared to cell content. Therefore, swards maintained at a leafy state have higher energy values.
Voluntary intake is also greater for leafy herbage. Fibrous material is bulky and slows the outflow rate from the rumen. This affects the grazing time and total intake may be reduced compared to a less fibrous material. In order to maximise nutritive value and utilisation, the sward management must maintain high leaf content.

Grass tillers that survive winter have also been vernalised with low temperature and short day length; therefore these tillers have the ability under the increased day length in spring to undergo reproductive growth. Growth of these tillers, if it remains uninterrupted, will produce shoots and elongate with formation of a flower head. The apical dominance of reproductive tillers prevents the further production of vegetative tillers. Defoliation of tillers in spring will interrupt this growth, maintaining a greater proportion of tillers in the vegetative state. Therefore, management of a sward in early season needs to include relatively frequent defoliation in order to maintain vegetative growth by removing stem apices.

The severity of defoliation in spring has been shown to affect sward morphology in the mid season (Korte, 1982; Dillon and Stakelum, 1988; Fisher and Roberts, 1995). Severely grazed swards have more vegetative tillers and less tall infrequently grazed patches. Swards that have been grazed insufficiently in spring are usually of lower quality because of increased selectivity of grazing leads to more IG patches showing reproductive growth. High yielding spring calving cows require maximum intake of grass in spring which is often not compatible with the high grazing pressure required to fully utilise the grass at that time. Unfortunately, these swards will carry through into mid season with a relatively high level of IG areas. Mid season grazing of these swards could lead to continued poor utilisation, or if high grazing pressure is applied, grazing of these IG patches may not maintain milk production.

One management tool that would ensure frequent, severe defoliation during the early season, in order to maintain leafy swards, would be mechanical topping. Topping in mid season is too late, since apical dominance by reproductive tillers has already occurred and reduced the renewal of vegetative tillers. Topping in mid season will only remove stem and flower heads without enhancing the morphology (Fisher and Roberts, 1995). Topping in early season has been shown to enhance quality of swards and milk production from rotational grazed swards topped after lenient early season grazing compared to non topped leniently grazed swards (Stakelum and Dillon, 1990).

There is no work on the effect of topping, or the frequency of that topping, from early season under continuous stocking systems on the morphology of infrequently grazed patches, grazing behaviour and milk production of dairy cows. Therefore this chapter describes an experiment designed to investigate such effects.

5.2 MATERIALS AND METHODS

The experiment was designed to examine the effect of mechanical topping at two different frequencies throughout the season, on the morphology of the IG patches within the sward. The effect on animal grazing behaviour together with grazed grass intake and milk production was also investigated. Three treatments were compared. The control was a conventionally grazed sward without the use of mechanical topping. There were two topped treatments: Topped every two weeks (T2) and topped every four weeks (T4). All toppings commenced at 18th May 1998 and continued to the end of August 1998. Topping was carried out to a height of approximately 8 cm using a Wylie eight foot trailed offset pasture topper, leaving the grass toppings on the surface. The sward was managed by target sward height of 7 cm for the frequently grazed (FG) areas.

The grazing management was continuous stocking from turnout on 22nd April 1998 until completion of the trial on 4th September 1998. The experimental design was randomised complete block with each treatment having 3 replicates. Blocking occurred prior to the treatments being imposed taking into account the soil and sward variations across the 10ha field. Each block consisted of 3 1.1ha plots with treatments allocated randomly to plots within blocks. The sward was predominately *Lolium perenne* receiving a total of 375 kg N, 45 kg P_2O_5 and 45 kg K_2O per ha during the grazing season with Nitrogen applied at monthly intervals.

Continuous stocking was maintained throughout the experiment with the control of SSH by put and take of non experimental cows. The height of the FG areas fell below the target height of 7 cm towards the end of June until mid August due to poor grass growing conditions.

Thirty six multiparous Holstein/Friesian cows, calving between 19 December to 25 May were grouped into trios according to calving date, milk yield at end of May and lactation number. Cows were randomly allocated to a treatment within a block on 1 June. There were a total of 12 experimental cows per treatment with additional cows allocated from the main herd if required to control SSH. Cows were milked at 6.30h and 15.30h daily. All cows received a supplement of 2.9 kg DM day^{-1} of a 200g kg^{-1} DM Crude protein concentrate throughout the experiment irrespective of their stage of lactation.

5.3 MEASUREMENTS

Sward surface height was measured three times per week, Monday, Wednesday and Friday by taking 40 hits per plot in a 'W' shape using the HFRO sward stick (Hill Farming Organisation, 1986). If a hit was subjectively determined as to be within an IG area this was recorded to allow for a proportion of these patches to be estimated. From these height records the average height including both patches, the height of the short FG area alone and the height of the taller, IG patches and also their proportion within the sward was estimated.

Herbage mass of both the FG and IG patches within the sward was estimated every two weeks, commencing directly prior to the first topping of 18 May. This was estimated by cutting strips 1.5m x 0.33m of a total known area to 2cm above ground level using an Alpino Motor Scythe. Herbage mass sampling occurred immediately before any mechanical topping was carried out on all occasions. All herbage was dried for 12 hours at 80°C to determine dry matter content. These samples were also used to take sub-samples for sward component analysis and for chemical analysis of quality.

Leaf: Stem ratio and Dead: Live was determined by separating a 50g sample of herbage for each of the infrequently and frequently grazed areas within the sward into the respective components.

Analysis by NIR, near infra-red spectroscopy, determined the quality aspects of the herbage i.e. DOMD, ME, CP, WSC and NDF. The calibration set for NIR used fresh grass samples from the fields at SAC Auchincruive and Crichton Royal Farm (Offer, N.W. personal communication) with the methodology for scanning and prediction being that published by Barber *et al.* (1990)

Tiller density was measured every two weeks, with 15 cores randomly sampled from both FG and IG patches within each plot. Live tillers within the cores (19.6 cm^2) were identified as Perennial ryegrass (*Lolium perenne*) or other species.

Leaf area index was recorded *in situ* using the inclined point quadrat as described by Warren Wilson (1959). Fifteen points were recorded within the FG and IG areas per plot, once every four weeks.

Individual intake of grazed grass by the 36 core cows was estimated using the n-alkane technique. This was estimated for three 5 day periods during the experiment: 22-26 June, 20-24 July and 17-21 August. Animals were dosed twice a day with pellets containing 640mg in total of dotriactane (C32) impregnated into shredded paper. After the initial 7 day period when the concentration of alkane reaches a constant level faecal sampling occurred for individual animals at each morning milking. These were then bulked for 5 consecutive days. Hand plucked herbage samples were also taken separately from the FG and IG areas daily. Samples were obtained randomly within the either area throughout the whole plot. These herbage samples were bulked over 3 days and 2 days during the 5 day intake period for both areas. Both faeces and herbage samples were frozen at -20°C initially prior to freeze drying. Milled samples were analysed for n-alkanes as described by Mayes *et al.* (1986). Total dry matter intakes were estimated using the equation of Dove and Mayes (1991).

Milk yield was recorded daily for the 36 core cows with samples taken mid week for consecutive am, pm milking for analysis of fat, protein and lactose content (Biggs, 1979). Cows were weighed and condition scored (Mulvany, 1977) every two weeks following afternoon milking.

Grazing behaviour of core cows was recorded as time spent grazing, ruminating or other activities during a continuous 24 hour period. These observations took place once every four weeks. Cows were observed every 15 minutes with activity recorded. Night recordings were aided by torch and coloured collars for core cows.
In addition, bite rate and the area of grazing within the sward was recorded on the day prior to 24 hour observations for each week. Bite rate was recorded as the natural bite rate, including the time spent searching for and manipulating herbage. The time for 20 bites was recorded for 20 observations on two core cows per plot after morning and afternoon milking. The day following the 24 behaviour observations the proportion of time spent by the core cows grazing within the infrequently grazed area was determined. For a 40 minute period after morning and afternoon milking, core cows were observed every 2 minutes with the grazing area, either IG or FG being recorded.

5.4 STATISTICAL ANALYSIS

The statistical comparison between treatments was estimated using statistical package Genstat 5 release 4.1 (Lawes Agricultural Trust, 1990). Animal performance data were analysed by analysis of covariance, in order to take into account the between animal variation. Those animal variables measured over the whole experimental period were analysed by repeated measures, with each cow treated as one unit, in order to account for the dependence on time for those variables. Animal performance data, analysed for change over time, was done by calculating the slope for each animal as a summary measure of response over time. A comparison of slopes between treatment groups was made by one way ANOVA.

Sward data were analysed at timepoints throughout the experiment by analysis of variance with three treatments, each with three replicates. Using time as a factor within the ANOVA these results were compared over the experimental period, since the same unit was not sampled at each timepoint and therefore repeated measures could not be imposed.

5.5 RESULTS

5.5.1 SWARD

5.5.1.1 Sward Surface Height and Proportion of Infrequently grazed patches

The FG patch height dropped below the target 7cms on a number of occasions. This occurred within all treatments between week 6 and 9 and for T2 and T4 for weeks 10, 15 and 16 (Figure 5.1). There was a significant effect of treatment on the height of the FG patches when compared over all weeks with the C treatment being significantly greater than either the T2 or T4 treatment ($P \leq 0.001$) (Table 5.1).

There was also a significant treatment effect over all weeks within the IG patches with the height of the T2 treatment being significantly lower than both T4 and C treatment and T4 being significantly lower than the Control ($P \leq 0.001$). The height of the IG patches within the control treatment remained fairly constant up to week 8 then there was a reduction of a few centimetres. There was little change of height again until week 15 when a gradual decline over the last 2 weeks of the experiment was evident within the control treatment (Table 5.2; Figure 5.1). The topping treatments had regular height reductions through the mechanical topping treatment (Figure 5.1). The regrowth of those patches within T4 treatment was usually sufficient by the fourth week not to be significantly different from the control. There was a significant interaction between treatment and week for the IG patch height ($P \leq 0.001$) (Table 5.2).

Table 5.1: Height (cm) of the frequently grazed patches within C, T2 and T4 treatments during the experimental period.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	7.1	6.7	6.7	0.08	***
Week	Treatment x Week Interaction				
1#	8.9	8.4	8.0	0.31	ns
2	7.9	7.8	7.6		
3$	6.9	7.0	6.8		
4	7.0	6.6	6.7		
5#	7.4	6.4	6.3		
6	6.3	6.0	6.0		
7S	6.3	5.9	6.1		
8	6.6	6.2	6.3		
9#	6.6	6.2	6.0		
10	7.0	6.5	6.5		
11$	7.4	7.1	7.0		
12	7.1	7.3	6.9		
13#	7.4	6.8	7.5		
14	7.3	6.9	6.8		
15$	7.0	6.5	6.4		
16	7.1	6.5	6.4		

***=$P \leq 0.001$, ns = non significant

= topping carried out on both T2 and T4 treatments

$ = topping carried out on T2 treatment only

Table 5.2: Height (cm) of the infrequently grazed patches within C, T2 and T4 treatments during the experimental period.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	20.0	14.6	16.5	0.25	***
Week	Treatment x Week Interaction				
1#	24.1	13.8	13.9	1.0	***
2	22.9	17.7	17.7		
3$	20.0	13.1	16.9		
4	23.3	17.9	20.9		
5#	20.0	13.8	14.3		
6	20.0	15.8	16.6		
7$	23.2	13.1	21.9		
8	20.9	15.3	18.4		
9#	18.7	12.3	12.7		
10	19.0	15.3	15.2		
11$	16.8	12.8	15.7		
12	19.1	15.6	17.3		
13#	20.3	13.9	15.5		
14	18.2	15.8	15.6		
15$	16.4	13.3	13.6		
16	16.5	13.6	14.8		

***=$P \leq 0.001$

= topping carried out on both T2 and T4 treatments

$ = topping carried out on T2 treatment only

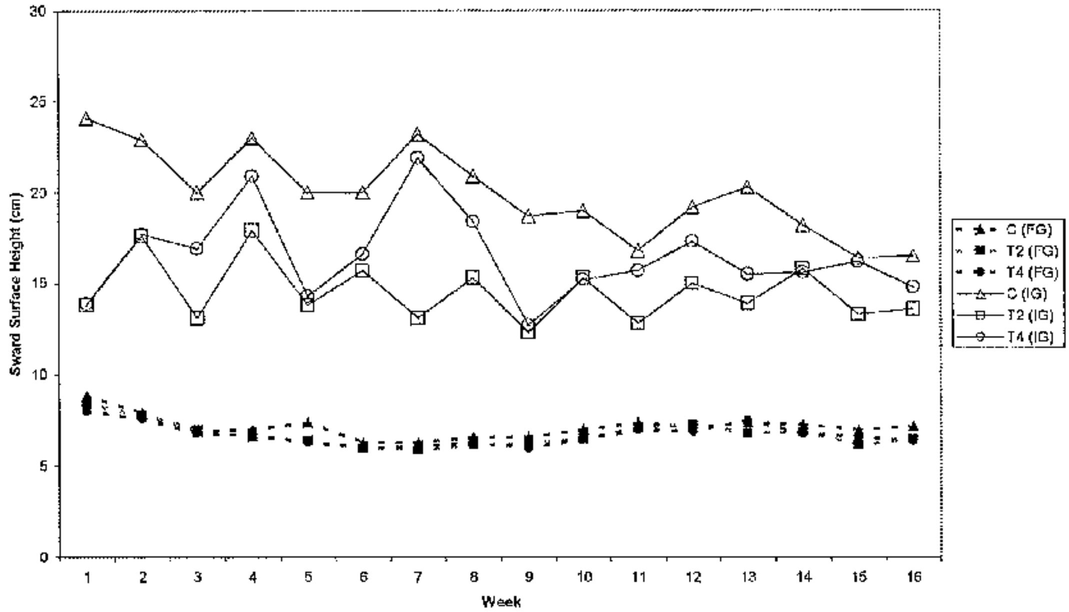


Figure 5.1: The effect of C (▲), T2 (■) and T4 (•) on the height (cm) of IG and FG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept)

The proportion of the IG patches for all treatments was 20% at the beginning of the experimental period. This remained around this level until mid June (week 4) when there was a sudden increase which gradually continued until reaching a peak of around 35%-38% by mid July (week 10) within all treatments (Table 5.3; Figure 5.2). Both Control and T4 remained around the 30%-35% range until the end of the experiment, however T2 treatment showed a steady decline to 23% by week 16. The proportion of IG patches was significantly lower for both T2 and T4 treatments when compared over all weeks ($P \leq 0.001$). Figure 5.2 shows a divergence of T2 from the other treatments at week 12 when there was a rapid decline in IG proportion of the sward compared to an increase up to week 15 followed by a decline at week 16 for both the C and T4 treatments. This resulted in a difference of 10% in the proportion of IG patches between T2 and the other two treatments at the end of the experiment.

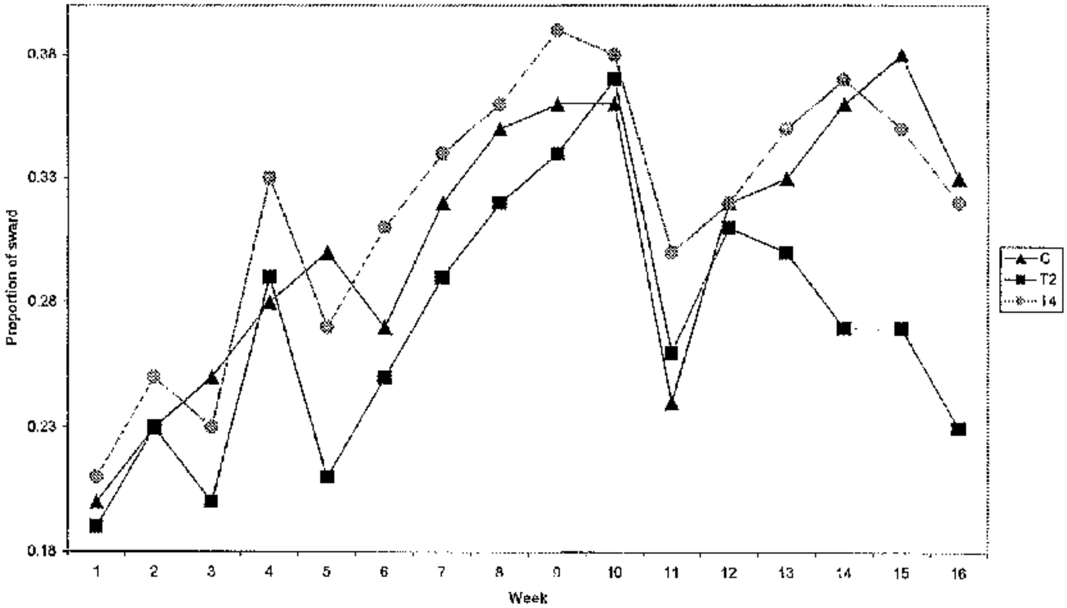


Figure 5.2: The effect of C (▲), T2 (■) and T4 (•) on the proportion of IG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept).

Table 5.3: Proportion of the infrequently grazed patches within C, T2 and T4 treatments during the experimental period.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	0.31	0.27	0.32	0.007	***
Week	Treatment x Week Interaction				
1#	0.20	0.19	0.20	0.03	***
2	0.23	0.23	0.25		
3$	0.25	0.21	0.23		
4	0.29	0.25	0.34		
5#	0.30	0.22	0.27		
6	0.27	0.25	0.31		
7$	0.33	0.30	0.34		
8	0.35	0.33	0.36		
9#	0.36	0.34	0.39		
10	0.36	0.37	0.37		
11$	0.24	0.36	0.29		
12	0.33	0.31	0.32		
13#	0.34	0.30	0.36		
14	0.37	0.27	0.37		
15$	0.38	0.27	0.35		
16	0.33	0.23	0.32		

***= $P \leq 0.001$

= topping carried out on both T2 and T4 treatments

$ = topping carried out on T2 treatment only

5.5.1.2 Herbage mass

The herbage mass within the FG patches of the sward was significantly lower under both topping treatments compared to the control over all weeks ($P \leq 0.05$) (Table 5.4). The differences would appear to be greatest at weeks 1 and 7 with more similar levels from weeks 9 to 15. (Figure 5.3).

The herbage mass of the IG area was significantly lower over all weeks under the topping treatments compared to control during June ($P \leq 0.001$) (weeks 3 and 5) and again in late July (week 11) (Table 5.5). Figure 33 shows a similar pattern in change of herbage mass within the IG patches up to week 7 for all treatments. Thereafter, the Control treatment remains at a constant higher herbage mass the T2 or T4, finishing at week 15 with approximately 1.0 t DM ha^{-1} greater than either topping treatment.

Table 5.4: Herbage mass (tDM/ha) of the frequently grazed patches within the sward of C, T2 and T4 treatments during the experimental period.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	0.95	0.84	0.80	0.05	*
Week	Treatment x Week Interaction				
1#	0.97	0.78	0.68	0.14	ns
3$	0.95	0.84	0.78		
5#	0.78	0.69	0.72		
7$	0.98	0.65	0.82		
9#	0.97	0.93	0.83		
11$	0.81	0.76	0.62		
13#	1.15	1.08	0.99		
15$	0.99	0.99	0.98		

*=$P \leq 0.05$, ns = non significant
\# = topping carried out on both T2 and T4 treatments
$ = topping carried out on T2 treatment only

Table 5.5: Herbage mass (tDM/ha) of the infrequently grazed patches within the sward of C, T2 and T4 treatments during the experimental period.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	3.0	2.2	2.2	0.12	***
Week	Treatment x Week Interaction				
1#	2.2	2.1	1.7	0.35	ns
3$	2.8	2.3	1.9		
5#	1.6	1.1	1.4		
7$	3.7	3.1	2.1		
9#	3.5	2.6	3.0		
11$	3.4	2.2	2.2		
13#	3.4	2.3	3.0		
15$	3.5	2.4	2.3		

***=$P \leq 0.001$, ns = non significant

= topping carried out on both T2 and T4 treatments

$ = topping carried out on T2 treatment only

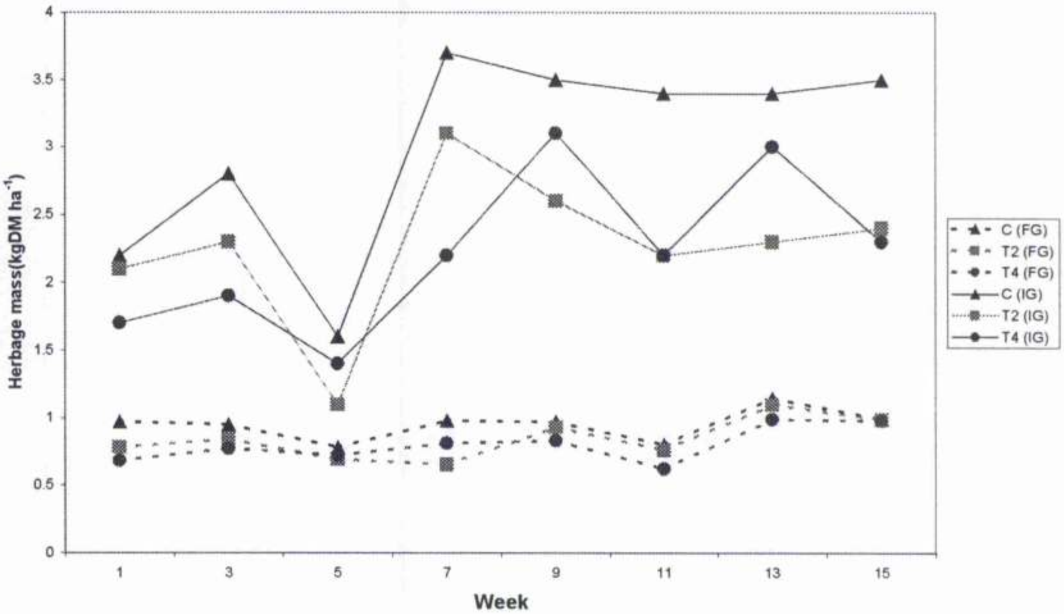


Figure 5.3: The effect of C (▲), T2 (■) and T4 (•) on the herbage mass (kg DM ha^{-1}) of IG and FG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept).

5.5.1.3 Tiller Density

The density of tillers within the FG patches varied over time, falling in week 3 then remaining fairly constant during July and increasing again in late August (Figure 5.4). There was no significant difference between treatments over all weeks (P >0.05). There was a significant interaction between treatments and weeks ($P \leq 0.05$) (Table 5.6). There was a significantly higher tiller density maintained at week 3 under the T2 treatment compared to the Control and T4 treatment. There was no significant difference at any other week (P >0.05).

The tiller density within the IG patches followed a similar trend to that within the FG patches with a drop at week 3 with T2 showing higher density than the T4 or Control at this time (Table 5.7). When compared over all weeks, the T2 treatment had a significantly greater tiller density than both T4 and Control ($P \leq 0.01$). There was a general trend for higher tiller density within the T2 treatment at most weeks, although this was only significant at week 13 (Figure 5.4).

The tiller density of the FG patches was much greater, generally by two fold, than the IG patches from June onwards (Figure 5.4).

Table 5.6: Tiller density (number/m^2) of frequently grazed patches during the experimental period within C, T2 and T4 treatments.

	Treatment				
	C	T2	T4	s.e.d.	*P*
		Mean over all weeks			
	8129	8353	8205	285	ns
Week		Treatment x Week Interaction			
1#	9024	9668	9369	807	*
3$	5470	8500	6783		
5#	7472	8081	8782		
7$	7838	7495	7746		
9#	7294	6909	7359		
11$	8006	8502	7746		
13#	10570	9232	10070		
15$	9353	8436	7788		

*=$P \leq 0.05$, ns = non significant, # = topping carried out on both T2 and T4, $ = topping carried out on T2 only

Table 5.7: Tiller density (number/m²) of infrequently grazed patches during the experimental period within C, T2 and T4 treatments.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	4761	5562	4984	242	**
Week	Treatment x Week Interaction				
1#	8070	8244	8734	686	***
3$	4992	6090	5037		
5#	4003	3703	4263		
7$	4349	5226	4619		
9#	2402	3582	2023		
11$	4391	5121	4608		
13#	5165	6994	5467		
15$	4714	5540	5121		

**=$P \leq 0.01$, ***=$P \leq 0.001$, ns = non significant,
= topping carried out on both T2 and T4, $ = topping carried out on T2 only

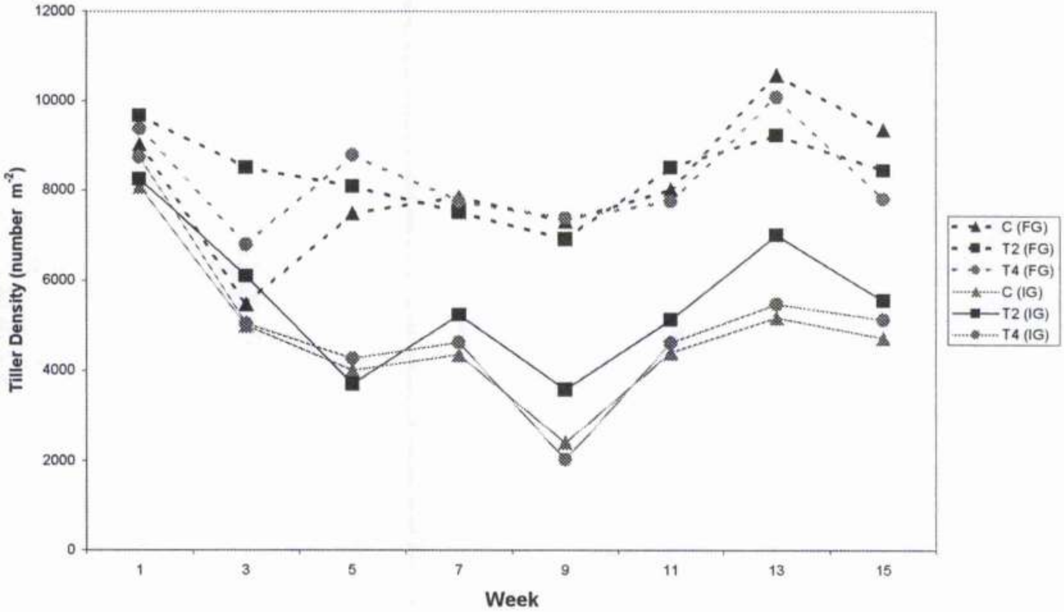


Figure 5.4: The effect of C (▲), T2 (■) and T4 (●)on the tiller density (number m^{-2}) of IG and FG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept).

5.5.1.4 Leaf : Stem ratio

The trend within the FG patches of all treatments was for a constant leaf:stem below 1.5 until mid July. Thereafter, there was a gradual increase up to a ratio of over 2:1 by the end of August (Figure 5.5).There was no significant difference between treatments when compared over all weeks($P \leq 0.05$) (Table 5.8).

There was a significant difference between treatments over all weeks within the IG patches when T2 and T4 had greater leaf content than the control ($P \leq 0.01$) (Table 5.9). The T2 and T4 treatments had higher leaf:stem ratios than the Control from week 11 to the end of the experiment (Figure 5.5).

The leaf:stem ratio of the IG patches within the T2 and T4 treatments was greater than that within the FG patches of these treatments in most weeks during August, unlike that of the Control.

Table 5.8: Leaf : Stem ratio of frequently grazed patches during the experimental period within C, T2 and T4 treatments.

	Treatment				
	C	T2	T4	s.e.d.	P
	Mean over all weeks				
	1.5	1.6	1.5	0.13	ns
Week	Treatment x Week Interaction				
1#	1.4	0.8	0.9	0.35	ns
3$	1.3	1.2	1.4		
5#	1.3	1.0	1.2		
7$	1.1	1.5	1.3		
9#	1.2	2.3	1.3		
11$	2.0	1.7	1.6		
13#	1.8	1.9	1.8		
15$	2.2	2.2	2.8		

ns = non significant,

= topping carried out on both T2 and T4, $ = topping carried out on T2 only

Table 5.9: Leaf : Stem ratio of infrequently grazed patches during the experimental period within C, T2 and T4 treatments.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	1.1	1.6	1.4	0.16	**
Week	Treatment x Week Interaction				
1#	1.6	1.4	1.1	0.45	ns
3$	1.1	1.1	1.2		
5#	1.1	0.9	0.8		
7$	0.7	1.4	1.1		
9#	0.8	1.2	1.0		
11$	0.7	2.2	2.0		
13#	1.0	2.5	2.2		
15$	1.6	2.4	2.0		

**=$P \leq 0.01$, ns = non significant,
= topping carried out on both T2 and T4, $ = topping carried out on T2 only

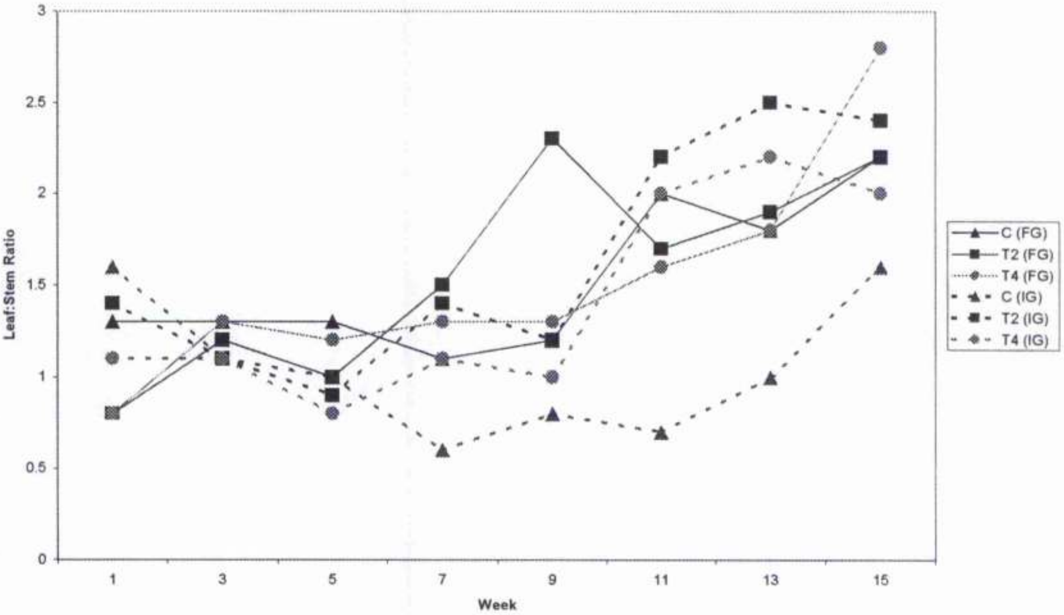


Figure 5.5: The effect of C (▲), T2 (■) and T4 (•) on the leaf:stem of IG and FG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept).

5.5.1.5 Live : Dead

There was no significant difference in the Live:Dead ratio within the FG or IG patches between the treatments over all weeks, although there was a large variation between treatments at weeks 3, 11, 13 and 15 ($P \leq 0.05$) (Table 5.10,5.11; Figure 5.6).

Table 5.10: Live:Dead ratio of frequently grazed patches during the experimental period within C, T2 and T4 treatments.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	9.7	6.9	11.2	2.8	ns
Week	Treatment x Week Interaction				
1#	2.1	2.2	2.3	7.9	ns
3$	14.3	7.8	10.3		
5#	5.8	6.5	6.8		
7S	8.2	5.6	5.6		
9#	8.3	11.7	7.3		
11$	8.8	7.7	21.4		
13#	8.9	9.1	22.7		
15$	20.9	4.9	12.9		

ns = non significant,
# = topping carried out on both T2 and T4, $ = topping carried out on T2 only

Table 5.11: Live:Dead ratio of infrequently grazed patches during the experimental period within C, T2 and T4 treatments.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	10.0	10.3	9.4	2.2	ns
Week	Treatment x Week Interaction				
1#	2.0	1.7	2.2	6.3	ns
3$	30.3	12.6	12.9		
5#	9.4	12.5	12.8		
7$	9.4	10.9	7.2		
9#	9.5	9.6	11.8		
11$	6.7	6.3	10.7		
13#	8.1	9.3	7.1		
15$	4.2	19.3	10.7		

ns = non significant,

= topping carried out on both T2 and T4, $ = topping carried out on T2 only

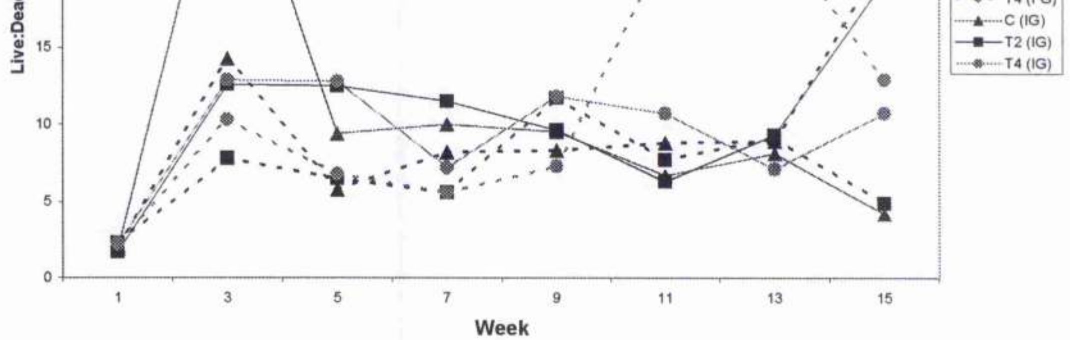


Figure 5.6: The effect of C (▲), T2 (■) and T4 (•)on the live:dead of IG and FG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept).

5.5.1.6 Leaf area index (LAI)

The trend for both FG and IG LAI was for an increase during May and early June declining gradually by early August (Figure 5.7). The difference between the FG patches was not significant when compared over all weeks ($P > 0.05$) (Table 5.12).

There was significant difference between treatment within the IG patches of the swards with the T2 treatment having significantly lower LAI than the C and T4 treatments ($P \leq 0.001$) (Table 5.13). There was also a significant interaction between treatments and weeks with C and T4 showing lower LAI than T2 at week 1 but significantly greater LAI at week 4, 8 and 12 ($P \leq 0.001$).

Table 5.12: Leaf area index (area of leaf per unit area of ground) of the frequently grazed patches during the experimental period within C, T2 and T4 treatments.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	5.4	5.6	5.3	0.34	ns
Week	Treatment x Week Interaction				
1#	3.9	5.2	3.8	0.68	ns
3$	7.2	7.6	7.1		
5#	6.0	5.2	5.3		
7$	4.7	4.4	4.7		

ns = non significant,
# = topping carried out on both T2 and T4, $ = topping carried out on T2 only

Table 5.13: Leaf area index (area of leaf per unit area of ground) of the infrequently grazed patches during the experimental period within C, T2 and T4 treatments.

	Treatment				
	C	T2	T4	s.e.d.	*P*
	Mean over all weeks				
	10.5	9.0	10.3	0.34	***
Week	Treatment x Week Interaction				
1#	5.9	7.3	5.9	0.67	***
3$	13.8	11.5	14.1		
5#	11.6	8.9	11.0		
7$	10.6	8.3	10.2		

***=$P \leq 0.001$

= topping carried out on both T2 and T4, $ = topping carried out on T2 only

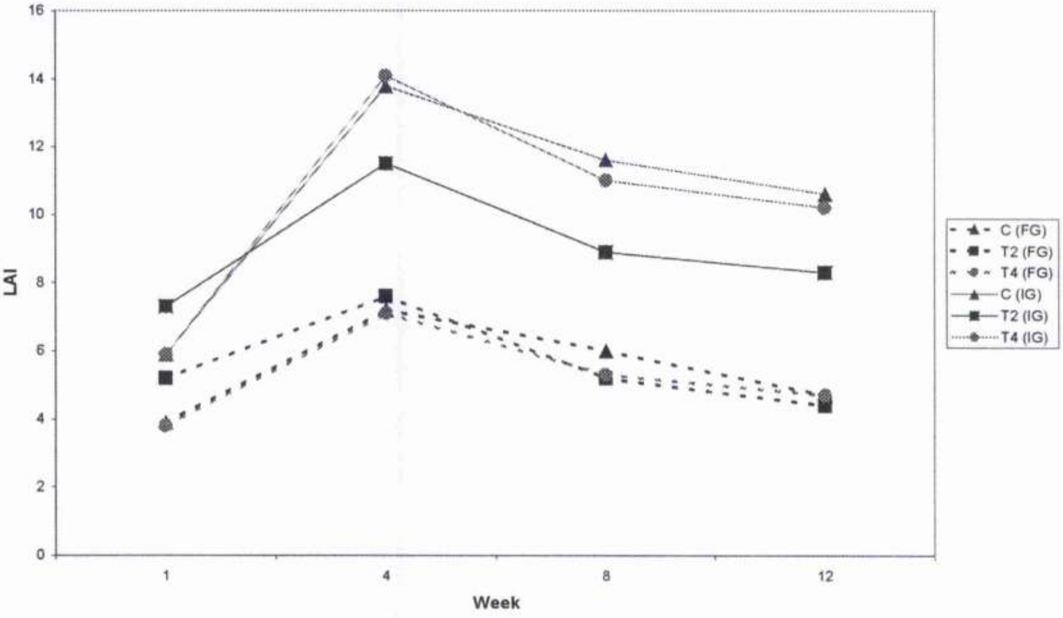


Figure 5.7: The effect of C (▲), T2 (■) and T4 (•) on the Leaf Area Index (LAI) of IG and FG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept).

5.5.1.7 Herbage quality

The chemical analysis for the FG patches showed no significant differences between treatments for any of the qualities measured when considered over all the weeks ($P > 0.05$) (Table 5.14).

There was no significant difference in ME, D-value and NDF between treatments within the IG patches over all weeks ($P > 0.05$) (Table 5.15). The IG patches within all treatments in general were higher in ME than the FG patch at equivalent weeks over the experimental period. The general trend in each treatment was for a rise in NDF content at the end of August (Figure 5.9). Crude protein was significantly higher and WSC significantly lower within T2 and T4 over all weeks compared to the C treatment ($P \leq 0.001$) (Table 5.16, Figure 5.10;5.11).

Table 5.14: Chemical analysis (by Near Infra-Red Spectroscopy) of frequently grazed patches within C, T2 and T4 treatments during the experimental period

	Week	Treatment				
		C	T2	T4	s.e.d	*P*
ME ($MJ\ kgDM^{-1}$)	5	9.4	10.1	9.9	0.48	ns
	9	9.4	9.7	9.2		
	13	9.6	9.1	9.0		
	Mean over all weeks	9.5	9.6	9.4	0.28	ns
D-Value (%)	5	62.3	67.3	66.3	3.09	ns
	9	62.3	64.3	61.0		
	13	63.7	61.0	60.0		
	Mean over all weeks	62.8	64.2	62.4	1.78	ns
NDF ($g\ kgDM^{-1}$)	5	595	611	602	22.7	ns
	9	590	591	606		
	13	639	604	610		
	Mean over all weeks	608	602	606	13.1	ns
Crude Protein ($g\ kgDM^{-1}$)	5	184	193	203	28.8	ns
	9	178	190	190		
	13	234	180	188		
	Mean over all weeks	199	188	194	16.6	ns
WSC ($g\ kgDM^{-1}$)	5	22.3	25.0	$\leq$20	3.0	ns
	9	$\leq$20	22.7	$\leq$20		
	13	$\leq$20.0	$\leq$20	$\leq$20		
	Mean over all weeks	20.8	22.6	$\leq$20	1.7	ns

ns = non significant

Table 5.15: Chemical analysis (by Near Infra-Red Spectroscopy) of ME, D-Value and NDF of infrequently grazed patches within C, T2 and T4 treatments during the experimental period

	Week	Treatment				
		C	T2	T4	s.e.d	*P*
ME ($MJ\ kgDM^{-1}$)	5	10.2	10.2	10.3	0.19	ns
	7	10.1	10.2	10.2		
	9	9.9	9.9	10.0		
	11	10.5	10.5	10.5		
	13	10.0	10.0	9.7		
	15	9.9	9.7	9.9		
	Mean over all weeks	10.1	10.1	10.1	0.08	ns
D-Value (%)	5	68	67.7	68.7	1.3	ns
	7	67.7	68.0	68.0		
	9	66.3	66.3	66.7		
	11	70.3	70.0	69.7		
	13	66.3	66.7	64.3		
	15	65.7	65.0	65.7		
	Mean over all weeks	67.4	67.3	67.2	0.54	ns
NDF ($g\ kgDM^{-1}$)	5	607	597	590	14.5	ns
	7	588	571	582		
	9	611	608	595		
	11	572	577	588		ns
	13	621	633	632		
	15	640	630	626		
	Mean over all weeks	607	603	602	6.0	ns

ns = non significant

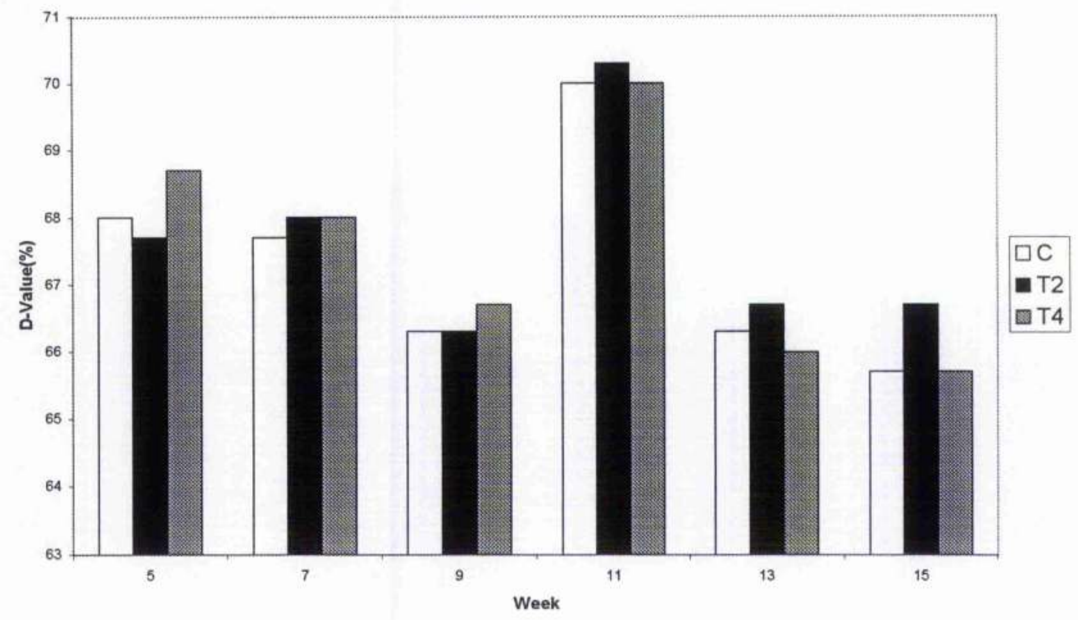


Figure 5.8: The effect of C, T2 and T4 on the D-value (%) of IG and FG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept).

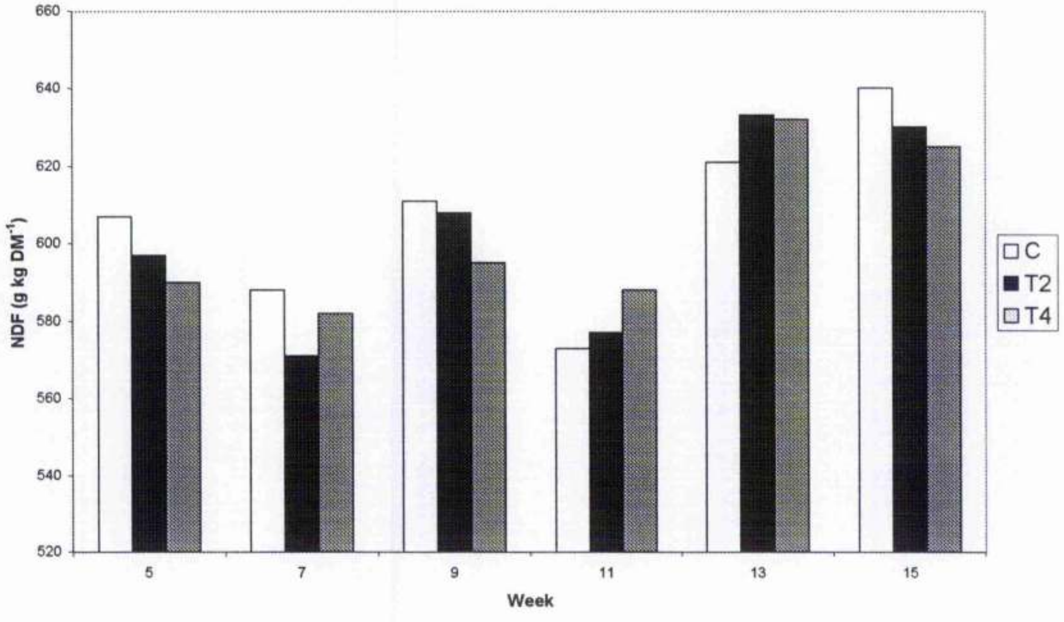


Figure 5.9: The effect of C, T2 and T4 on the NDF (g kg dm^{-1}) of IG and FG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept).

Table 5.16: Chemical analysis (by Near Infra-Red Spectroscopy) of Crude Protein and WSC of infrequently grazed patches within C, T2 and T4 treatments during the experimental period

	Week	Treatment				
		C	T2	T4	s.e.d	*P*
Crude Protein g $kgDM^{-1}$	5	172	197	200	14.4	ns
	7	159	180	188		
	9	163	202	199		
	11	143	187	159		
	13	164	198	185		
	15	176	190	194		
	Mean over all weeks	163	192	187	6.0	***
WSC g $kgDM^{-1}$	5	46	27	27	8.4	ns
	7	48	41	27		
	9	33	≤20	≤20		
	11	100	66	77		
	13	32	≤20	≤20		
	15	24	33	≤20		
	Mean over all weeks	47	35	32	3.0	***

***=$P \leq 0.001$, ns = non significant

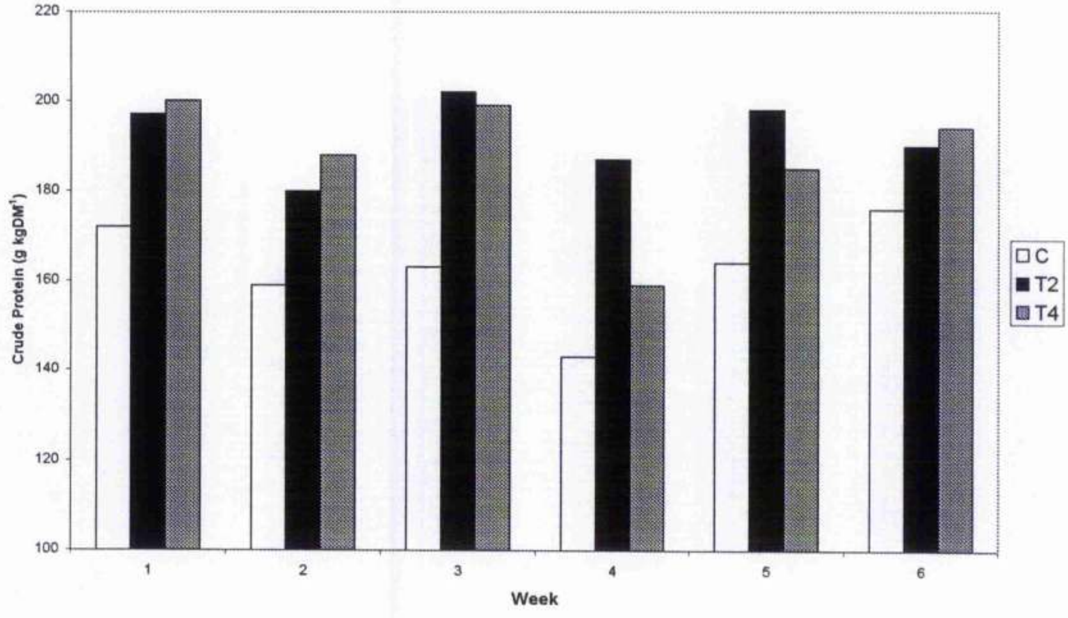


Figure 5.10: The effect of C, T2 and T4 on the Crude Protein (g kg dm^{-1}) of IG and FG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept).

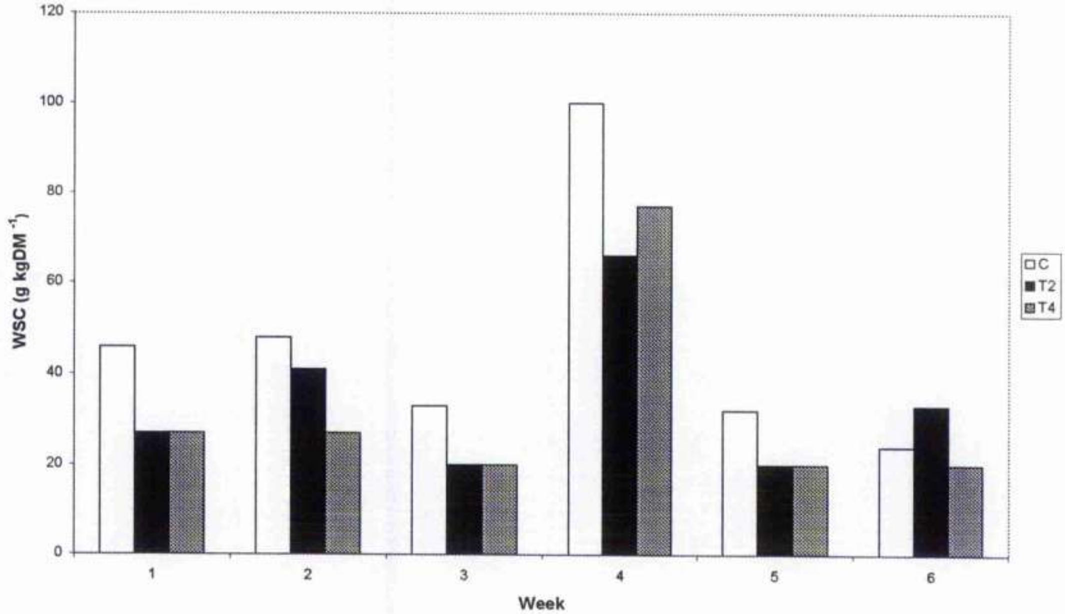


Figure 5.11: The effect of C, T2 and T4 on the WSC (g kg dm^{-1}) of IG and FG patches within the sward during the experimental period (week 1= 18th May- week 16 =1st Sept).

5.5.2 ANIMAL

5.5.2.1 Herbage Intake

The total dry matter intake was significantly different between the treatments when compared over all weeks ($P \leq 0.001$) (Table 5.17), with the control treatment showing significantly greater intake than T2 and T4 treatment. There was also a significant treatment and week interaction with significantly greater intake within the C treatment than the topping treatments at week 10 and 14 ($P \leq 0.001$). The intake under T4 treatment was significantly greater than T2 at week 10 but significantly less at week 14. The difference in total daily DM intake was in the magnitude of 6 kg greater for the C treatment at week 14.

The intake from the IG patches was significantly higher under both T2 and T4 treatments compared to the C ($P \leq 0.001$). Intakes for T2 were significantly greater than T4 when compared over all weeks (Table 5.18). Cows within the C treatment were estimated to have minimal intake from the IG patches while that for the T2 treatment was 50% of total intake. The interaction of treatment and week shows T2 treatment to have a significantly greater intake from IG patches at week 10 than C and T4 treatment ($P \leq 0.001$), however by week 14 both T2 and T4 showed significantly greater intake than the C treatment (Table 5.18)

Table 5.17: Estimated total daily herbage dry matter intake (kg dm day^{-1}) for cows within C, T2 and T4 treatments during the experimental period using the n-alkane technique.

	Treatment				
	C	T2	T4	s.e.d.	*P*
Mean over all weeks	19.2	14.0	15.6	0.62	***
Week	Treatment x Week Interaction				
6	17.3	15.9	17.1	1.07	***
10	19.1	13.7	17.3		
14	21.1	12.4	12.3		

***=$P \leq 0.001$

Table 5.18: Estimated daily herbage dry matter intake (kg dm day^{-1}) from the infrequently grazed patches for cows within C, T2 and T4 treatments during the experimental period using the n-alkane technique.

	Treatment				
	C	T2	T4	s.e.d.	*P*
Mean over all weeks	0.5	7.5	4.6	0.6	***
Week	Treatment x Week Interaction				
6	0.2	2.4	2.3	1.05	***
10	1.0	9.7	1.8		
14	0.2	10.5	9.9		

***=$P \leq 0.001$

5.5.2.2 Milk yield and composition

There was no significant difference in milk yield between any of the treatments at any week or accumulated over the weeks during the experimental period (P >0.05) (Table 5.19). All treatments showed a gradual decline form 29kg cow^{-1}day^{-1} at the beginning of June to 17.5kg cow^{-1}day^{-1} in early September. The change of milk yield over time for the treatments, as analysed by linear regression (Table 5.20) showed no significant difference (P >0.05).

When the milk yield was corrected to standard fat and protein, FPCM there was no significant difference between treatments over the experimental period (Table 5.19) or as change of FPCM over time when analysed by linear regression (P >0.05) (Table 5.20, Figure 5.12).

The composition of the milk showed no significant difference for fat or protein or Lactose over time (P >0.05) (Table 5.21, 5.22 and 5.23).

The yield of fat was only significantly different between treatments at week 14 and there was no accumulation effect of time during the experimental period ($P \leq 0.05$) (Table 5.24). Protein yield was significantly different at week 10 and 16 with the Control and T2 showing higher yield than T4 at week 10 and lower yield than T4 at week 16 ($P \leq$ 0.05), however this was not significant when analysed over all weeks. The trend was for a steady decline of yield components with time (Figure 5.13). The change in fat and protein yield of milk derived from linear regression over weeks was not significantly different between treatments (P >0.05) (Table 5.25).

Table 5.19: Milk Yield (kg cow^{-1} day^{-1}) and Fat and Protein corrected milk yield, FPCM (kg cow^{-1} day^{-1} corrected to fat and protein content of 40g kg^{-1} and 30 g kg^{-1} respectively) for cows on treatment C,T2 and T4 during the experimental period.

	MILK YIELD					FPCM				
	Treatment					Treatment				
Week	C	T2	T4	*P* at week	*P* accumulated up to week	C	T2	T4	*P* at week	*P* accumulated up to week
3 1st June	29.1	29.7	29.2			27.9	28.0	28.3		
4	30.2	30.1	29.5	ns	ns	28.5	28.8	27.9	ns	ns
5	29.2	29.6	28.7	ns	ns	27.5	28.1	26.2	ns	ns
6	28.9	29.1	28.1	ns	ns	26.0	25.3	24.5	ns	ns
7	27.8	28.3	27.1	ns	ns	25.7	25.4	24.9	ns	ns
8	26.5	27.3	26.4	ns	ns	24.9	25.9	24.6	ns	ns
9	26.4	26.9	25.5	ns	ns	24.8	25.2	24.0	ns	ns
10	25.7	26.1	24.4	ns	ns	24.6	24.0	22.3	*	ns
11	24.8	25.5	24.1	ns	ns	23.1	23.0	22.4	ns	ns
12	23.2	24.0	23.1	ns	ns	22.2	21.6	21.4	ns	ns
13	21.9	21.9	21.3	ns	ns	21.0	20.1	20.0	ns	ns
14	20.2	19.7	19.5	ns	ns	19.8	18.6	18.7	ns	ns
15	18.9	18.5	18.4	ns	ns	18.0	16.4	17.0	ns	ns
16	17.1	17.5	18.4	ns	ns	16.5	16.4	17.1	ns	ns

*=$P \leq 0.05$, ns = non significant

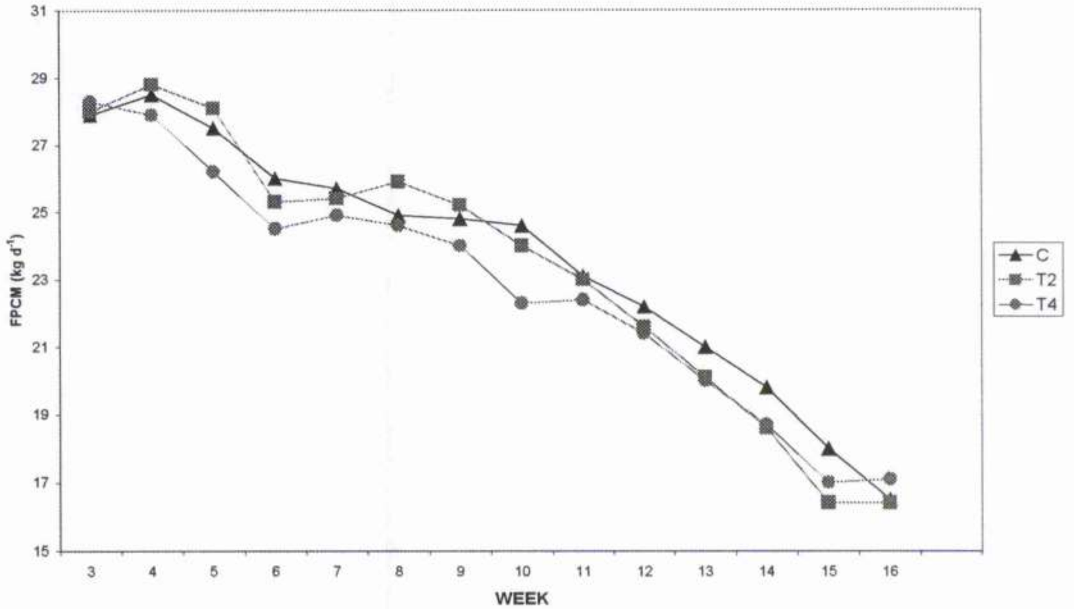


Figure 5.12 : The effect of C (▲), T2 (■) and T4 (•) on the FPCM (kg d^{-1}) of dairy cows during the experimental period (week 1= 18th May- week 16 =1st Sept).

Table 5.20: Linear regression (slopes) of milk yield (kg cow^{-1} $week^{-1}$) and FPCM (kg cow^{-1} $week^{-1}$) (corrected to fat and protein content of 40g kg^{-1} and 30 g kg^{-1} respectively) for cows on treatments C, T2 and T4 over the four week experimental period.

	Treatment				
Linear regression	C	T2	T4	s.e.d	*P*
Milk Yield (kg cow^{-1} $week^{-1}$)	-0.95	-0.99	-0.93	0.11	ns
FPCM (kg cow^{-1} $week^{-1}$)	-0.86	-0.96	-0.86	0.14	ns

ns = non significant

Table 5.21: Fat concentration of milk (g kg^{-1}) for cows on C, T2 and T4 treatments during the experimental period.

Week	Treatment C	Treatment T2	Treatment T4	*P* at week	*P* accumulated up to week
3 (1st June)	40.4	40.2	42.3	ns	ns
4	38.0	38.8	37.5	ns	ns
5	37.4	38.4	36.9	ns	ns
6	35.0	33.8	34.9	ns	ns
7	37.1	35.6	38.0	ns	ns
8	37.3	37.5	36.8	ns	ns
9	36.9	38.0	37.6	ns	ns
10	36.8	34.9	34.5	ns	ns
11	35.9	35.1	36.9	ns	ns
12	37.2	34.8	36.8	ns	ns
13	38.1	34.8	37.0	ns	ns
14	38.7	35.0	36.5	ns	ns
15	40.6	38.2	38.9	ns	ns
16	41.5	38.7	38.9	ns	ns

ns = non significant

Table 5.22: Protein concentration of milk (g kg^{-1}) for cows on C, T2 and T4 treatments during the experimental period.

Week	Treatment C	Treatment T2	Treatment T4	*P* at week	*P* accumulated up to week
3 (1st June)	31.6	30.6	31.1	ns	ns
4	32.1	31.0	31.4	ns	ns
5	32.0	30.9	31.2	ns	ns
6	31.8	31.1	31.3	ns	ns
7	31.5	30.7	31.0	ns	ns
8	31.6	31.0	31.6	ns	ns
9	31.4	30.7	31.2	ns	ns
10	32.0	31.2	31.4	ns	ns
11	32.5	31.6	32.0	ns	ns
12	32.8	31.9	32.2	ns	ns
13	32.9	31.9	31.9	ns	ns
14	33.0	32.0	31.9	ns	ns
15	33.8	32.3	32.4	ns	ns
16	33.8	32.6	32.9	ns	ns

ns = non significant

Table 5.23: Lactose concentration of milk (g kg^{-1}) for cows on C, T2 and T4 treatments during the experimental period.

	Treatment			P at week	P accumulated up to week
Week	C	T2	T4		
3 (1st June)	46.3	46.0	46.2	ns	ns
4	46.2	46.1	46.5	ns	ns
5	45.4	45.2	45.5	ns	ns
6	45.8	45.7	45.7	ns	ns
7	45.5	45.0	45.0	ns	ns
8	45.4	45.2	45.3	ns	ns
9	45.0	44.8	45.0	ns	ns
10	45.2	45.1	45.0	ns	ns
11	45.9	45.5	45.7	ns	ns
12	45.2	45.6	45.6	*	ns
13	45.0	45.3	44.9	ns	ns
14	44.7	44.6	44.6	ns	ns
15	44.0	44.2	43.9	ns	ns
16	43.8	44.2	43.6	ns	ns

*=$P \leq 0.05$, ns = non significant

Table 5.24: Fat and Protein yield (g cow^{-1} day^{-1}) for cows on treatments C, T2 and T4 during the experimental period.

	FAT YIELD (g cow^{-1} day^{-1})					PROTEIN YIELD (g cow^{-1} day^{-1})				
	Treatment					Treatment				
Week	C	T2	T4	*P* at week	*P* accumulated up to week	C	T2	T4	*P* at week	*P* accumulated up to week
3 1stJune	1177	1171	1208	ns	ns	902	890	898	ns	ns
4	1149	1182	1116	ns	ns	960	939	930	ns	ns
5	1102	1144	1041	ns	ns	926	913	877	ns	ns
6	998	959	937	ns	ns	901	877	842	ns	ns
7	1021	990	998	ns	ns	864	850	823	ns	ns
8	998	1041	968	ns	ns	832	851	830	ns	ns
9	992	1026	960	ns	ns	815	817	792	ns	ns
10	971	924	847	ns	ns	835	819	775	*	ns
11	895	882	882	ns	ns	808	789	765	ns	ns
12	875	822	839	ns	ns	765	752	735	ns	ns
13	840	768	791	ns	ns	715	699	676	ns	ns
14	798	712	728	*	ns	676	649	639	ns	ns
15	742	655	660	ns	ns	611	557	571	ns	ns
16	668	644	642	ns	ns	537	544	559	*	ns

*=$P \leq 0.05$, ns = non significant

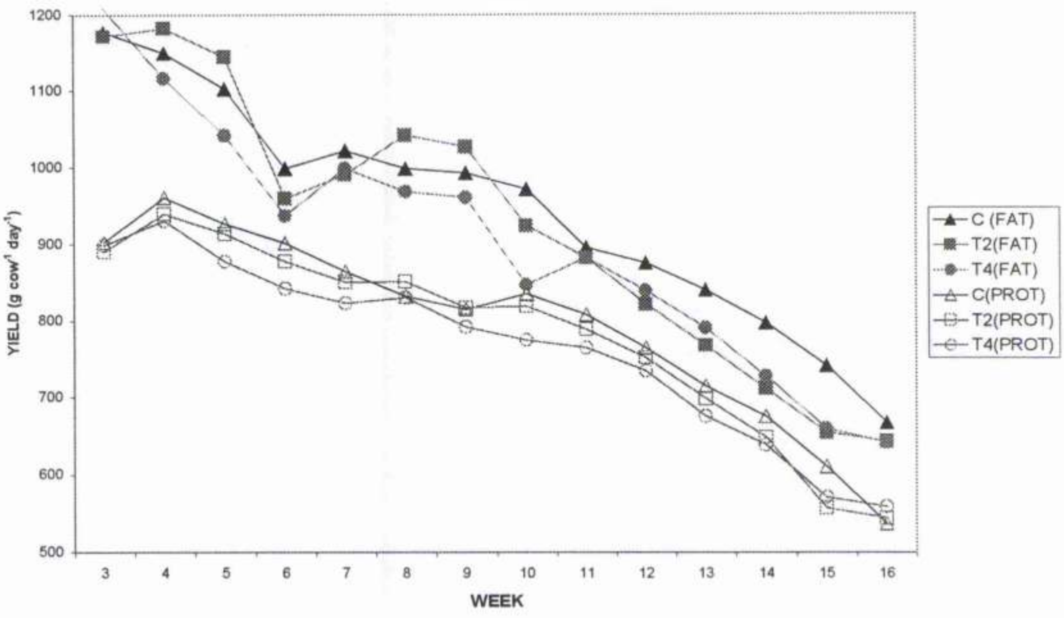


Figure 5.13: The effect of C (▲), T2 (■) and T4 (•) on the Fat and Protein yield of milk (g cow^{-1} day^{-1}) of dairy cows during the experimental period (week 1= 18th May- week 16 =1st Sept).

Table 5.25: Linear regression (slopes) of Fat and protein yield (kg cow^{-1} day^{-1}) for cows on treatments C, T2 and T4 over the experimental period.

	Treatment				
Linear regression	C	T2	T4	s.e.d	*P*
Fat Yield (kg cow^{-1} week^{-1})	-35.1	-42.4	-38.2	7.5	ns
Protein Yield (kg cow^{-1} week^{-1})	-27.9	-28.5	-27.1	4.5	ns

ns = non significant

5.5.2.3 Grazing Behaviour

There was no significant difference between treatments with time spent grazing or ruminating when compared over weeks (P >0.05) (Table 5.26). There was evidence for longer grazing for the T2 and T4 treatments during week 6, with on average one hour greater grazing than the control. There was also evidence of greater ruminating time for the Control at week 14, by approximately 40 minutes, while the grazing time was similar for all treatments at this week (Table 5.27).

Natural biting rate showed no significant difference between treatments over all weeks, however there was a trend for slightly greater biting rate for the T2 and T4 treatments than the control at each of the three observation weeks ($P > 0.05$) (Table 5.28).

The proportion of time spent grazing within the IG areas varied between 30% and 40% of the period observed. Highest values were recorded at week 14. There was no significant difference between treatments (P >0.05) (Table 5.29).

The selection ratio, which depends on both the area of the IG patches within the sward and the time spent grazing these patches, was significantly higher for T2 when compared over all weeks ($P \leq 0.05$) (Table 5.30). It would appear that cows within the T2 treatment at the end of July and August were actively selecting the IG patches, while those in the other treatments were grazing at a level related to the proportion within the sward, neither actively avoiding or selecting.

Table 5.26: Time spent grazing (minutes) during a 24 hour observation period by cows within C, T2 and T4 treatments at weeks 6, 10 and 14 of the experiment.

	Treatment				
	C	T2	T4	s.e.d.	*P*
Mean over all weeks	569	587	612	16.9	ns
Week	Treatment x Week Interaction				
6	552	598	616	29.2	ns
10	622	628	536		
14	534	536	562		

ns = non significant

Table 5.27 : Time spent ruminating (minutes) during a 24 hour observation period by cows within C, T2 and T4 treatments at weeks 6, 10 and 14 of the experiment.

	Treatment				
	C	T2	T4	s.e.d.	*P*
Mean over all weeks	426	396	395	19.0	ns
Week	Treatment x Week Interaction				
6	356	322	332	33.0	ns
10	366	356	344		
14	558	512	520		

ns = non significant

Table 5.28: Natural biting rate (bites min^{-1}) by cows within C, T2 and T4 treatments at weeks 6, 10 and 14 of the experiment.

	Treatment				
	C	T2	T4	s.e.d.	*P*
Mean over all weeks	64.8	69.0	68.5	2.3	ns
Week	Treatment x Week Interaction				
6	68.4	70.0	67.1	3.9	ns
10	61.9	69.1	70.0		
14	64.0	68.0	68.0		

ns = non significant

Table 5.29: The effect of treatment on the proportion of total grazing time spent grazing infrequently grazed patches by cows within C, T2 and T4 treatments at weeks 6, 10 and 14 of the experiment.

	Treatment				
	C	T2	T4	s.e.d.	*P*
Mean over all weeks	0.32	0.35	0.30	0.04	ns
Week	Treatment x Week Interaction				
6	0.27	0.27	0.41	0.07	ns
10	0.30	0.34	0.42		
14	0.22	0.34	0.35		

ns = non significant

Table 5.30: The effect of treatment on the selection ratio (1= neutral, >1= positive selection, <1= negative selection) of infrequently grazed patches by cows within C, T2 and T4 treatments at week 6, 10 and 14 of the experiment.

	Treatment				
	C	T2	T4	s.e.d.	*P*
Mean over all weeks	1.0	1.3	0.9	0.14	*
Week	Treatment x Week Interaction				
6	1.0	1.2	0.7	0.24	ns
10	0.8	0.9	0.9		
14	1.1	1.6	1.0		

*= $P \leq 0.05$, ns = non significant

5.5.2.4 Live weight and Condition score

Live weight of cows on the T2 and T4 treatment was lower than the Control at all weeks which was significant by the end of the experiment ($P \leq 0.05$) (Figure 5.14; Table 5.31). T2 and T4 showed a decline in weight over the 16 week experimental period while the Control showed no overall change, although the difference between treatments was not significant ($P > 0.05$) (Table 5.32; Figure 5.14).

Condition score started and remained similar for each treatment (Table 5.31). The trend over time was similar for all treatments, with a gradual decline over the experimental period (Table 5.32; Figure 5.14). There was no significant difference at any week or over all weeks ($P > 0.05$).

Table 5.31: Live weight (kg) and Condition score (0-5 scale, 0= poorest) for cows within C, T2 and T4 treatment during the experimental period.

	Liveweight (kg)					Condition Score(1-5 scale)				
	Treatment					Treatment				
Week	C	T2	T4	*P* at week	*P* accumulated up to week	C	T2	T4	*P* at week	*P* accumulated up to week
3 1st June	595	572	578			2.3	2.2	2.3	ns	ns
4	590	559	562	ns	ns	2.3	2.1	2.1	ns	ns
5	587	564	569	ns	ns	1.9	1.8	1.9	ns	ns
6	586	561	565	ns	ns	1.8	1.8	1.8	ns	ns
7	594	559	570	ns	ns	-	-	-		
8	601	573	575	ns	ns	1.8	1.8	1.8	ns	ns
9	583	557	561	ns	ns	1.5	1.4	1.6	ns	ns
10	584	547	549	*	ns	-	-	-		
11	895	882	882	ns	ns	808	789	765	ns	ns
12	875	822	839	ns	ns	765	752	735	ns	ns
13	840	768	791	ns	ns	715	699	676	ns	ns
14	798	712	728	*	ns	676	649	639	ns	ns
15	742	655	660	ns	ns	611	557	571	ns	ns
16	668	644	642	ns	ns	537	544	559	*	ns

*=$P \leq 0.05$, ns = non significant

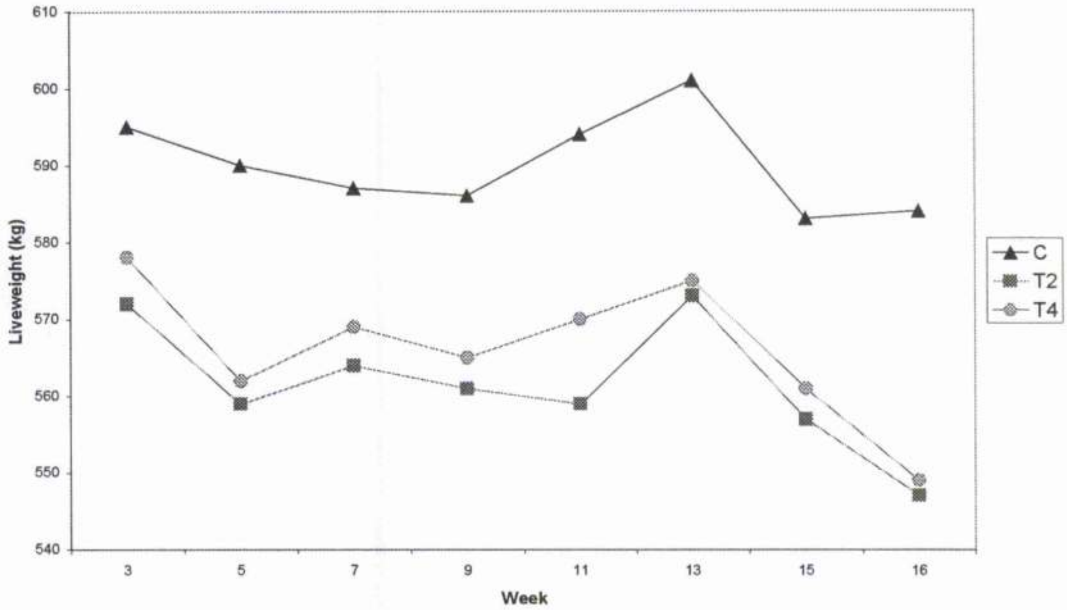


Figure 5.14: The effect of C (▲), T2 (■) and T4 (•) on the Liveweight (kg) of dairy cows during the experimental period (week 1= 18th May- week 16 =1st Sept).

Table 5.32: Linear regression (slopes) of Liveweight (kg) and Condition Score (1-5 scale) for cows on treatments C, T2 and T4 over the experimental period.

	Treatment				
Linear regression	C	T2	T4	s.e.d	*P*
Fat Yield (kg cow^{-1} week^{-1})	0.0	-1.6	-2.6	1.8	ns
Protein Yield (kg cow^{-1} week^{-1})	-0.16	-0.14	-0.12	0.04	ns

ns = non significant

5.6 DISCUSSION

Achieving an average height of 7cm within the FG patches proved difficult within the confined plot area, while maintaining minimal cow numbers for reliable intake measurement during the experiment. As a result, on a number of occasions, the average height fell to below 7cm. This applied to all plots, and only on one occasion was the heights of the FG patches significantly different between treatments. However, it became evident that the height and herbage mass within the topped treatments was significantly lower ($P \leq 0.001$) for both the FG and IG patches over the experimental period, while stocking rate was the same for all treatments. This would imply that the topping, even though it was set at 8 cm, was reducing the production throughout the sward and not only the tall IG patches. McDonald (1986) recorded a temporary reduction of herbage accumulation during the summer after mechanical topping. Holmes and Hoogendorn (1983) also reported an immediate decrease in pasture production caused by topping. They showed a reduction of around 200kgDM/ha up to 3 weeks after topping compared to non-topped pastures. If topping was frequent, you would expect a persistent reduction in growth compared to a non-topped treatment, which would agree with the general trend in both height and herbage mass found in the current experiment. Within the T4 treatment, regrowth of the infrequently grazed patches after topping was generally sufficient by the second week so that the height was similar to that of the control. The herbage mass of these patches took four weeks before being similar to the control. Therefore removing material stimulated growth, and together with the high concentration of plant nutrients provided by the dung pat associated with these patches, allowed for high growth rates, which achieved ceiling yield again within the four weeks.

Leaf area index (LAI) of the frequently grazed patches was similar for all treatments during June, July and August. The IG patches within the T2 treatment started with a significantly higher LAI in May, however thereafter it was significantly lower than both the T4 and Control in June, July and August ($P \leq 0.001$). This would also suggest that topping at 4 weekly intervals allowed for regrowth to a similar state as in the non topped treatment by the fourth week. The topping interval of 2 weeks was detrimental as it reduced total dry matter production. Alternatively, a higher utilisation of these IG patches by the dairy cow could be responsible for the significantly lower height and herbage mass for T2 compared to the T4 and Control treatments ($P \leq 0.001$). The balance between effects on production and utilisation is uncertain without the use of exclusion cages, however, grazing behaviour observations indicate increased selection of IG patches within the T2 treatment during June and August period.

Bao *et al.* (1998) found that dairy cows initially selected short grass areas when entering a paddock within rotational grazing, and then selected the tall grass as the sward was grazed down. The switch to tall grass happened earlier within topped swards, which resulted in greater utilisation of these areas and reduced the area by 4% from the start of the grazing period.

The proportion of IG within the current experiment showed a similar pattern within each treatment over the first 12 weeks of the experiment. Starting in June at around 20%, this increased to a peak by the end of July at around 37%. The temporary and sudden decline within each treatment in early July was probably due to a change in recorder and where subjective determination of IG patches may have been different to the recorder who had carried out all the other weekly measurements (Figure5.2). It was not until August that the differences between treatments became apparent. Both T4 and Control maintained the area of the IG patches at approximately 35% whereas the area declined to 23% within the T2 treatment, being significantly less than the other treatments ($P \leq 0.001$). There was on average a reduction of 10% in the area of the IG patches within the T2 sward from mid August to early Sept when the experiment ended. Work by Stakelum and Dillon (1990) showed that swards topped after rotational grazing between April and June had on average 5% and 13% less tall grass areas during July to September than those either tightly (6cm residual sward height) or leniently (8 cm residual sward height) grazed without topping respectively. However, Zom *et al.* (2001), in preliminary results comparing rotational grazing with and without topping after each grazing cycle, reported no difference in size and number of rejected areas within the swards.

Fisher and Roberts (1995) found tiller density to drop in mid summer for a sward leniently grazed and topped once in June. McDonald (1986) found little difference in ryegrass vegetative tillers when swards were topped once in either early, mid or late season. Their work showed a trend for higher tiller density within swards topped 3 times over the season, once during early, mid and late season. Our current work has shown no significant difference between treatments in the tiller density within the FG patches over the experimental period ($P > 0.05$). Frequent topping did prevent the natural decline of tiller density in these patches during early June, however thereafter all treatments maintained a similar trend of tiller density within the FG patches. The IG patches also showed a decline in tiller density from May through to July, which was much more dramatic than within the FG patches. All treatments increased tiller density again through August with T2 showing a trend for higher tiller density than either T4 or Control. The T2 treatment showed significantly greater tiller density than both T4 and the Control treatments over the whole experiment ($P \leq 0.01$). Therefore it would appear from these results that frequent defoliation of at least once every two weeks from the early season could maintain a higher tiller density within the IG patches. This supports the theory of Langer (1977) who suggested that if the apices are removed early enough, renewed vegetative tillers may occur. Less frequent defoliation does not have the same effect which agrees with the conclusions of McDonald (1986).

The composition of the FG patches in relation to leaf and stem did not differ significantly over the whole experimental period ($P > 0.05$), however, during July there was a trend for higher leaf content than the Control within the FG patches of the topped swards, although this was not significant ($P > 0.05$).

The leaf content of the IG patches was significantly greater under topping treatments than the non-topped sward when compared over the whole experiment ($P \leq 0.01$). The IG patches within all treatments had similar leaf content until the end of June. The trend thereafter was for greater leaf content within T2 with T4 than the Control, although this was not significant until August. Stakelum and Dillon (1990) observed that topping from early season significantly increased the proportion of leaf up to mid June within both FG short patches and IG tall patches. The greatest difference was within the IG patches with a three-fold difference between topped and non-topped treatments. This agrees with the current experiment with the leafier IG patches being present in July and August, with up to two and a half fold increase in leaf over the non-topped patches. The FG patches also

benefited in mid season through a constant 14 day defoliation coupled with lower SSH in June which suppressed stem elongation and maintained leaf growth in July. This was not as evident within the 28 day mechanical defoliation interval. Defoliation interval has been reported by Hodgson (1966) to be between 7-8 days and 11-14 days under heavy and medium stocking with sheep respectively. Curll and Wilkins (1982) also reported a 5 day interval for sheep at a high stocking rate. Fisher and Roberts (1995) using dairy cows measured a defoliation interval, averaged over the season, of 27 and 10 days for low and high stocking rates respectively. The stocking rate used within the current experiment would be medium in relation to those of Fisher and Roberts (1995). Therefore, without the record of defoliation within the current experiment, it can only be suggested the defoliation interval due to grazing would fall within the range of 10-26 days. If so, then the T4 treatment would not be beneficial to the FG patches within the sward since the natural defoliation interval would be less than the 28 day mechanical defoliation interval.
The composition with respect to live and dead material within both the FG and IG patches was similar for all treatments over most weeks. The large variability within this data would suggest a variation within the plots leading to a high sampling error. McDonald (1986) reported topping to significantly reduce dead matter within two of three trials carried out. Stakelum and Dillon (1990) also reported a reduction in dead matter content of both short and tall grass patches when under a moderate stocking rate and topping after each grazing cycle from early season. However, in their study there was no difference between moderate stocking rate with topping and high stocking rate without topping for the short grass areas. In the current experiment the proportion of dead matter within the IG patch was similar, however in absolute terms there would be less within the T2 treatment due to the lower herbage mass of these patches.

The effect of topping on sward quality, as measured by digestibility was not significantly different between single, multiple or non topped treatments, although there was some improvement from topping early rather than in mid or late season (McDonald, 1986). Stakelum and Dillon (1990) found significantly greater organic matter digestibility with topped swards compared to a medium stocked sward without topping. When this was compared to a sward with a high stocking rate, there was significantly lower organic matter digestibility in the short, frequently grazed patch but greater within the tall, IG patches compared to the medium stocked sward with topping. The topped swards were not sampled separately, but randomly throughout. Therefore, a direct comparison of tall and short patches within this study and the current experiment is not possible. The current experiment suggests higher D-value in mid June with both topping frequencies compared to the Control for the FG patches. By mid-July, the greater D-value was evident only for T2, although this was marginal. This could be due to the higher leaf and lower dead material present, especially in mid July, within the T2 treatment since stem and dead material are of lower digestibility (Terry, 1964 and Wilman *et al.* 1996).

There was a decline in D-value of the FG patches over the season for the topped treatments, which agrees with Beever *et al.* (1986). The non-topped treatment appeared to maintain the D- value albeit at a lower value

The D-value of the IG patches was higher than that of the FG patches at all sampling occasions during the experiment. Again, this could be due to the generally lower dead or higher leaf content within these patches. The digestibility of the IG patches between treatments was not significantly different over all sampling periods despite the variation between the leaf: stem ratio during the later period of the experiment ($P > 0.05$). The presence of seeds within the flowering heads within the IG patches of the control treatment from mid July onwards may be responsible for the greater digestibility than expected from the leaf and stem content of these patches.

The protein levels were significantly greater within both T2 and T4 treatment compared to the control, over the whole experiment ($P \leq 0.001$). This would be expected, due to the higher leaf content within the topped treatments. Water soluble carbohydrate (WSC) was the reverse being significantly higher in the Control than the topped treatments over all occasions($P \leq 0.001$). This would be expected since Wilman (1996) reported a negative correlation between WSC and Nitrogen concentration within Perennial ryegrass.

It has been suggested there is an upper limit of 16.9kg DM/d intake of grazed grass under good grassland management (Meijs and Hoekstra, 1984), however, recent work has reported higher intakes at grazing over 18kg DM /d for high yielding dairy cows (Dillon *et al.*, 1999; Gordon *et al.*, 2000). The estimate of herbage intake within the present experiment ranged between 12 and 21 kgDM/d using the n-alkane technique.

This upper range would appear high when taking into account milk production level and liveweight change of the cows, especially under the T4 treatment. It would also be expected for the intake to decline over the season as milk production levels declined, however this was only true for the T2 treatment, with the C treatment increasing over the sampling periods, while T4 maintained intake until the third period when there was a dramatic decline. A comparison between the intakes estimated from the n-alkane technique and that calculated by the energy balance method (AFRC, 1993) can be seen in Table 82. The energy balance calculations take into account the ME required for maintenance and production and the ME supplied from concentrates and liveweight loss.

Table 5.33: Comparison of estimated daily intake of grazed grass by cows within C, T2 and T4 treatments during June, July and August using the energy balance calculations and n-alkane methods.

	Treatment								
	June			July			August		
	C	T2	T4	C	T2	T4	C	T2	T4
ME required (MJ/d)									
Maintenance	60.2	58.4	58.4	60.2	58.4	59.0	60.2	58.4	58.4
Milk Prod.	134.5	129.4	126.8	124.2	124.2	113.9	103.5	98.3	98.3
ME supply (MJ/d)									
Concentrate	30	30	30	30	30	30	30	30	30
Lwt change	0	4.4	7.0	0	4.4	7.0	0	4.4	7.0
Energy Balance (MJ/d)	164.7	153.4	148.2	154.4	148.2	135.9	133.7	122.4	119.8
ME grass (MJ/kg)	9.4	10.1	9.9	9.4	9.9	9.6	9.6	9.5	9.5
Intake - energy balance (kg/d)	17.5	15.2	15.0	16.4	15.0	14.0	13.9	12.9	12.6
Intake - n-alkane (kg/d)	17.3	15.9	17.1	19.1	13.7	17.3	21.1	12.4	12.3

These two methods would appear to be in good agreement for the T2 treatment on all occasions but for T4 and C on only the late and early season sampling occasions respectively. The C treatment estimates using n-alkane were much greater than for the energy balance calculation during July and August. The closest agreement is for the T2 treatment on all 3 occasions, C treatment in June and T4 in August. Generally we can conclude that the n-alkane technique predicted intakes higher than those from energy balance calculation for the C treatment. Fisher *et al.* (1995) report higher intakes from n-alkane than energy balance. However, both these methods of estimating grazed grass intake have potential sources of errors within the procedure. The n-alkane procedure used within the present experiment could have had errors attributed to:

Plucked herbage sampling error

If the herbage sampled is different with respect to the plant parts from that which is actually consumed by the grazing animal, this can led to a source of error within the diet composition and intake calculation (Dove and Mayes, 1995). Greenhalgh and Reid (1968) reported a relatively lower digestibility of the diet of zero grazed cows than strip grazed cows in the summer months when the maturity of herbage gave an opportunity for selection. Tayler and Deriaz (1963) found ingested herbage was higher than that on offer, by up to 13 units of digestible organic matter when grazing in areas designated grazed and rejected. It would appear that animals can select within the patch avoiding dead material, which is of low digestibility and selecting leaf of high digestibility. Le Du *et al.* (1981) found that herbage selected may be 3-10% higher in digestibility than the average of that on offer indicating a positive selection toward the leaf. Laredo and Minson (1975) concluded that voluntary intake of the leaf fraction by sheep was 20% higher than the stem.

Variation of sward morphology through the season and between treatments

The total dry matter intake of grass was significantly different between all treatments when meaned over all weeks, with the greatest being within the C treatment and the least within T2 ($P \leq 0.001$). The absolute values of intake were high, which would appear to be due to the relatively low concentrations of C_{33} alkane within the herbage samples. This increased over the season within the T2 and T4 treatments but not within the control. Dove *et al.*, 1996 reported the variation of the alkane concentrations within various plant parts. They showed the leaf to contain the highest concentrations in the order of 130 mg/kg DM compared to the stem or inflorescence containing 20 and 40 mg/kg DM respectively. This agrees with the difference in the herbage concentrations between the treatments and the morphology of the herbage within. As the season progressed, T2 and T4 herbage concentrations of C_{33} alkane rose to within the range 50 –120 mg/kg DM within the IG patches were as within the control this remained constantly throughout the season at 40-80 mg/kg DM. This would agree with the observed proportions of leaf and stem within these patches, being much higher within the IG patches of the topped treatments than in the control.

If the animals select a diet of constant leaf content, irrespective from that offered by the sward, then there is a risk of a greater discrepancy between C_{33} concentrations within the grazed diet and that hand plucked for C treatment, than either T2 and T4. In order to correct for the variation and bias of C_{33} a 30% increase within the C treatment herbage was applied to the calculations during July and August This brought the C_{33} in the sampled herbage and the leaf:stem ratios within all three treatments to similar levels, therefore trying to standardise the ingested material to similar leaf content. This correction alters the absolute intake values to 17.4 and 20.0 kg DM/day for control, during July and August period respectively compared to 19.1 and 21.1 kg DM/day without correction. Therefore, this correction does not fully explain the higher than expected intake from the C treatment in absolute terms or comparative to T2 and T4.

Diet selection bias between treatments and over time

Within the current experiment it would be feasible to assume that the sampling of the herbage was not the same as that selected by the grazing cow, which would have contained higher leaf, less stem and dead material. Therefore the concentration of C_{33} alkane within the grazed herbage is likely to have been higher than that obtained from the samples collected by hand plucking. Sampling error is likely to be higher within the control treatment when there was a lower leaf:stem ratio within both the FG and IG patches during the July sampling and within the IG patches in August than either topping treatment. The selection ratio of grazing behaviour has shown that cows on treatment T2 actively selected IG patches compared to T4 or C. Since these patches had higher leaf content the hand plucked samples are likely to be more similar to that consumed by the cow. Cows within the T4 treatment avoided the IG patches at a similar level to those in C treatment. The increased grazing of the FG patches may have led to sampling bias since selection for leaf by the grazing animal may be greater in these patches but not true for hand plucked samples. This would have caused higher intake estimates.

T4 cows also grazed longer than T2 or C by approximately 30 minutes, which could contribute to the greater intake compared to T2 during June and July. The August intake fell dramatically for T4 to a similar level to T2. The only change in the sward at this time was an increase in the Leaf:Stem of the FG patch to a similar level to that of the IG patches. This may have reduced the sampling error when plucking herbage and hence a more accurate estimate of diet during August. Alternatively the use of fistulated animals to collect extrusa samples of the grazed diet would enhance the accuracy of herbage samples for alkane analysis.

The errors within the diet composition calculations are again through accuracy of the sampling of diet components i.e. IG and FG herbage. The great variation in sward morphology of the IG patch (leaf,stem, dead, flower heads) present between treatments, together with the animal interactions associated with these characteristics, ultimately could lead to unequal bias between C and topping treatments. This may explain why there is minimal intake estimated from IG patch within treatment C, although continual sampling was observed within grazing behaviour. The very high intakes estimated from the IG patches within T2 and T4 may be due to the higher leaf content of these patches being similar to that of the whole diet selected by the animal. Therefore, this suggests that a high proportion of the diet composition came from the IG patches.

In order to overcome the problem associated with the diet selection for leaf within a patch and the error in hand plucked samples it would be ideal to add naturally occurring n-alkanes, which are found at low concentrations e.g. C36 to these patches. A different alkane addition for the IG and FG patch would then give a very unique profile pattern to each component of the diet and allow for more accurate determination of the diet consumed. This would reduce or eliminate the variation of alkane profile over time and between treatments.

The energy balance method for estimating intake is also prone to error. This method relies on very accurate measuring of liveweight. The gut fill can greatly affect the weight, however on all occasions all animals were weighed directly after the afternoon milking to minimise inaccuracies. The regression of liveweight over the experiment was different between the treatments and had a dramatic effect on the energy balance calculations. The composition of the liveweight loss may also vary between animals, which will have an effect on the accuracy of the mean value of 19 MJ/kg lwt loss used within the method in Table 82. The ME of the grass grazed may not be the same as that measured from plucked samples due to the selection of diet by the animal. The proportion of IG and FG patch intake would also affect the ME since NIRS measurements show the IG patches to have a slightly higher ME than FG patches.

Both the n-alkane and the energy balance methods of estimating grazed grass intake by dairy cows contain sources of potential errors and bias. However, both these methods estimate higher intakes within the C treatment, especially in July and August. Milk production was not significantly different at any week of the experiment ($P > 0.05$). All treatments showed a steady decline from the initial 30 kg/day in May to 18 kg/day in September without any difference in the rate of change of milk yield over time between treatments. The Control treatment had a higher predicted intake than both T2 and T4, however the milk yield was not significantly different to T2 ($P > 0.05$). This could also be attributed to the lower quality of the FG patch from which 95% of the diet was sourced, or indeed the actual intake was lower than predicted due to the herbage sampling error. The August intake period also showed both T2 and T4 to be significantly less than the control ($P \leq 0.001$), while milk yield was the same for all treatments. At this time, the proportion of the total intake from the IG patches within the topped treatments was approximately 80% compared to 1% for the control. The D-value of the IG patches within T2 and T4 was on average 3 units higher then the FG patches within the control. This higher energy value coupled with a weight loss within T2 and T4 of 1.6 and 2.6 kg/day respectively could have compensated for the lower dry matter intake maintaining the milk yield similar to the control, which had no weight loss but a higher dry matter intake.

The grazing behaviour showed the bite rate to be lower for the control treatment than T2 and T4 during mid July and mid August recording period, although not significantly so ($P > 0.05$). This would suggest that within the control there was more time spent searching or selecting within and between patches thereby reducing the overall natural bite rate. Laca *et al.* (1994) point out that cattle are able to change their grazing strategy during eating. Therefore cows within the control treatment of the current experiment may have reduced their bite rate by increasing the proportion of time spent searching between the patches and selection of material within the encountered patch than those within the T2 or T4 treatment, were patches were more uniform in morphology. The selection ratio would also suggest that cows within the T2 treatment actively selected the IG patches in late summer, while those in C and T4 continued to graze at a level in proportion to these patches within the sward. This would explain the higher estimated intakes from the IG patches, together with the reduction in the proportion of these patches in this treatment by the end of August.

5.7 CONCLUSION

Topping:

(1) Enhanced sward morphology of the IG patches through

- Significantly increased tiller density ($P \leq 0.001$)
- Significantly increased leaf content ($P \leq 0.001$)
- Significantly increased crude protein content of herbage ($P \leq 0.001$)
- reduced dead material ($P > 0.05$)
- increased digestibility over the FG patch ($P > 0.05$)

(2) Significantly reduced height and herbage mass of FG patches ($P \leq 0.001$, $P \leq 0.05$ respectively)

(3) Significantly reduced height, herbage mass and proportion within the sward of IG patches ($P \leq 0.001$)

(4) Significantly greater selection of IG patches ($P \leq 0.05$) and altered grazing through increased bite rate ($P > 0.05$)

(5) Significantly reduced dry matter intake of dairy cows ($P \leq 0.001$)

(6) Increased Liveweight loss ($P > 0.05$)

(7) No significant affect on milk production or composition ($P > 0.05$)

Topping every two weeks compared to every four weeks:

(1) Significantly reduced height of IG patch ($P \leq 0.001$)

(2) Significantly reduced proportion, by 10%, of IG patches in the sward during august ($P \leq 0.001$)

(3) Significantly increased tiller density within IG patch from mid summer ($P \leq 0.001$)

(4) Significantly greater selection of IG patches in August ($P \leq 0.05$)

(5) Increased leaf content in mid/late summer ($P > 0.05$)

(6) Had no significant affect on the digestibility of the herbage ($P > 0.05$)

(7) Had no significant affect on milk yield ($P > 0.05$)

CHAPTER 6. DISCUSSION AND CONCLUSION

6.1 GRAZING MANAGEMENT AND SWARD CHARACTERISTICS

6.1.1 Sward height

Sward height, herbage mass, bulk density, leafiness and herbage availability have been shown to be the major characteristics of a sward which affect the grazing behaviour, intake and milk production of dairy cows (Parga *et al.*, 2000; Peyraud & Gonzalez-Rodrigez, 2000). It is therefore critical that grazing management optimises SSH. Current recommendations are for 8-10 cm and 6-8 cm SSH residual paddock height for high and low yielding cows respectively under rotational grazing. The difficulty which arises with high merit cows is the deterioration in sward structure and composition with high residual swards. Continuous stocking recommendations for height fall in the range of 6 cm in early spring increasing to 8 and 10 cm in mid summer and autumn respectively. The difficulty, which is presented within this management, is achieving suitable high intakes to sustain the high yielding cow. Therefore, whether these target SSH are achieved in practice depends on both the ability to manage the grazing system and whether the objective is to maximise output per hectare or output per animal (Mayne & Peyraud, 1996).

Lax grazing in spring has been shown to be detrimental to the sward density and quality in mid season (Korte, 1986; Holmes *et al.*, 1983; Stakelum & Dillon, 1990; Fisher *et al.*, 1996). There is also a high variability of height throughout swards laxly grazed, which results in heterogeneity with patches of tall or short height (Ginane & Petit, 2002). Height heterogeneity within a grazed sward, if dynamic as a result of defoliation intervals being out of phase at any point in time, is not detrimental to sward characteristics. However, if the heterogeneity of height is relatively stable, then production and utilisation of the sward is reduced (Parsons & Chapman, 2000). This heterogeneity increases over the season as herbage becomes mature and reduced quality associated with tall height becomes apparent (Gibb *et al.*, 1997). Stakelum & Dillon (1990) reported increased herbage yield of lower leaf, higher stem and dead content with an overall lower digestibility for both tall and short phases within a sward grazed during early season at 10-13 cm compared to 5.5-6 cm.

Mean sward height is often used as a descriptor of herbage available to the grazing animal. However, this has limitations as it does not consider other variables which interact to affect the true availability to the grazing animal, e.g. bulk density, leaf and stem content and variability of sward structure (Peyraud & Gonzalez-Rodrigez, 2000; Swain, 2000).

The results of the present series of experiments show how SSH under continuous stocking affects other sward characteristics and are presented in Table 6.1.

Table 6.1: The effect of grazing management on sward height and associated sward characteristics.

		Experiment 1		Experiment 2			Experiment 3		
		HP	MP	6	8	10	C	T2	T4
FG height (cm)		6.6	7.3***	7.0	8.6	9.8***	7.1	6.7	6.7***
IG height (cm)		21	23***	23.6	28	28.1***	20	14.6	16.5***
% IG patches		26	31.5***	27	39	40**	31	27	32***
Herbage mass (tDM/ha)		1.1	1.2	0.88	1.19	1.42*	0.98	0.84	0.8*
FG		3.3	3.8*	4.1	5.4	5.5*	3.0	2.2	2.2***
	IG								
Tiller density (no/m^2)	FG	8718	8458	-	-	-	8129	8353	8205
	IG	5660	5459	-	-	-	4761	5562	4984**
Leaf :Stem	FG	1.21	1.24	2.0	1.8	2.1	1.5	1.6	1.5
	IG	0.63	0.76	1.2	0.7	0.6	1.1	1.6	1.4**
Live:Dead	FG	3.66	4.36	11.7	12.4	8.1	9.7	6.9	11.2
	IG	9.1	8.7	7.5	8.7	6.8	10.0	10.3	9.4
Quality D-value (%)	FG	63.3	65.4	-	-	-	62.8	64.2	62.4
	IG	66.3	66.5	69	68	69	67.4	67.3	67.2
NDF (g/kg)	FG	596	584	-	-	-	608	602	606
	IG	612.5	604	554	584	560	607	603	602

*=P≤0.05, **=P≤0.01, ***=P≤0.001, ns = non significant

The heterogeneity of the sward during mid season increases, through greater proportion of taller infrequently grazed patches which have greater mean height. The herbage mass is generally increased with increasing height, however, tiller density was less affected at the heights maintained in the experiments of this study. Leaf content was similar, unless the frequency of defoliation was increased through mechanical topping (Experiment 3). Dead leaf and stem within the sward was increased at the 10 cm height range only. The quality of the herbage with respect to D value and fibre content was not affected within this series of experiments. This may be attributed to the inaccuracy of NIR calibrations for fresh grass with the level of leaf and stem within the samples of the experiments.

There is good agreement on the effect of SSH on sward morphology between these experiments during mid season with published literature on the effect of SSH in spring (Fisher & Dowdeswell, 1995; Stakelum & Dillon, 1990; Tallowin *et al.*, 1985), except for the digestibility measurements.

6.1.2 Herbage mass and tiller density

Swards of similar heights can vary in herbage mass through differing density (Mayne *et al.*, 1997). Tiller density has been shown to be significantly greater when grazing management in spring or early season is tight (below 6 cm) compared to swards grazed at higher levels, or laxly, during the early season (Matthew *et al.*, 1989; Fisher *et al.*, 1996). Such swards have the potential to allow higher intakes in late season, through the increased density at the same height, compared to those swards with lower density. However, it was not purely the density variation but also the interaction of increased leafiness and quality of those swards. Fisher & Dowdeswell (1995) showed that swards of high tiller density, which were allowed to regrow to SSH of 9 cm or above, lost the density of tillers and other factors, such as leaf content and organic matter digestibility, associated with a high intake potential sward. Experiments 1 and 3 within this study had SSH maintained below the 9 cm level. Tiller density was not measured in Experiment 2 when SSH in one treatment was 9.8 cm. This sward had no significant difference in leaf or dead content and had significantly greater herbage mass than swards grazed to 7 and 8.6 cm SSH. If we assume the tiller density would have been reduced, according to Fisher & Dowdeswell (1995), compared to the other treatments, then the sward characteristic of the taller less dense sward would not have enhanced intake rates unless SSH was increased to above 13 cm (Cushnahan *et al.*, 1996).

6.1.3 Sward digestibility

Sward leafiness is positively correlated with herbage quality (Beever *et al.*, 2000). Leafiness generally declines through the season especially if the tillers are allowed to undergo reproductive development (Parsons & Chapman, 2000). Leafiness and herbage quality has been shown to decline in rotationally grazed swards as they are progressively grazed down (McGilloway *et al.*, 1999).

It has often been presumed that digestibility of the tall infrequently grazed patches were of lower value than the short frequently grazed patch, however, relatively few studies have measured this directly and rely on the L:S ratio to indicate the quality of the patch. Stakelum & Dillon (1990) and Tallowin *et al.* (1986) both report higher digestibility of the shorter frequently grazed herbage coupled with greater L:S and less dead material than the tall patches. The results of Experiment 1 and 3 do not agree and indicate the reverse (Table 6.1). This discrepancy could possibly be due to the methods used to determine digestibility, sampling procedure used or the differences in sward morphology associated with the rotational grazed swards of their study.

In this study, NIRS was used compared to wet chemistry of Tilley and Terry (1963) within the published work. Smit, 2000 concluded that NIRS underestimated the digestibility of stems and leaves of perennial ryegrass by 6 and 2 D-value units compared to the Tilley and Terry method. However in the present study NIRS calibrations were against the Tilley and Terry method, with the statistics of the calibration and validation set summarised in Table 6.2 (Offer, N.W. personal communication). Samples for these calibrations were taken from the fields at SAC, Auchincruive and Crichton Royal Farm, Dumfries, therefore they were of very similar composition and type to that used in this study. The samples from the current study for digestibility prediction fell mainly within the calibration range, although there were a few outliers. However, the data set for calibration was large with good validation samples and a low standard error of prediction (SEP) for digestibility. The NDF calibration set was much smaller and possibly less reliable, especially since the samples from the current study fell at the high end of the calibration set and indeed out with the range on most occasions. It is therefore reasonable to suggest that the NDF predictions may be less reliable than digestibility. In order to investigate this possibility a few samples from Experiment 3 were crossed checked by NIRS and wet chemistry for NDF levels. This showed generally that the NIRS measurements were higher than wet chemistry and the discrepancy was greater for the FG patches (9%). There was a variation in discrepancy of methods between treatments, with 17%, 7% and 0% difference for FG patches of 10, 8 and 6 cm treatments respectively. The NDF levels for IG patches appeared to be 6% higher under NIRS, with no difference in the discrepancy between treatments. Due to the small set of samples analysed in this way, it is only possible to suggest that NIRS was over estimating the NDF levels in the samples and that there may be bias to the predictions between treatments.

Table 6.2: The validation and calibration statistics for NIRS model used to predict D-value (%) and NDF (g/kg DM) for Experiments 1,2 and 3

	Validation Statistics				Calibration population			
	n (cal.)	N (val)	R^2 (val)	SEC(V) [1] or SEP [2]	Mean	sd	Min Value	Max Value
IVOMD (%) [2]	248	180	0.87	2.05	72.6	5.6	58.6	85.2
NDF (g/kg DM) [1]	61	61	0.94	13.5	465	52.9	383	573
NIR prediction of experimental samples (pooled for Experiment 1,2&3)								
				D-value (%)	66.4	3.5	37	73
				NDF (g/kg DM)	591	30.2	521	700

In Experiment 1 and 3 the IG patches had higher and similar levels of NDF to the FG patches respectively, with correspondingly higher D values. The higher NDF and D-value of IG patches in Experiment 1 could be due to the presence of seeds in the flower heads. Within Experiment 3 the topped treatments did not have flower heads present therefore, the high NDF and D-value of IG is difficult to explain, other than inaccuracy or error in NIRS calibration for NDF.

The contradiction between the results for digestibility between Stakelum and Dillon (1990) and this study could be attributed to the contrasting leaf content of the FG and IG patches within the swards. The rotational swards of Dillon and Stakelum (1990) were rotationally grazed swards sampled above 4.5 cm with the FG patches having a leaf content of 3 to 4 fold greater than IG patches. This contrasts with the continuously stocked swards of this study, sampled to ground level, and where the FG patches had leaf content similar or twice that of the IG patches.

Experiment 3 involved topping treatments in order to mechanically defoliate the IG patches. This significantly increased the leaf content and tiller density of the patches from mid July onwards ($P \leq 0.001$, $P \leq 0.01$ respectively), however, this was not reflected in higher D values or lower NDF values. This contradicts the findings of Stakelum & Dillon (1990) and McDonald (1986), who both reported increased OMD % with topping. The only possible explanation is the sampling to ground level, as opposed to above 4.5 cm in the published literature, which may increase the stem and dead content and reduce the digestibility of the samples in the current study.

Topping frequency significantly affected tiller density and proportion of IG patches in the sward ($P \leq 0.001$), however, leaf content, dead content and quality remained similar for both 14 and 28 day defoliation interval. McDonald (1986) concluded that topping once in early season gave the same advantages as topping on multiple occasions through the season.

It can be concluded that other studies have shown grazing management to be critical in the early season, in order to provide swards with characteristics to allow potential high animal performance in mid and late season. In this study, we can also conclude that in order to maintain swards of good characteristics in the mid season, grazing management needs to be kept relatively tight (SSH 7 cm), otherwise a higher proportion of the sward becomes infrequently grazed. These patches would naturally have lower tiller density, leaf content and higher dead matter unless modified through mechanical defoliation. The frequency of topping starting in the early season can affect certain morphological characteristics of the IG patches, however, it was only under the 14 day defoliation interval that the proportion of IG patches in the sward was affected.

6.2 GRAZING MANAGEMENT AND SWARD HETEROGENEITY

An overall mean SSH of a sward can be misleading, as it does not indicate the spatial heterogeneity of a sward, in terms of horizontal patchiness. Grazed swards become a mosaic of short frequently grazed patches dispersed between infrequently taller patches, as a result of faecal contamination causing avoidance of an area associated around the dung pat (Bao *et al.*, 1998). This results in under-utilised swards. The grazing pressure in early season greatly affects the level of patch heterogeneity in the sward in mid season (Marsh & Campling, 1970; Stakelum & Dillon, 1990). Irrespective of the grazing pressure, the trend within swards is to reach a maximum proportion of the taller infrequently grazed patches by July, which usually coincides with the increased reproductive development of tillers to produce stem and flower heads within these patches (Ginane & Petit, 2002). This was evident in Experiment 1, 2 and 3 where maximum heterogeneity was present by July (Figure 6.1)

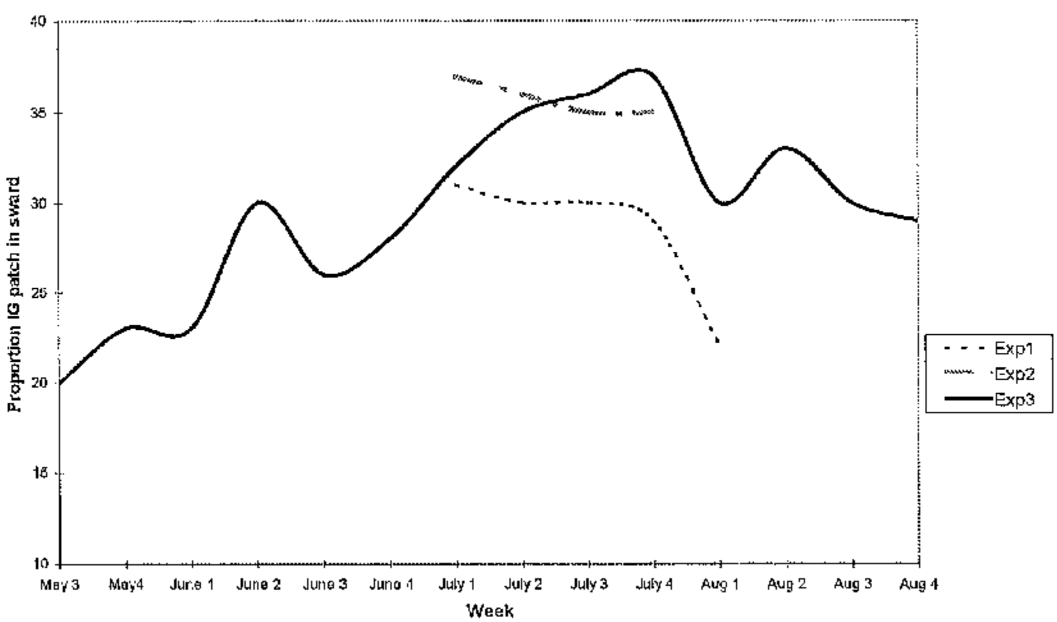


Figure 6.1: The change in proportion of IG patches through the season for Experiment 1 (----), 2 (- - -) and 3 (—).

Grazing of these patches in the mid season is suggested to increase as the height of the FG patch declines (Dumont *et al.*, 1995). The results of Experiment 1 and 2 showed that the proportion and height of IG patches was significantly less at the lowest FG patch height, of approximately 6.5 and 7 cm ($P \leq 0.001$). Therefore, the relationship between the height and proportion of IG patches was not simply linear with FG height but asymptotic. Using data pooled from both Experiment 1 and 2, Figure 6.2 and Figure 6.3 shows the relationship with curves of r^2 between 0.67 and 0.77 being fitted. The good fit of this data to the equations could mean it would be possible to use such equations as a decision support model, predicting the effect of the FG patch height of a sward on the height and proportion of IG patches.

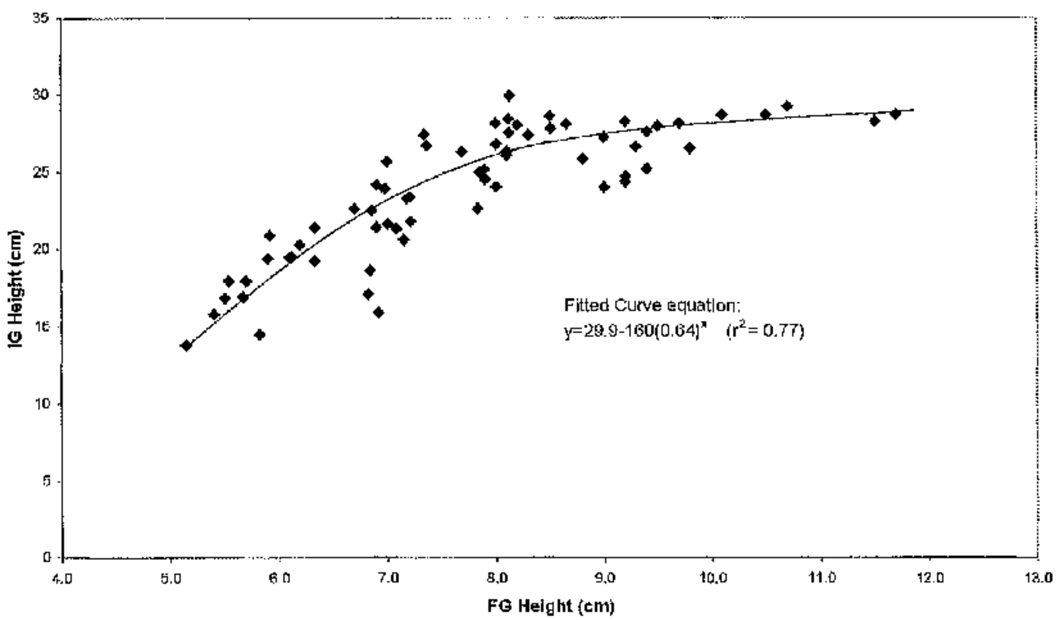


Figure 6.2: The relationship between FG height and IG height for data pooled from both Experiment 1 and 2.

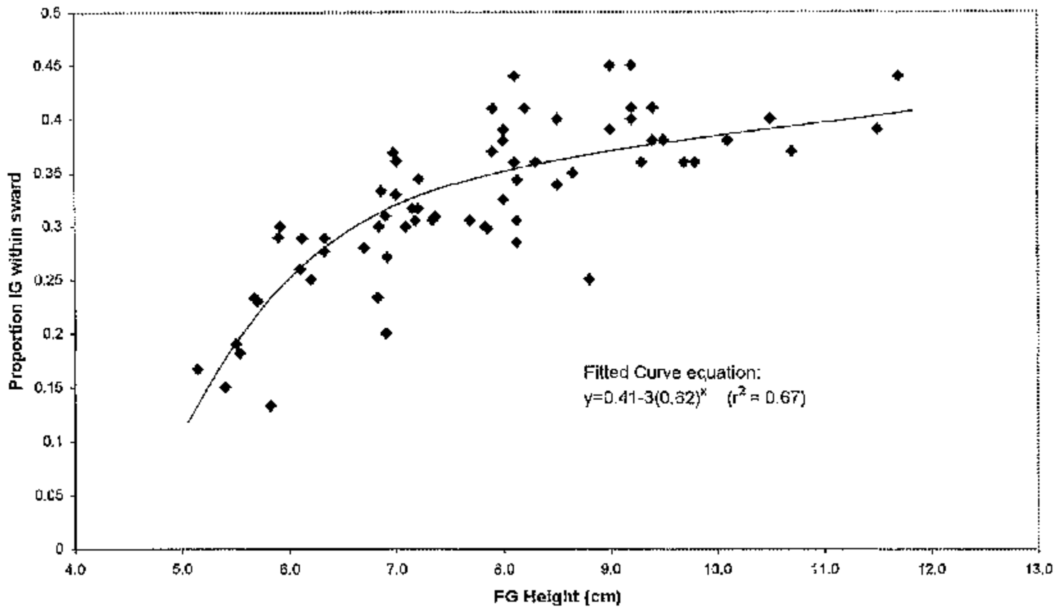


Figure 6.3: The relationship between FG height and proportion of IG patches within the sward for data pooled from both Experiment 1 and 2.

The heterogeneity of the sward in mid season can be reduced through grazing management. Experiment 1 and 2 show that by increasing the grazing pressure, through reducing the SSH under continuous stocking, the proportion of IG patches can be reduced over a 3-4 week period to significantly lower levels ($P \leq 0.001$), compared to a SSH resulting from moderate or low grazing pressure. Both the height and area of these IG patches were reduced through grazing within both experiments. Alternatively in Experiment 3, maintaining adequate SSH, whilst modifying the morphological characteristics of the IG patch through topping, also allowed for a reduction in the heterogeneity of the sward in the mid season through increased utilisation. However, topping not only modified the morphology of the patches but also significantly reduced the herbage mass and height of both the FG and IG patch in the sward ($P \leq 0.001$). Therefore, this is similar to applying a higher grazing pressure and may be the reason why the IG patches were utilised better and sward heterogeneity reduced in August.

6.3 SWARD AND ANIMAL INTERACTIONS

6.3.1 Ingestive Behaviour

Understanding the factors affecting plant-animal interactions requires knowledge of the relationship between sward components, structure and the mechanics of the grazing process of the animal. The factors of the sward which have a major influence on intake have been well documented (Hodgson, 1981; McGilloway & Mayne, 1996; Mayne *et al.*, 1997; Peyraud & Gonzalez-Rodrigez, 2000). These factors have a direct effect on the short-term intake rate, i.e. bite rate, bite mass and grazing time. Table 6.3 summarises the ingestive behaviour data gathered for the 3 experiments in this study.

Table 6.3: Ingestive Behaviour of dairy cows measured over the experiments in the study

	Experiment 1		Experiment 2			Experiment 3		
	HP	MP	6	8	10	C	T2	T4
NBR (Bites/min)	62.3	64.4	-	-	-	65	69	68.5
Grazing time (mins) #	516	514	481	470	452	569	587	612
Ruminating (mins) #	471	458	193	197	216	426	396	395
Selection ratio for IG patch	1.4	1.1	1.0	0.7	0.7	1.0	1.3	0.9*

#Exp 2 behaviour watch for 12 hours not 24 as with Exp 1 and 3.
*=$P\leq0.05$, **=$P\leq0.01$, ***=$P\leq0.001$, ns = non significant

Bite Rate

Bite rate has been demonstrated to be more variable than bite mass (Barrett *et al.*, 2001). Increasing the bite rate is one mechanism, which may allow cows to increase their intake rate. Gibb *et al.* (1997) suggests that lactating cows are unlikely to increase jaw movement rate to any appreciable extent over the long-term, however, they can alter the ratio of biting to non-biting jaw movements, especially in the evening (Gibb *et al.*, 1998).

Bao *et al.* (1998) suggests, that under rotational grazing, a reduction in bite rate as the sward is being grazed down might be partially attributed to the increase in proportion of bites from the tall infrequently grazed areas within the sward. Experiment 1 within this study would support this suggestion, as the selection of IG patch increased, the trend was for a reduction in the bite rate. This could be due to the increased height of sward associated with these patches requiring more manipulation of the prehended material within the mouth, alternatively it could be due to more time selecting within the patch prior to prehending the bite. The manual observations within this experiment did not allow for a differentiation as to the reason for reduced bite rate. Dumont *et al.* (1995) concluded that heifers had reduced bite rate on reproductive patches of Cocksfoot, compared to vegetative patches, due to a change in grazing tactics and greater selection. Within Experiment 3, however the scenario was the opposite, increased bite rate within the topped treatments being reflected in an increased proportion of time spent grazing within the IG patch. However, the much increased leaf:stem ratio of these patches compared to the untopped IG and indeed FG patch, suggests that an increase in selection time would not have been necessary, therefore allowing for greater bite rate even with somewhat taller herbage. This evidence suggests that the reduced bite rate associated with the preference for IG patch in Experiment 1 could be partially due to a need for increased selection within these patches and not entirely caused by a difficulty in manipulating the taller herbage.

Bite Mass

Cows can increase bite mass through greater depth rather than area of grazing, since the muzzle width limits the area which can be encapsulated into a bite. However, there is a barrier to grazing suggested to be the pseudostem height in vegetative swards, which has been found to be at 6 cm in short grass and 10 cm in tall grass (Flores *et al.*, 1993; Bao *et al.*, 1998). A number of studies within the literature also demonstrate that cows bite a depth of constant proportion to the sward height. However, the actual proportions have varied considerably within these studies (Wade *et al.*, 1989, Laca *et al.*, 1992) and most tend to be hand constructed swards, not in a field situation.

Experiment 2 showed the depth of defoliation, as a proportion of the extended tiller height, within short FG patch was not constant but significantly lower in the taller 10 cm SSH ($P \leq 0.05$). Within both the 6 and 8 cm there was a constant approximately 50% depth of defoliation. This conflicts with the results of the studies in literature, probably mainly due to the field conditions in which this study took place and not hand constructed swards presented to housed animals. The present result suggests that the grazing barrier of 6 cm is not applicable to all grazing systems or managements imposed.

The depth of defoliation within the IG patches, although not significantly different ($P > 0.05$), was 10% less under the 10 cm treatment than either 6 or 8 cm SSH where the IG patch height was on average the same as those under the 8 cm treatments. This also contradicts the constant proportion of tiller height being removed, however the height of the IG tillers were well in excess of the normal grazing heights, but were within the range studied by Wade *et al.* (1989). The difference within this study and that reported in other literature is twofold:

(i) Swards were growing under natural field conditions not hand constructed.

(ii) These taller tillers were associated with dung contamination which may interfere with the normal ingestive behaviour observed within the other studies.

Grazing Time

Cows can adjust grazing time by lengthening the duration of meals (Gibb *et al.*, 1999). Total grazing time in Experiment 2 and 3 appeared to be related to SSH or herbage mass available, since more grazing time was observed with lowering SSH, or reduced herbage mass within the topping treatment of Experiment 3. This could be a response to the lower intake potential of these swards in order to try to maintain DM and energy intakes. The grazing time within Experiment 3 was high, reaching the upper 10 hour limit as suggested by Rook *et al.* (1994).

Ruminating time is also required by cows, which increases with higher intakes and as the sward quality and digestibility declines (Beever *et al.*, 2000). In Experiment 2 and 3 the greater grazing time was associated with less ruminating time. This could be because the increased grazing time did not always lead to higher intakes as cows spent more time searching, or had reduced bite mass. Alternatively, lower intakes of lower quality herbage required relatively greater rumination. One or more of these possible mechanisms may have been involved. Rumination time in Experiment 2 was much less than Experiment 1 and 3 due to the behaviour watch only occurring for 12 hours (8am-8pm). Ruminating and idling are a much greater proportion of the night activities and would increase their total to that in the region of Experiment 1 and 3 if 24 hour observations were made.

6.3.2 Selective grazing

Diet selection is an important means by which grazing animals seek to obtain their nutrient requirement from a heterogeneous sward. This can be seen as a behavioural adoption to a variation in the spatial heterogeneity of sward structure and quality. Selection of morphological components of a sward arise from the animal's preference (Forbes, 1982). In order to make an informed decision as to preferred diet on offer the animal must sample all food sources to gain a relative value (Illius, 1996). Illius *et al.* (1987) concluded that cattle showed a preference for short grass of higher digestibility but sampled from all parts of the sward. Wallis de Vries (1994) also concluded that cattle selected short and tall patches of similar digestibility over stemmy patches of lower digestibility, with a stronger degree of selectivity when the differences between diet source increase.

Table 6.3 shows the selection ratio for the IG patches observed in the experiments of this study. This agrees with the constant sampling theory since the IG patches were not totally avoided. Positive selection (selection ratio >1.0) was associated with swards of low SSH, or where grazing pressure was high. Topping in Experiment 3 also increased the positive selection of IG patches by grazing animals, however it is difficult to determine if this was as a result of lower herbage availability, i.e. increased grazing pressure, or the increased leafiness of the patches.

The digestibility of IG patches as predicted by NIRS contradicts the theory of selecting to optimise energy since in Experiment 1 and 3 the D value was higher in IG compared to FG patches, with selection not always in favour of the IG patch. This could be explained by the presence of dung in the IG patches causing offence and therefore negating the animal's preference for the higher digestible diet. The results of this study agree with Bao *et al.* (1998) who, under rotational grazing with dairy cows, report an initial selection for short grass when first encountering the paddock but increased their grazing of tall patches as grazing progressed. The switch in selection occurred earlier if swards were topped. They suggest that tall grass is selected as herbage mass and/or sward height decline.

6.3.3 Intake of grazed grass

Herbage intake is a major factor limiting milk production especially from high yielding dairy cows (McGilloway & Mayne, 1996; Peyraud & Deleby, 2001). Mayne (2001) calculated a potential support of 33kg milk d^{-1} assuming an ME of 12 MJ kg DM^{-1} with an intake of 18.7kg DM d^{-1} of grazed grass. Results from the literature show a vast range with maximum DM intakes of 27 kg reported by Stakelum & Dillon (1990). Such high levels of intake are rarely achieved in practice but rather over short periods within experimental conditions when sward conditions are optimal. Generally a range between 10-16kg OM $cow^{-1}d^{-1}$ have been reported for cows yielding up to 26kg milk d^{-1} (Table 2.5). A summary of the estimated intakes for Experiment 1, 2 and 3 using the n-alkane technique and energy balance methods is presented in Table 6.4.

Table 6.4: Summary of estimated intake of grazed grass using the n-alkane technique and energy balance method for Experiment 1, 2 and 3

	Exp 1		Exp 2			Exp 3		
	HP	MP	6	8	10	C	T2	T4
n-alkane estimate								
Total intake (kg DM d^{-1})	\$21.9	22.9 \$***	16.7	17.0	17.8 ***	19.2	14.0	15.6 ***
Intake from IG (kg DM d^{-1})	\$1.5	\$1.9 ***	3.5	3.4	2.8 ***	0.5	7.5	4.6 ***
Energy Balance Estimate (kg DM d^{-1})	12.5	14.0	15.1	15.1	18.1	16.0	14.3	13.6
Milk prod (kg cow^{-1} d^{-1})	22.2	23.2 *	24.2	24.5	26.7	23.6	23.3	22.8

*=$P\leq0.05$,***=$P\leq0.001$
\$= kg OM d^{-1}

The estimated intakes are towards the high end of that reported in the literature, especially with the corresponding milk yields of 26kg or less. Experiment 1 in particular showed very high intake estimates. Generally it can be presumed that, for the heterogeneous swards being grazed within these experiments, the sampling of hand plucked herbage and the diet consumed by the animal has the potential to differ widely.
In particular the leaf content of the FG patches within the swards of Experiment 1 (Table 6.1) was 30-100% lower than in Experiment 2 and 3. This may have led to the higher absolute values of n-alkane intake estimates and the greater discrepancy between the estimates of energy balance and n-alkane methods for this experiment. The concentration of C_{33} alkane was also lower in the herbage and faeces samples from Experiment 1. This probably relates to the lower leaf content, since C_{33} is of highest concentration in the leaf (Dove *et al.*, 1996). However, errors may have occurred within the analytical procedure for recovering the alkane from the samples. This would only cause an over estimate of the intake if the recovery of C_{33} of the herbage was less than that within the faeces, since similar errors would cancel each other out within the intake calculation. The concentration of C_{33} within the herbage samples of Experiment 1 was 50-75% of Experiment 2 and 3. The concentration of C_{33} within the faeces samples was 75-90% of

Experiment 2 and 3. This unequal variation for samples in Experiment 1 caused greater intake estimates, up to a maximum of 6 kg DM, than Experiment 2 and 3. The variation of C_{33} between the herbage and faeces of Experiment 1 could be due to, one or both of, biased error in analytical recovery of C_{33} from the samples and inaccuracy of plucked herbage samples compared to the diet selected by the animal.

Experiment 1 and 2 show that the relative intakes between treatments are appropriate to the milk yield. The proportion of total intake from the IG patch are also relatively correct in relation to the grazing behaviour and sward utilisation. Experiment 3 indicates much greater total intake for C than T2 or T4 and is particular high in relation to the milk yield. The T2 and T4 sward had less heterogeneity between the IG and FG patch in relation to leaf, stem and height. This may be responsible for better correlation between the hand plucked herbage samples and the diet actually selected by the animal.

The n-alkane technique for estimating intake involves a number of potential errors and inaccuracies, which can result in over estimation of intake. These are summarised in Figure 6.4. However, it may also be possible for treatments to interact with the sward to provide a source of biased error in the estimate of intake between treatments. This is likely to be related to the sward morphology, in terms of leaf content, and the interaction this has with the grazing animal. If animals select for a constant leafiness of their diet, while the hand plucked samples represent the sward average, then discrepancies will result in the estimated intake.

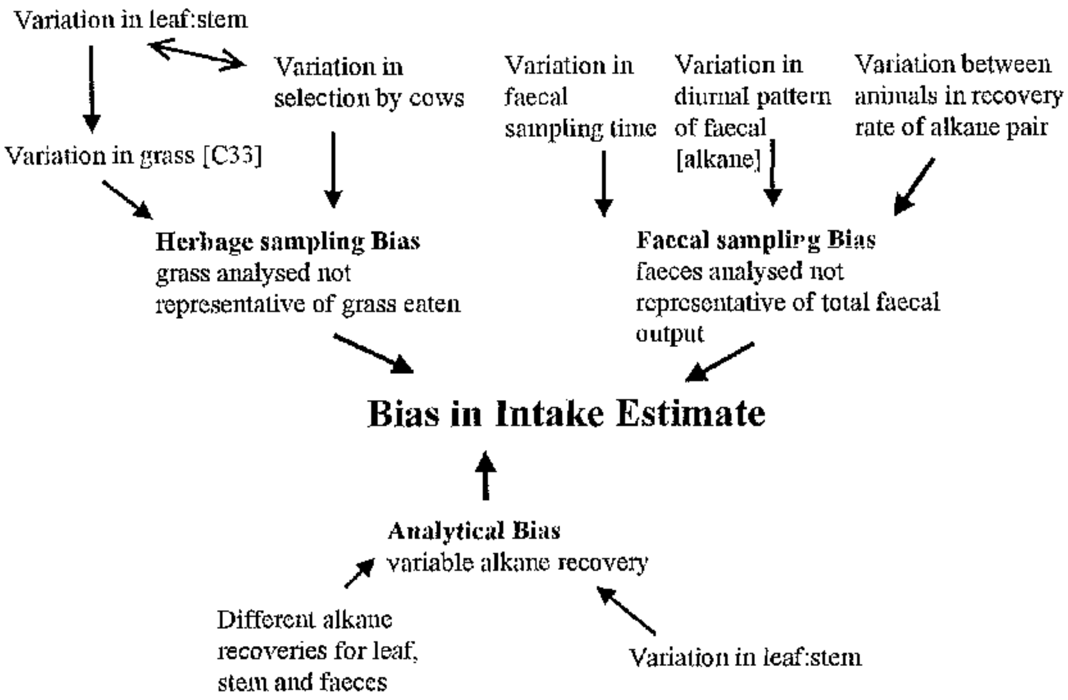


Figure 6.4: Possible origins of experimental errors and bias in estimating intake by the n-alkane technique

We can conclude that the sward characteristics in terms of SSH, herbage mass, leaf content and patch heterogeneity affect the grazing behaviour and intake of dairy cows. When grazing pressure is increased, through a reduction in SSH in FG areas, to levels which would restrict intake in mid season ($\leq$ 6 cm) then the animals will reduce their selectivity against the dung contaminated infrequently grazed patches. Associated with this was the tendency to increase the total grazing time and reduce bite rate. Overall, the intakes were lower under high grazing pressure than if grazing pressure was moderate, despite the modification to their grazing behaviour. Milk yield was only significantly reduced in one year ($P \leq 0.05$), otherwise there was no difference in the milk yield despite lower intake.

6.4 GRAZING MANAGEMENT AND ANIMAL PERFORMANCE

Herbage allowance or grazing pressure has been demonstrated to be the primary factor of grazing management influencing herbage intake and ultimately milk production (Leaver, 1985; Mayne & Peyraud, 1996). As the stocking rate is increased the grazing pressure is increased, or herbage allowance per animal decreased. Individual animal performance can be reduced through decreased intake, however, output per ha and utilisation of herbage is usually increased. The reduced daily intake is accepted to be due to lower bite mass, which is not offset by higher bite rates when swards decline below 7.5 cm (Mayne *et al.*, 2000). The quality of herbage on offer, together with the structure of the sward, also significantly affects milk production through intake (Peyraud *et al.*, 1996). Experiment 1 shows how increasing the stocking rate, to increase the grazing pressure during the mid-season, within a heterogeneous sward caused a reduction in daily intake and milk yield by 1kg d^{-1} for individual animals. This was also recorded within Experiment 2, when again, increasing the grazing pressure significantly reduced the intake by 1-1.5 kg DM d^{-1} ($P \leq 0.001$) and milk yield by similar amounts, although these differences were not significant ($P > 0.05$). Although the aim of this study was not at the system level, stocking rates were recorded but only the milk yields of core cows was measured. The effect of stocking rates on the production per hectare cannot be accurately predicted, however, if we assume that all cows were producing the average milk yield and consuming grass intakes similar to the cows recorded on the treatment, then some estimates can be made. Table 6.5 shows the estimated effect of stocking rate on milk production and UME on a per hectare basis. This indicates that utilisation of grass and production of milk would be greater, on a per hectare basis, when the stocking rate was sufficiently high to increase the utilisation of the infrequently grazed patches. Experiment 3 shows very different results to Experiment 1 and 2. Milk yield was not significantly different ($P > 0.05$), however in 2 of 3 treatments, intakes were approximately 5kg DM ha^{-1} lower. The other difference in these treatments was the much greater proportion of the total intake from the IG patches of the heterogeneous sward. The D-value of these patches was on average 4 units higher than the FG patches of the sward and therefore the lower intake maintaining the same milk yield may be partially due to the greater digestibility of the diet. In addition to this explanation, the cows within the lower intake treatments were losing liveweight (approx 2kg week^{-1}) unlike the cows on treatment with higher intakes maintaining their weight.

Table 6.5: Estimated Milk production (kg/ha/d) and UME (GJ/ha) for the grazing period

	Experiment 1		Experiment 2		
	HP	MP	6	8	10
Stocking Rate (cows/ha)	5.6	3.5	5.2	3.9	3.6
Milk Yield/cow (kg/cow/d)	22.2	23.1*	24.2	24.5	26.7
Milk yield /ha (kg/ha/d)	124.3	80.9	125.8	95.6	96.1
Grass intake (kg DM/ha/d)	122.6	80.1	86.8	66.3	64.1
UME Exp period (MJ/ha/d)	704	483	805	638	644
UME grazing season(GJ/ha)	127	87	145	115	116

* Significantly different ($P \leq 0.05$)

6.5 UTILISATION OF HETEROGENEOUS SWARDS BY GRAZING DAIRY COWS

Good grassland management is not only about producing adequate yields of grass to sustain target production but to utilise that grown efficiently. Growth not harvested through grazing or cutting will ultimately senesce and die. It is therefore good management to utilise optimal amount of growth without removing excess amounts, i.e. overgrazing. This is the basis of the recommended SSH suggested by Mayne & Wright (1988), where a compromise between herbage intake, animal performance and sward utilisation is achieved. McMeekan & Walshe (1963) were amongst the first to highlight the importance of stocking rate in determining the efficiency of herbage utilisation by both sheep and cattle.

Heterogeneous swards are often comprised of frequently grazed and infrequently poorly utilised patches. Even under the highest stocking rates, up to 20% of the sward can be under utilised through faecal contaminated patches being avoided (Arnold & Holmes, 1958; Maclusky, 1960; Greenhalgh & Reid, 1968). Reducing the stocking rate or grazing pressure reduces the overall utilisation of the sward, by increasing the proportion of the IG patches.

If we measure utilisation in terms of reduction in the height and proportion of the IG patches with grazing dairy cows, then we can say that, for Experiment 1, 2 and 3, the grazing management imposed significantly affected the utilisation of the IG patches and the whole heterogeneous sward ($P \leq 0.001$). Reduction in the proportion of IG patches within a sward was on average 10% by the end of the period in which the management was imposed. Height and mass of the IG patches were also significantly reduced on all experiments ($P \leq 0.001$). It was apparent that this increased utilisation was only achieved through an increased grazing pressure, reducing the SSH within the FG patches to heights of approximately 6 cm and below. Even in Experiment 3, when the morphology of the IG patch was modified through topping, the grazing cows did not utilise the patches to any greater extent until August, when the interaction of the FG SSH became evident. We can conclude that dairy cows, given the choice by providing sufficient herbage within the FG patches, will not efficiently utilise the IG patch.
Table 6.5 also indicates the greater utilisation potential for the whole sward when compared on a milk production and UME/ha if grazing pressure is increased for a short period of time. Therefore, grazing management is crucial in order to ensure efficient utilisation of a spatially heterogeneous sward.

6.6 STRATEGIES TO INCREASE THE UTILISATION OF HETEROGENEOUS SWARDS

6.6.1 Grazing pressure

Increasing the grazing pressure, either through increasing the stocking density or by reducing the herbage availability, has been shown to affect milk production on a per animal basis. Increasing the stocking rate by 1 cow/ha resulted in an average milk reduction per cow of 10% but an increase in production per hectare of 20%. A curvilinear relationship between stocking rate and production milk production per hectare has been confirmed (King & Stockdale, 1980). Coupled with a decline in individual animal production, liveweight can also be detrimentally affected. This is dependent on the severity of grazing pressure being applied as a result of increased stocking rate. King & Stockdale (1980) showed a loss of 22kg/cow at drying off when high stocking rate was applied, which may have a significant effect on the following lactation and fertility.

Increasing the grazing pressure increases the efficiency of herbage utilisation (proportion of herbage removed relative to that available). However, the challenge is to achieve optimal utilisation without over grazing and compromising total milk production per ha.

Utilisation of heterogeneous swards which are continuously stocked has been shown in this study to be increased through grazing pressure. The strategy to employ for greater utilisation of the whole sward, but in particular the IG patches, during mid season is to reduce the SSH of the FG area to at least 6 cm. This could be concentrated over a relatively short period of time by increasing the stocking rate, in order to reduce the detrimental effect of prolonged higher stocking rate and to minimise liveweight loss and reduced milk production. Over a period of 4 weeks, the sward can be better utilised with minimal reduction in milk yield or liveweight per animal, for cows in mid lactation. Output per hectare is unlikely to be affected. Grazing management recommendations to increase the SSH height to 8-10 cm for continuous stocking in mid-season will maintain individual animal performance. However, within a heterogeneous sward with under-utilised patches, this grazing management will result in a continued poor utilisation of the whole sward and the spatial heterogeneity will remain high.

6.6.2 Topping

Mechanical defoliation has been shown to be an effective tool within a rotational grazing system (Table 2.2) to control sward quality if grazing is lax and increase milk yield over non-topped laxly grazed swards (Bryant, 1982; Holmes & Hoogendorn, 1983; Dillon & Stakelum, 1988; Stakelum & Dillon, 1990). Sward improvements were variable, including increased leafiness and density and reduced tall grass areas of up to 13%, with animals grazing the tall grass areas sooner than untopped tall areas. Published literature involving topping and continuous stocking is much more limited. Fisher & Roberts (1995) report no effect on milk yield or sward quality when laxly grazed swards were topped once in mid season compared to lightly grazed swards. There are many questions unanswered in connection to a topping strategy – when to start; how frequently to carry it out; when to stop; what height to top?

The current study shows that topping within a continuous stocking system can enhance the morphology of the IG patches. Increasing the grazing pressure forces the cows to graze these patches, maintaining milk yield at lower intakes, thereby utilising the sward better. Topping every 4 weeks, however, did not reduce the area of the IG patches, despite the similar effect on sward morphology and quality of the IG patch as topping every 2 weeks. This could be due to the herbage mass and height of the IG patches topped every 2 weeks being reduced significantly ($P \leq 0.001$). Improved utilisation by grazing, observed with topping every 2 weeks but not every 4 weeks, may have been due to the much greater herbage mass and height of the latter requiring greater grazing pressure in order to observe a reduction in the proportion of IG patches within the sward. The optimum height of topping is 8 cm since lower topping may cause spread of the dung and greater contamination of the sward. The topping strategy within continuous stocking is to top from early season to a height of 8 cm at a frequency of every 4 weeks, if grazing pressure is sufficient to reduce the frequently grazed area to 6cm. Otherwise topping every 2 weeks together with maintaining approximately 7 cm

SSH for the frequently grazed areas would allow utilisation of the IG patches in a continuous stocking system.

Therefore, a combination of topping to enhance morphology and quality of the IG patch over the FG patch, coupled with a sufficiently high grazing pressure for a relatively short period of time is required to significantly utilise the IG patches of a heterogeneous sward. This should ultimately result in a reduction of IG patches in both sward proportion and height, together with an increased tiller density of these areas enabling better sward characteristics in late season. There should not be a detrimental effect on the milk production per hectare by this management strategy with minimal liveweight loss.

6.7 FUTURE RESEARCH OPPORTUNITIES

Most of the recent published work on grass utilisation through grazing has concentrated on rotational grazing. Although this system is increasing in importance with the need to be flexible and present swards in a state for maximum intake for high yielding cows, there is equally a substantial proportion of milk production being produced with continuous stocking. With this in mind, it is crucial that grazing management and utilisation continues to be investigated within continuous stocking systems.

Rotational grazing allows for high residual swards, remaining after high yielding cows have grazed without restricted intake, to be further reduced by dry cows, sheep, cutting or using a leader-follower grazing management. These strategies can help to reduce the heterogeneity of a sward and keep the IG patches to a minimal level. Under continuous stocking the flexibility of management is more difficult and therefore requires further research efforts as to the grazing management required to minimise the heterogeneity of a sward through frequently and infrequently grazed patches. Decision support models to allow a prediction of management on the patchiness of a sward, and ultimately utilisation, would allow for more efficient production of milk from grazed grass. The data provided here for the relationship between FG and IG height and proportion could be a starting point to develop a model to predict utilisation of grazed grass within a spatial heterogeneous sward under continuous stocking.

There has been substantial work published on the foraging strategies and grazing behaviour involved with patchy grassland (Illius *et al.*, 1987; Wallis de Vries, 1994; Ginnet *et al.*, 1999). This has tended to involve hand constructed or artificial swards for modelling purposes. Height heterogeneity has been explored and also effect of maturity of herbage associated with height (Wallis de Vries, 1994; Ginnet *et al.*, 1999). However, there have been no detailed studies of height heterogeneity associated with dung contamination. Work has concentrated on grazing behaviour with sheep and the trade-off between grazing faecal contaminated herbage and intake. Grazing behaviour of dairy cows has been studied in terms of ingestive behaviour using automatic behaviour recorders, which should be further researched as to the location in the sward and its associated ingestive behaviour. The use of an active transponder system, as described by Swain *et al.* (2003), together with behaviour recorders as described by Rutter *et al.* (1997), would allow for much greater understanding of the selective grazing behaviour associated with faecal contaminated induced spatial heterogeneous swards. Combining this approach with a marker technique to estimate intake from the different patches would allow for estimation of the utilisation of patches and the interaction of this with grazing management. Spraying different n-alkanes onto patches would allow for more accurate estimate of diet composition, as opposed to relying on the natural variation within heterogeneous swards, as used in the experiments of this study.

If there was a greater understanding of the plant-animal interactions involved with faecal contaminated patches this would allow for research into management which could alter the sward characteristics of these patches and increase their utilisation.

Topping is just one strategy which can be a useful tool in altering patch morphology. Experiment 3 has shown this to an extent, however, there are more questions to be answered on frequency, timing and height of topping. Published work on topping generally is limited, especially within continuous stocking and needs to be addressed properly if this is to be used correctly to improve grass utilisation. Currently, farmers use topping as a means to remove unsightly flower heads within the sward and is seen as a measure to correct poor grazing management. This latter assumption is incorrect. There is a need to obtain more detail at a component level to fully understand the effect of various topping aspects on sward morphology and the interaction with the grazing animal. Topping should be a tool for tactical use to improve grassland management not to correct or remove the evidence of improper grassland management.

System studies need to be conducted in order to evaluate the effect of these strategies to increase the utilisation of the heterogeneous sward on milk production.

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APPENDICES

Appendix 1: Weather Data

1997 Weather data: Experiment 1

1997			
Week Beginning	Experiment Week	Average max. Temp (°C)	Total weekly Rainfall (mm)
30-Jun	-2	16.3	12.3
07-Jul	-1	20.9	1.5
14-Jul	0	19.6	3.1
21-Jul	1	20.2	30.5
28-Jul	2	17.7	17.4
04-Aug	3	23.6	1.6
11-Aug	4	23.2	1.6
18-Aug	5	20.8	11.1
25-Aug	-	18.9	26.9

1998 Weather data : Experiment 3

1998			
Week beginning	Experiment week	Average max. Temp (°C)	Total weekly rainfall (mm)
01-Jun	1	14.9	4.2
08-Jun	2	14.3	23.9
15-Jun	3	18	16.2
22-Jun	4	17.2	20.4
29-Jun	5	16.7	2.7
06-Jul	6	15.7	38.8
13-Jul	7	16.5	36
20-Jul	8	17	25.2
27-Jul	9	17.4	30.6
03-Aug	10	18	30
10-Aug	11	18.3	25.2
17-Aug	12	15.7	34
24-Aug	13	16.3	2.9
31-Aug	14	15.3	23.1

1999 Weather Data: Experiment 2

1999			
Week beginning	Experiment week	Average max. Temp (°C)	Total weekly Rainfall (mm)
14-Jun	-2	16.8	31.3
21-Jun	-1	17.9	27.5
28-Jun	0	17.4	11.2
05-Jul	1	22	0.2
12-Jul	2	17.5	28.6
19-Jul	3	17.1	17.1
26-Jul	4	22.2	2.1

Appendix 2: Contour maps of the infrequently grazed areas within Experiment 1, using Mapinfo Software

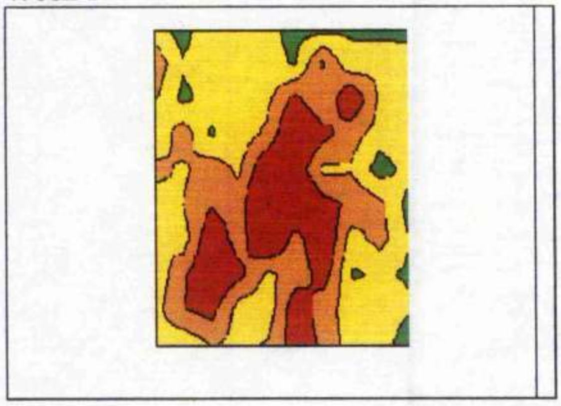
Contour map legend

Blue = height range 0-5 cm
Green = height range >5 – 10 cm
Yellow = height range >10 -15 cm
Orange = height range >15 –20 cm
Red = height range > 20 cm

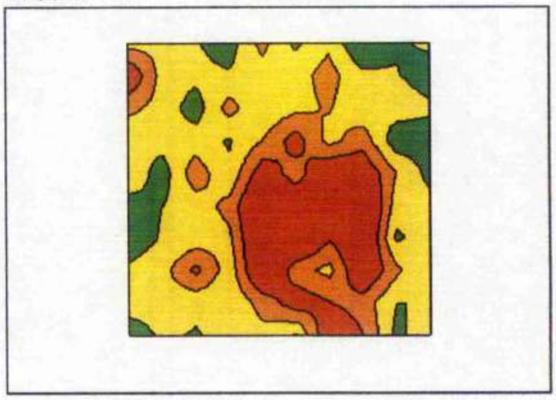
PLOT 1 (Treatment HP, Rep 1)

Quadrat 2

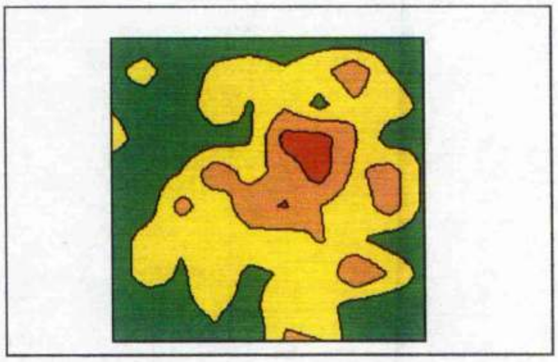
Week 0



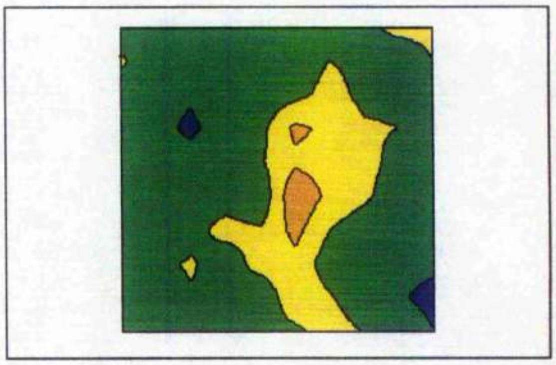
Week1



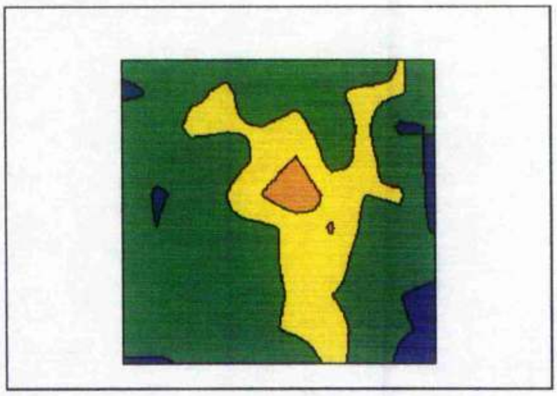
Week 2



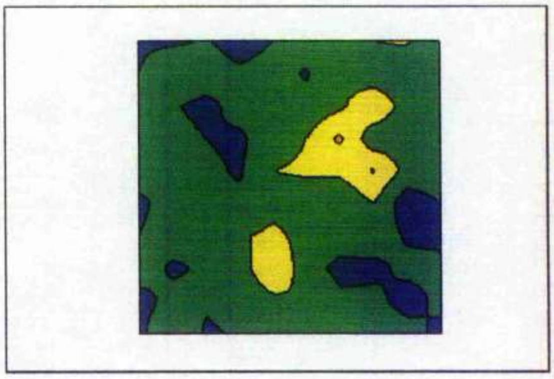
Week 3



Week 4

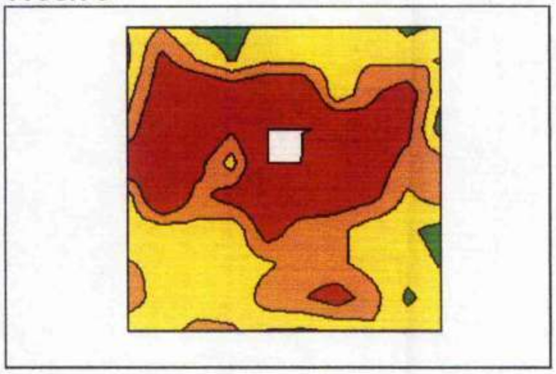


Week 5

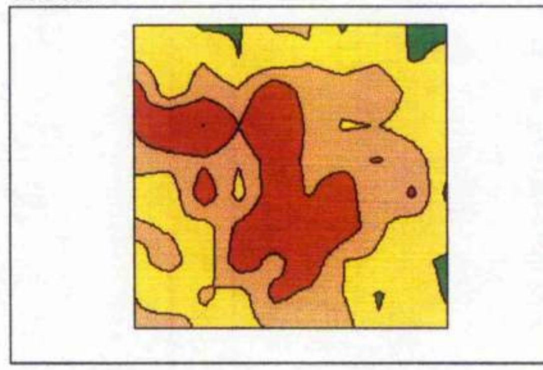


PLOT 1 (Treatment HP, Rep 1)
Quadrat 3

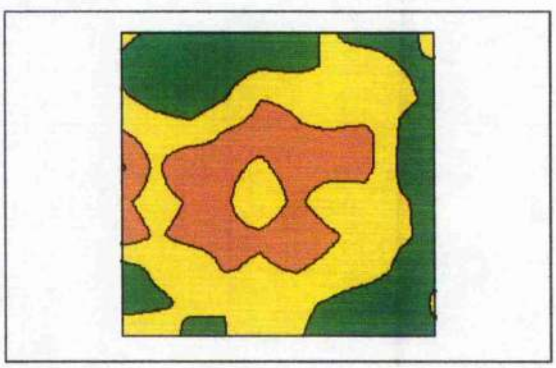
Week 0



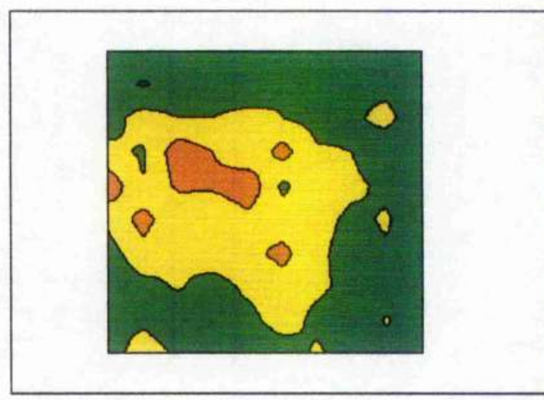
Week1



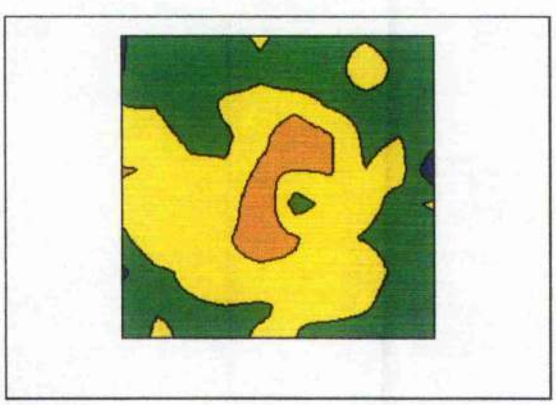
Week 2



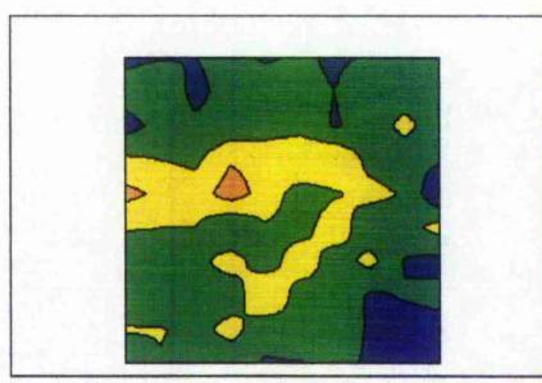
Week 3



Week 4



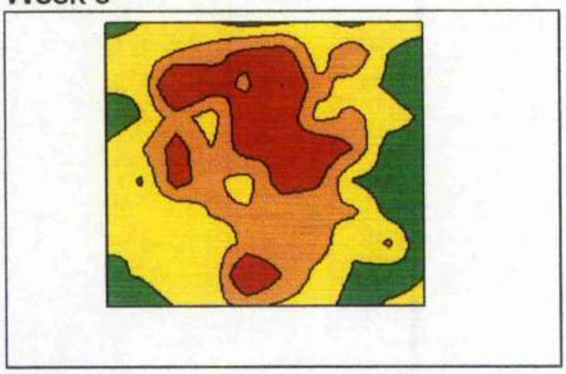
Week 5



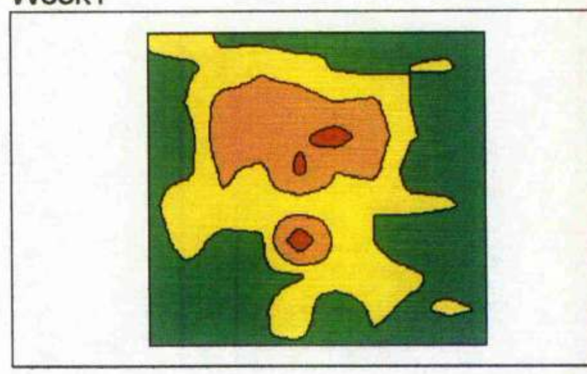
PLOT 2 (Treatment MP, Rep 1)

Quadrat 1

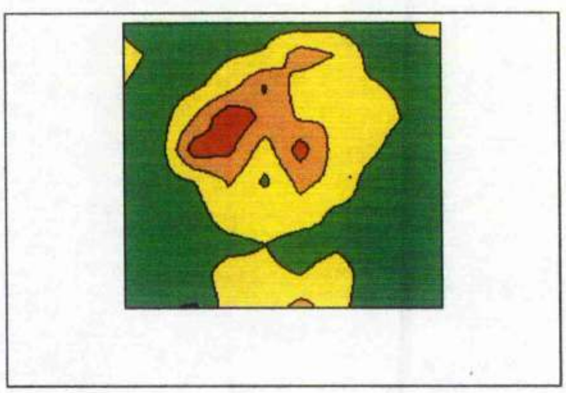
Week 0



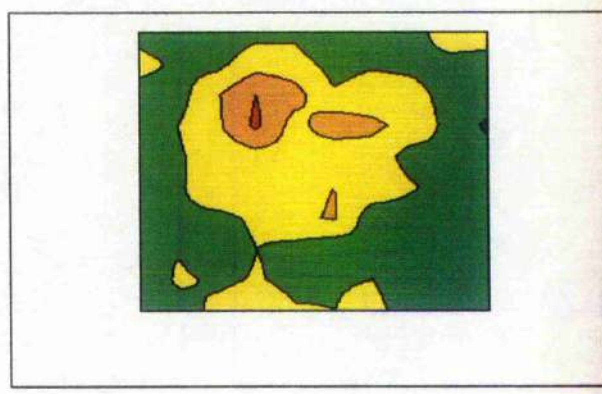
Week1



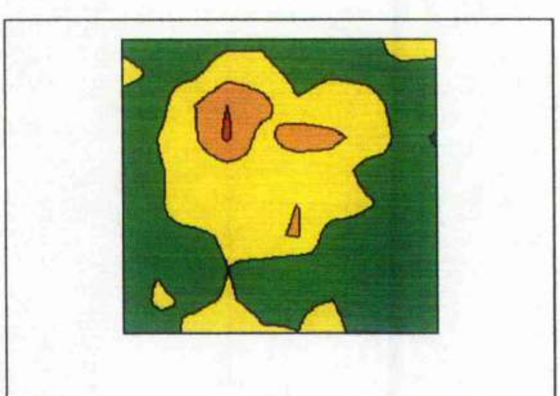
Week 2



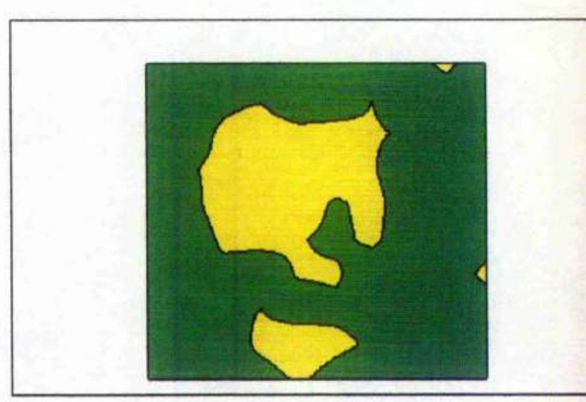
Week 3



Week 4

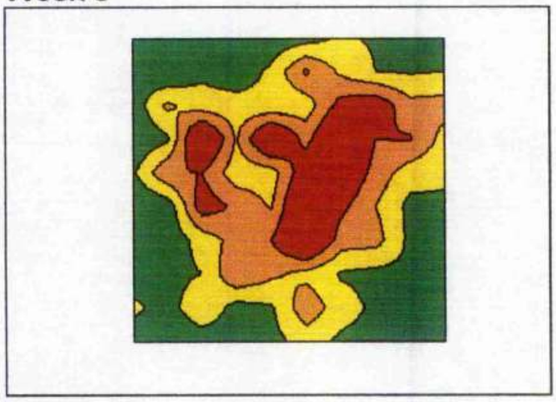


Week 5

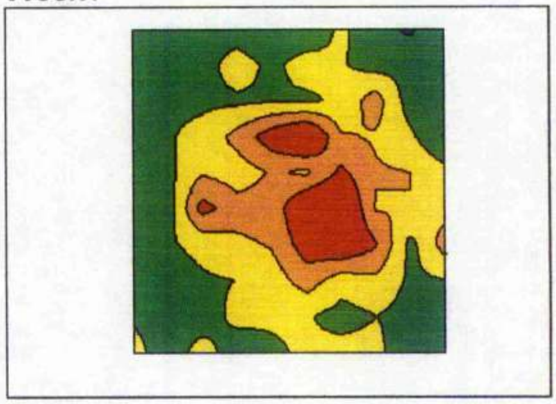


PLOT 2 (Treatment MP, Rep 1)
Quadrat 2

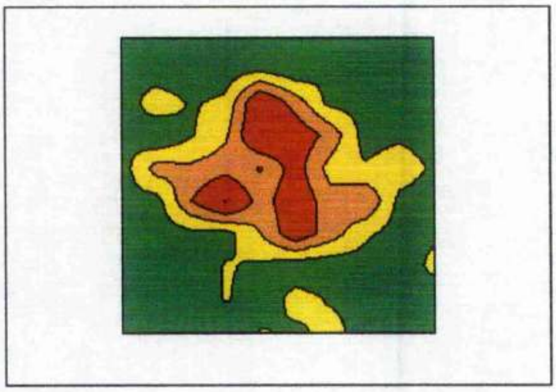
Week 0



Week1



Week 2



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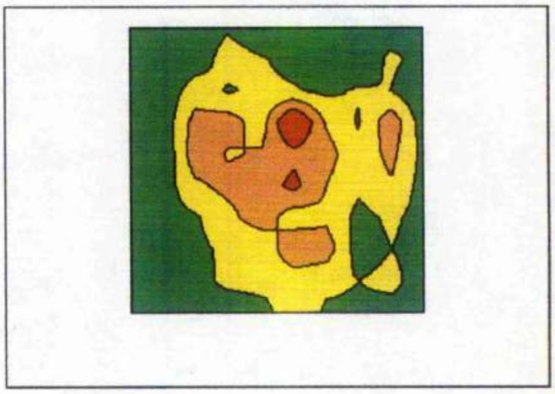

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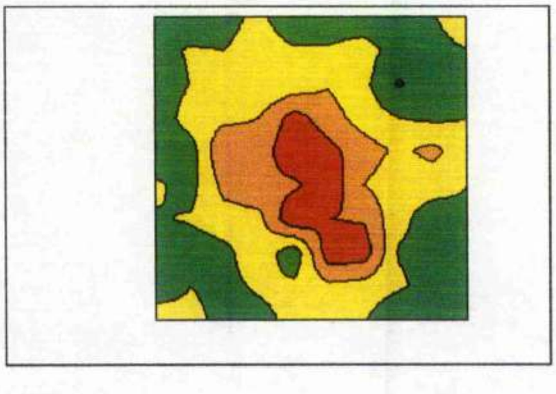
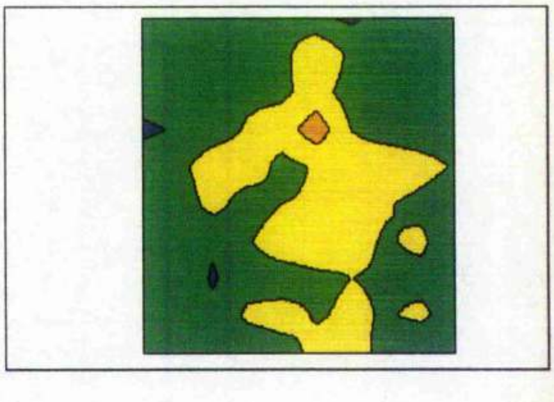
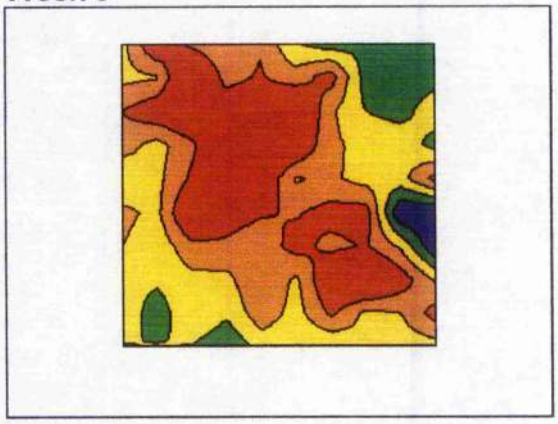


Week 5

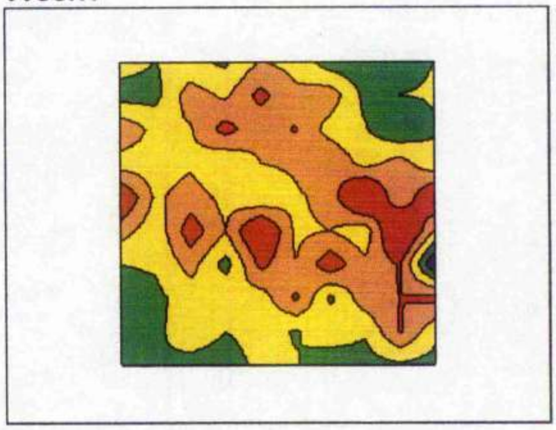


PLOT 2 (Treatment MP, Rep 1)
Quadrat 3

Week 0



Week1



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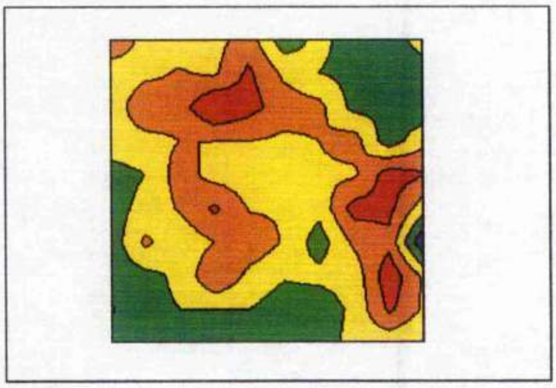
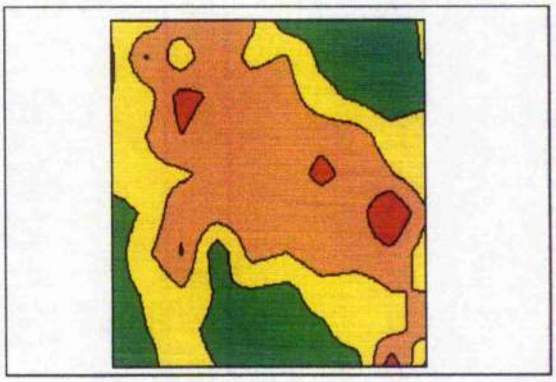


Week 3



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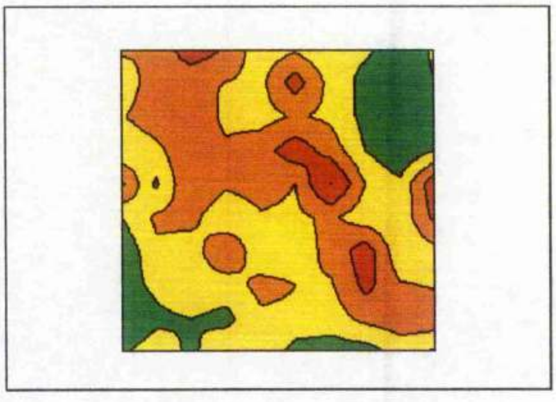
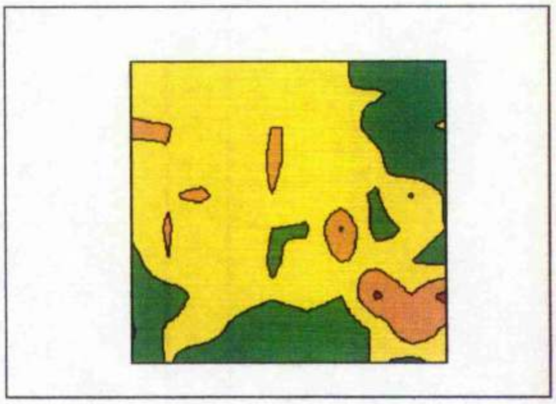
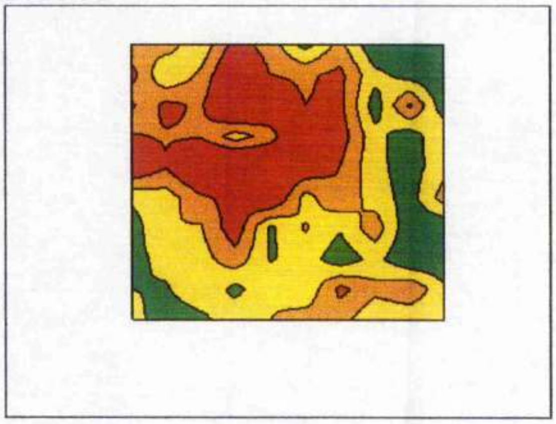


Week 5

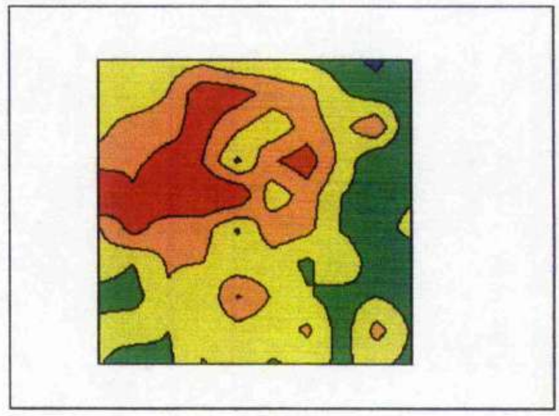


PLOT 3 (Treatment MP, Rep 2)
Quadrat 1

Week 0



Week1



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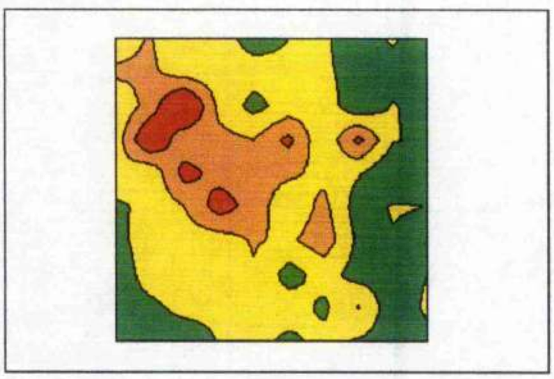
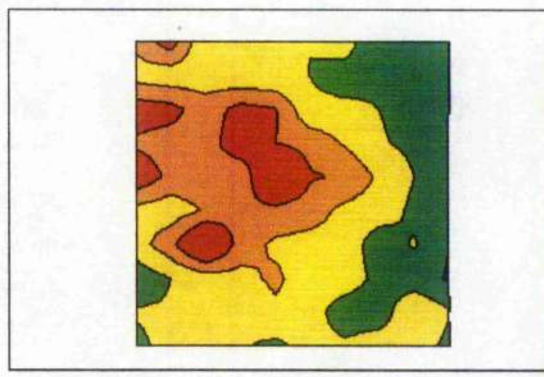


Week 3



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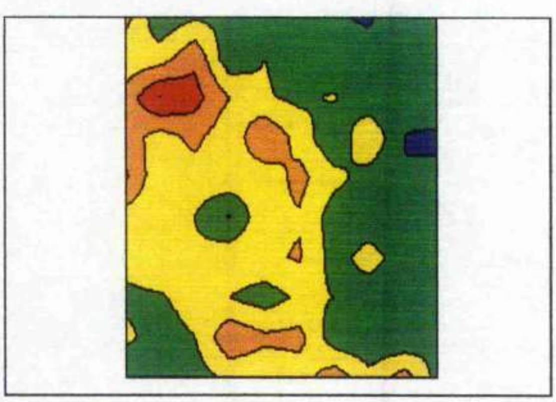

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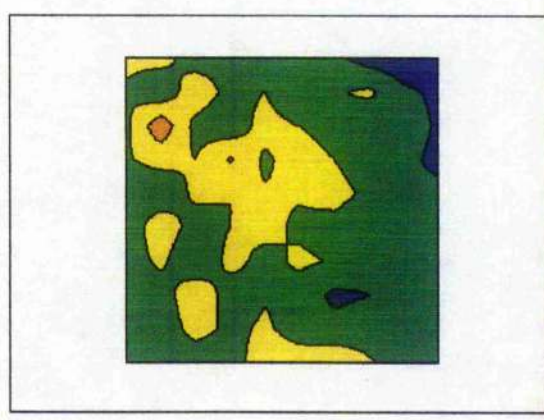
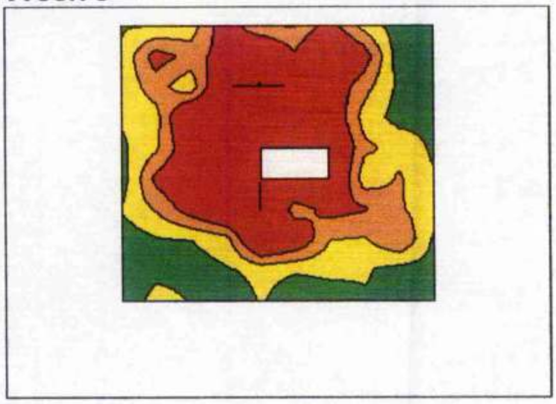
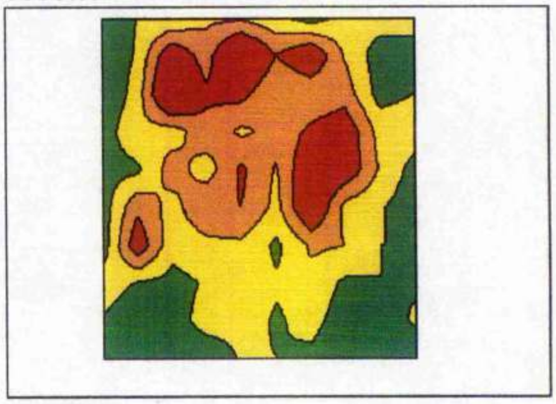


PLOT 3 (Treatment MP, Rep 2)
Quadrat 2

Week 0



Week1



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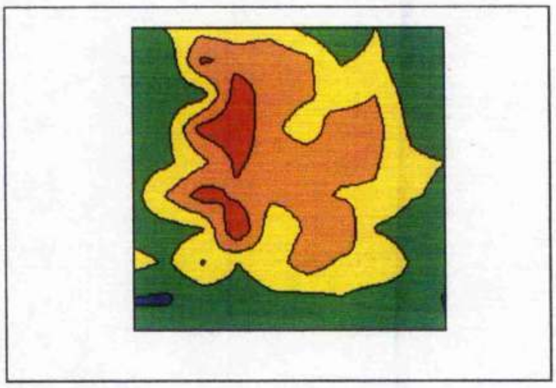

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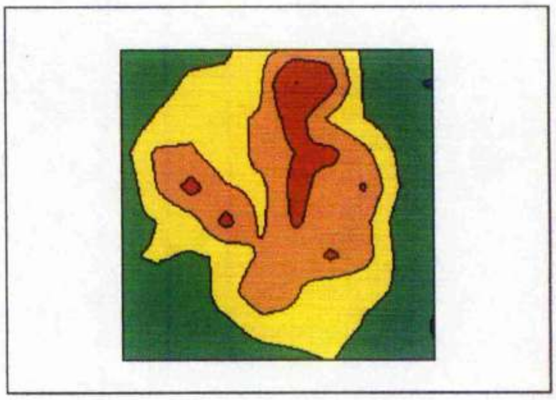

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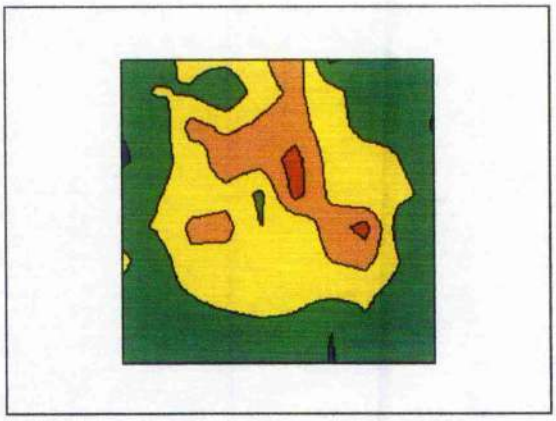
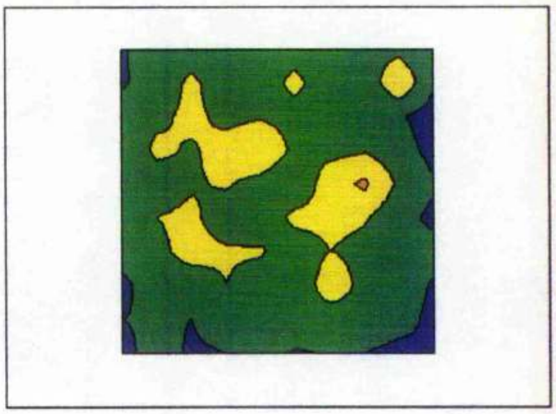
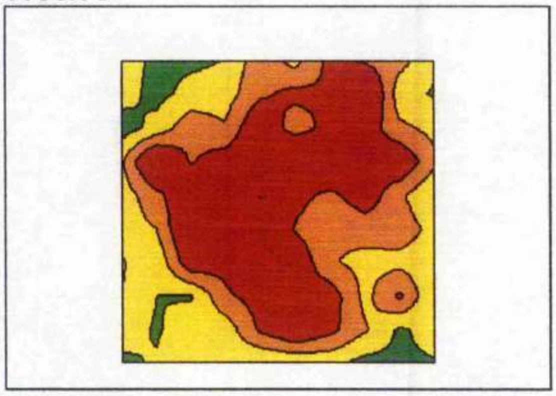


Week 5

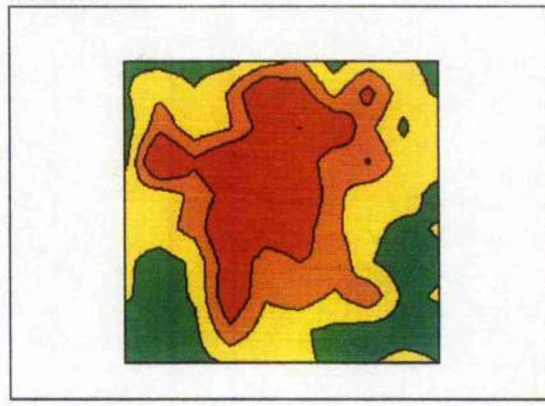


PLOT 3 (Treatment MP, Rep 2)
Quadrat 3

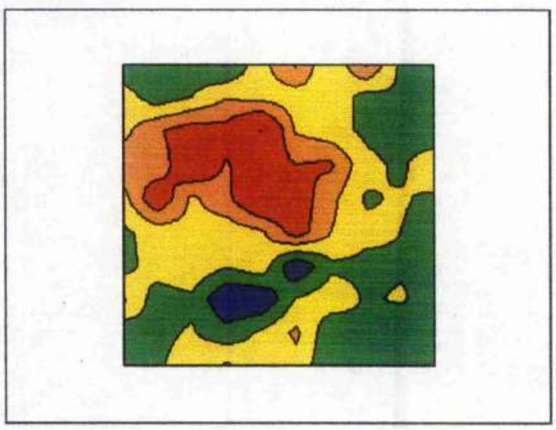
Week 0



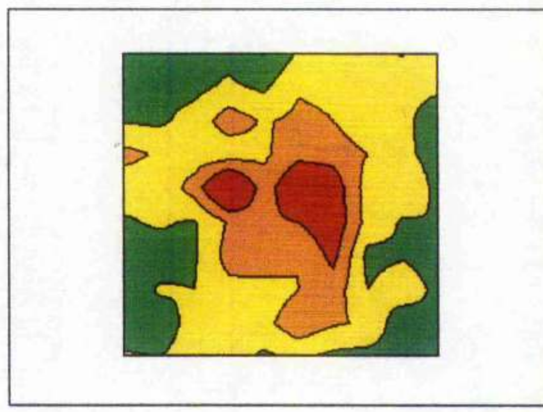
Week1



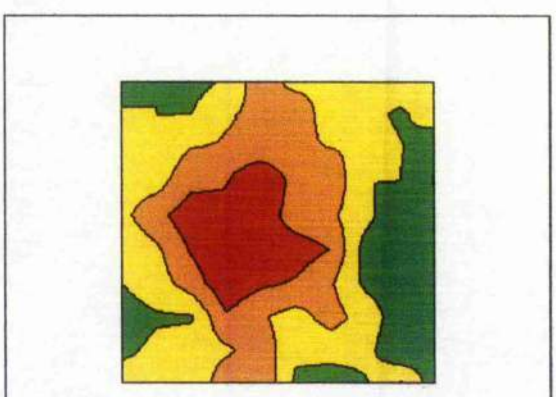
Week 2



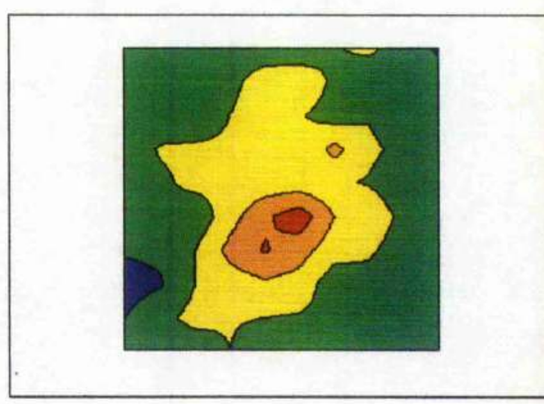
Week 3



Week 4

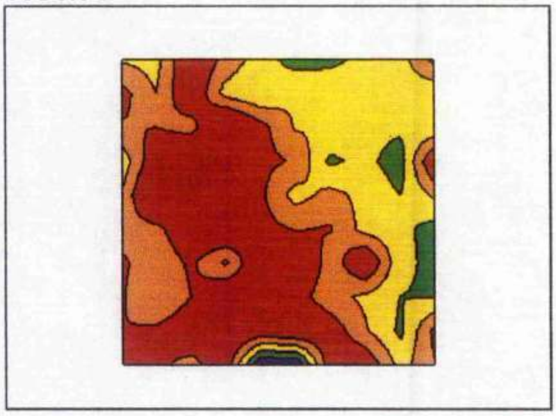


Week 5

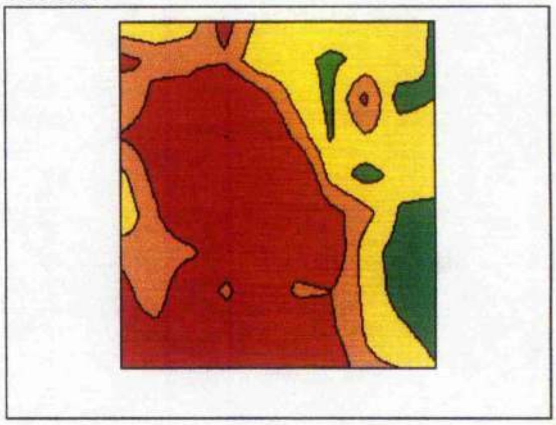


PLOT 4 (Treatment MP, Rep 3)
Quadrat 1

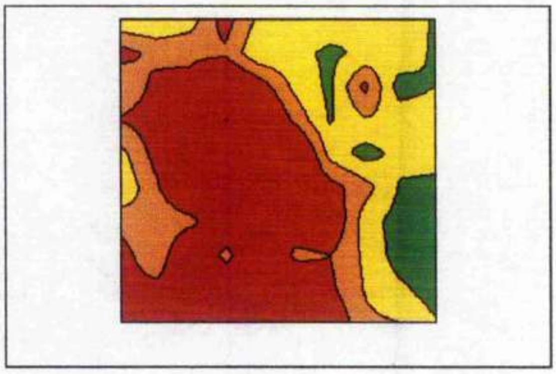
Week 0



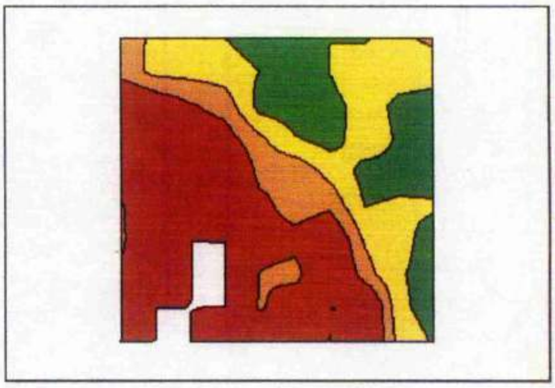
Week1



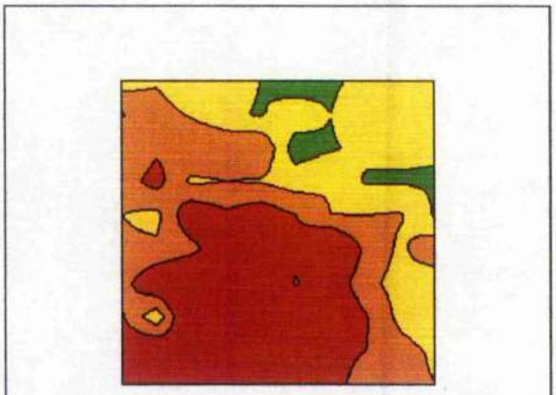
Week 2



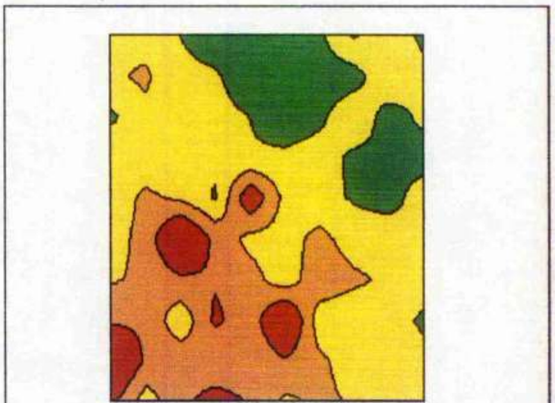
Week 3



Week 4

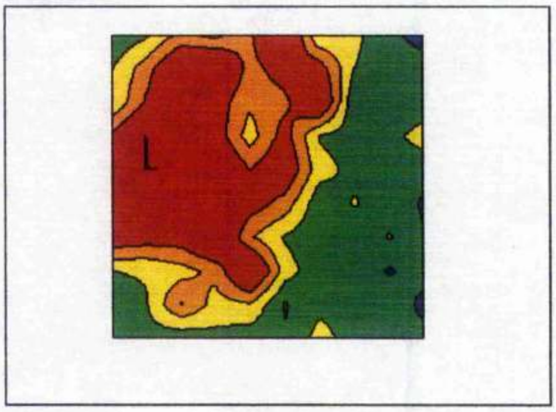


Week 5

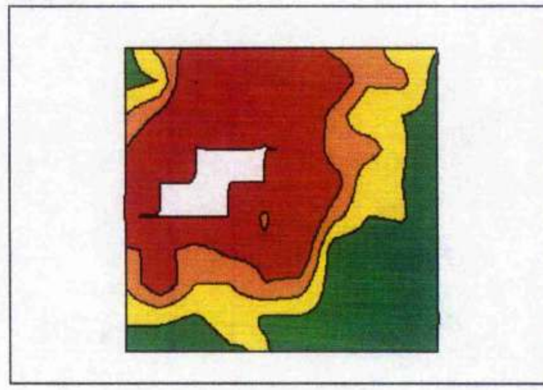


PLOT 4 (Treatment MP, Rep 3)
Quadrat 2

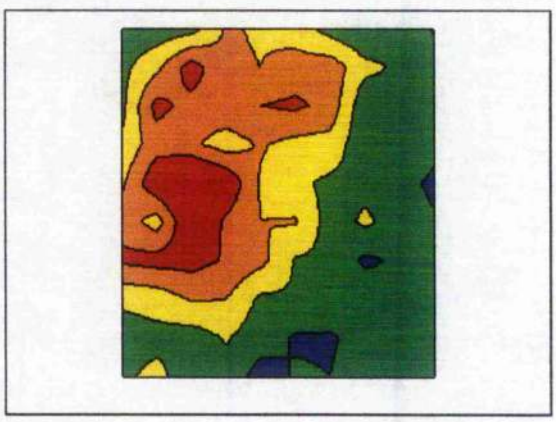
Week 0



Week1

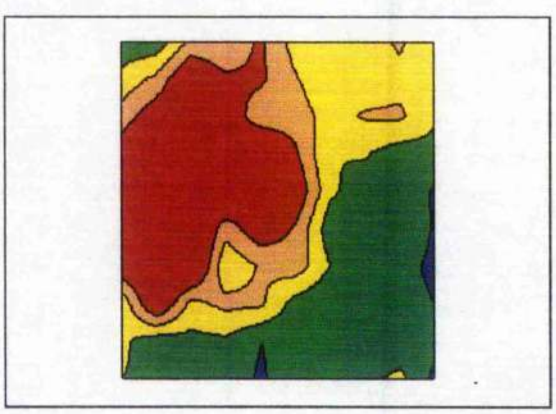


Week 2

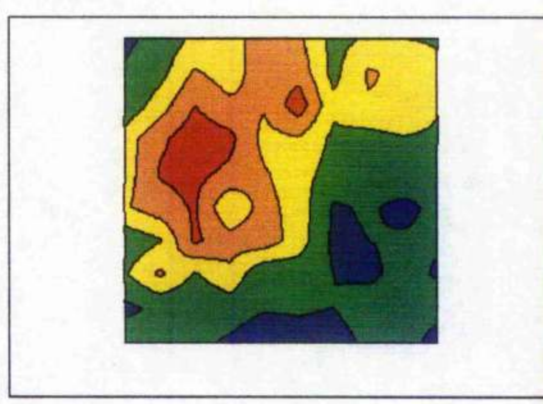


Week 3

Week 4

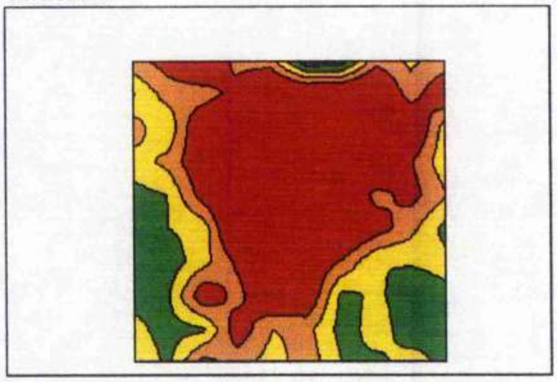


Week 5

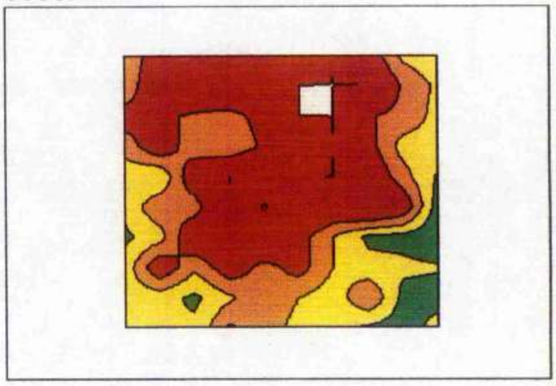


PLOT 4 (Treatment MP, Rep 3)
Quadrat 3

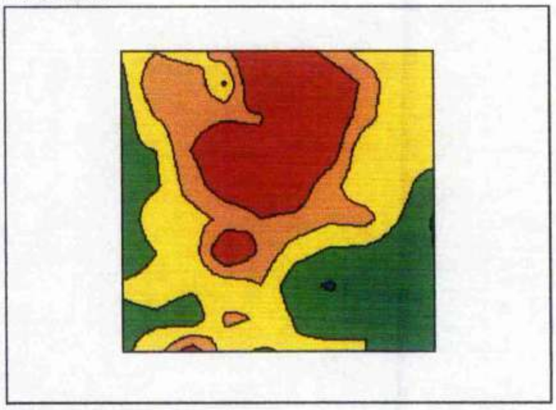
Week 0



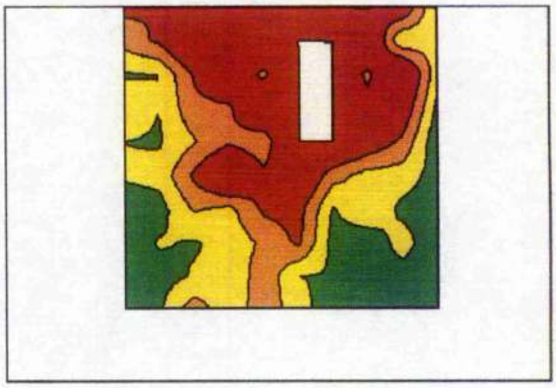
Week1



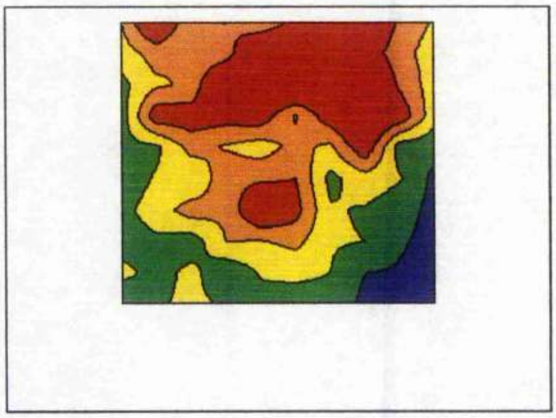
Week 2



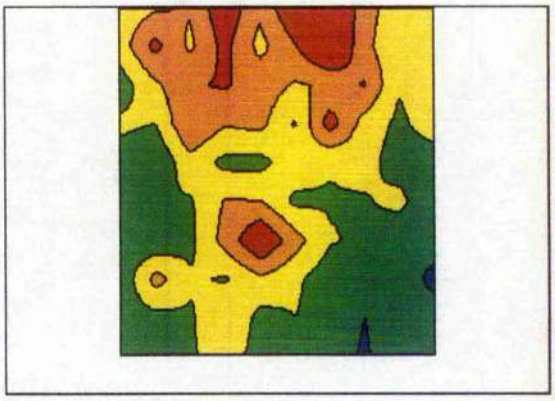
Week 3



Week 4



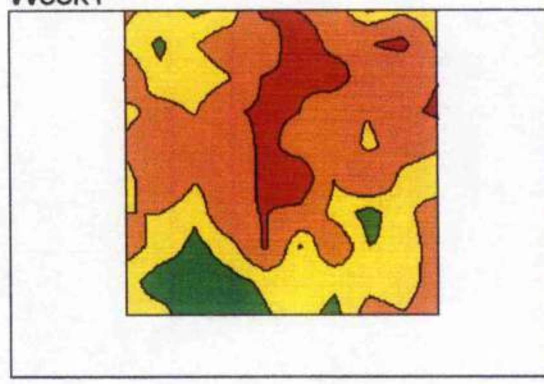
Week 5



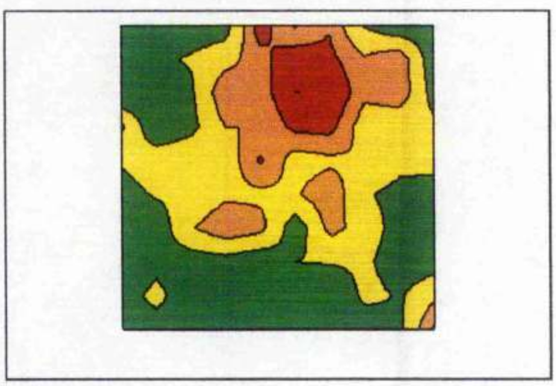
PLOT 5 (Treatment HP, Rep 2)
Quadrat 1

Week 0

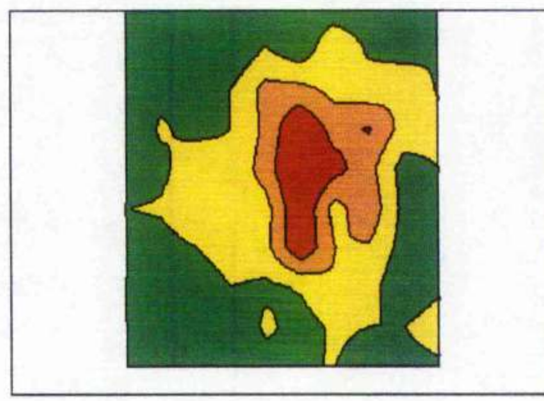
Week1



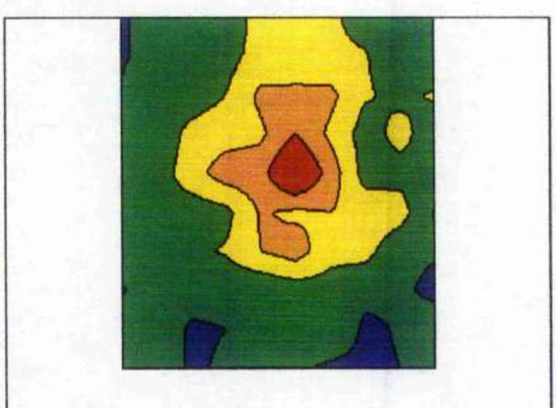
Week 2



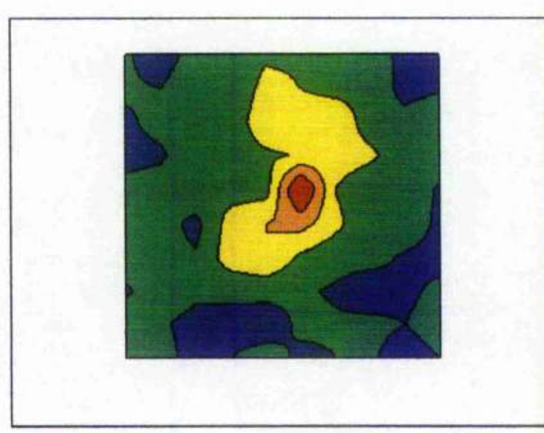
Week 3



Week 4



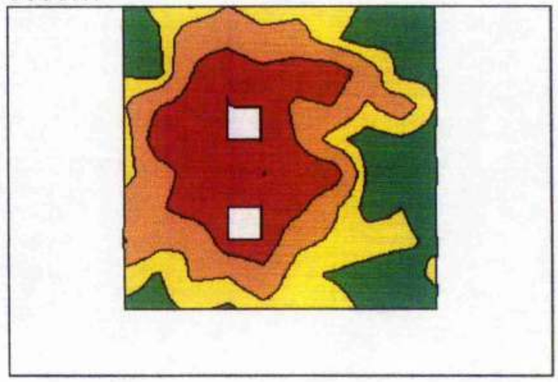
Week 5



PLOT 5 (Treatment HP, Rep 2)
Quadrat 2

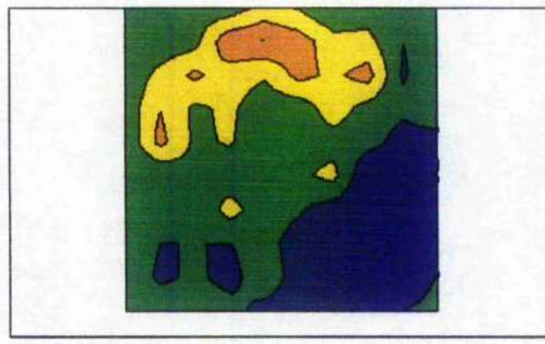
Week 0

Week1

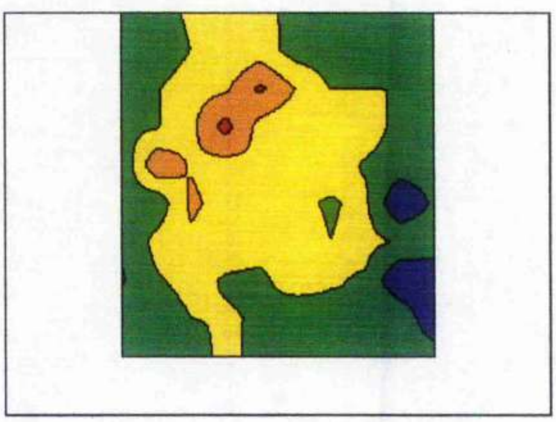


Week 2

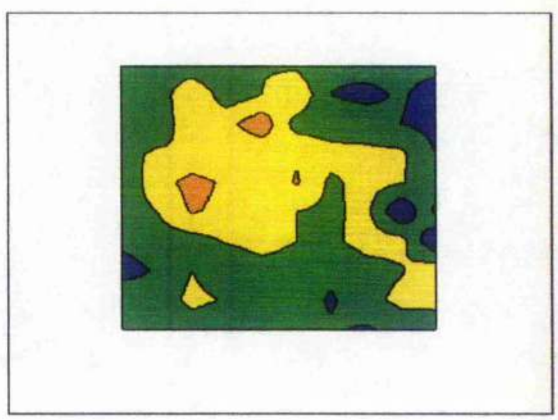
Week 3



Week 4

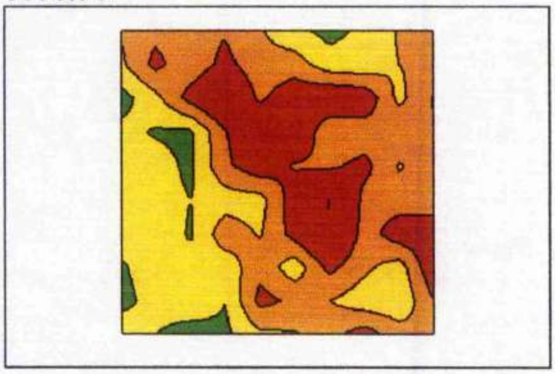


Week 5

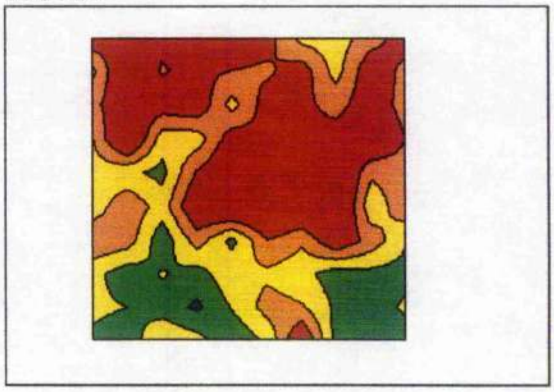


PLOT 5 (Treatment HP, Rep 2)
Quadrat 3

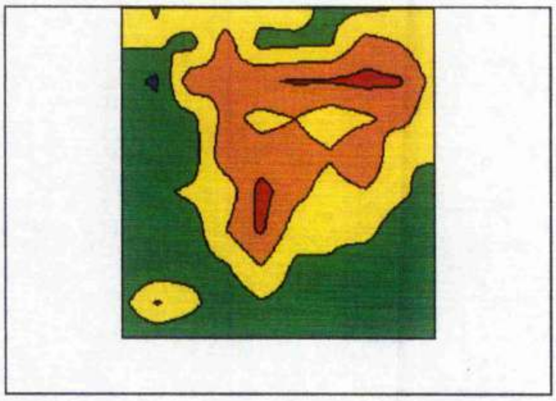
Week 0



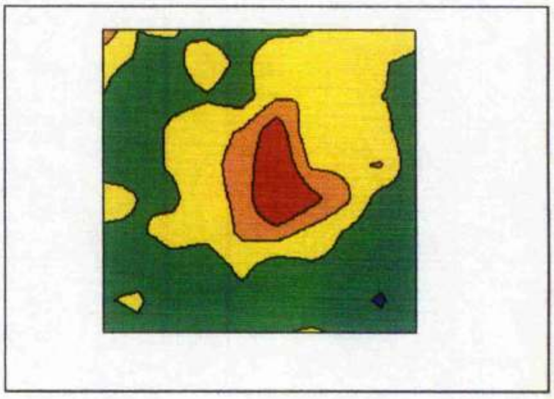
Week1



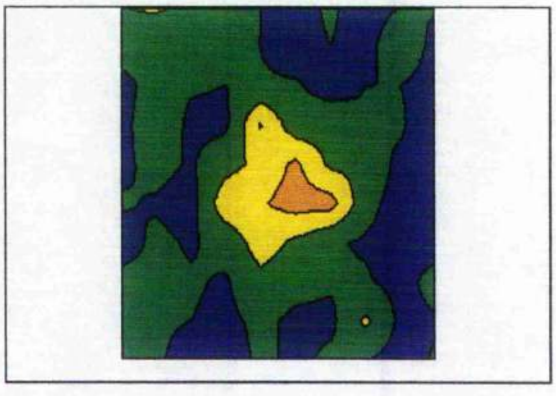
Week 2



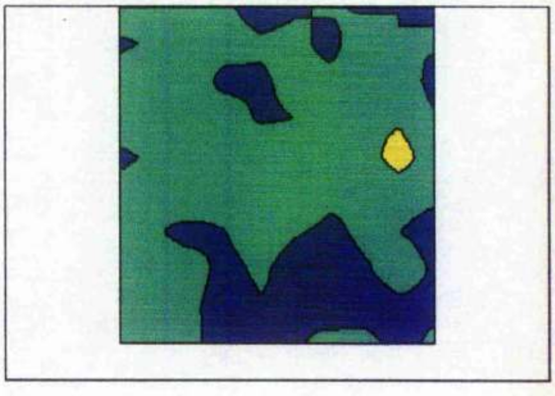
Week 3



Week 4

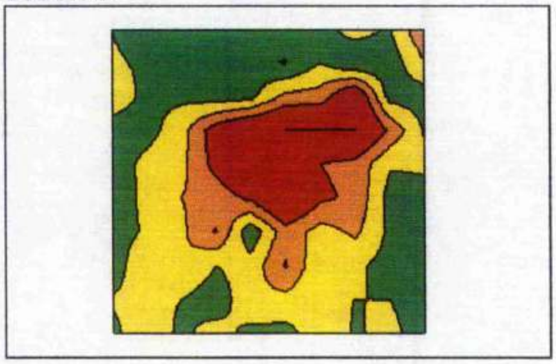


Week 5

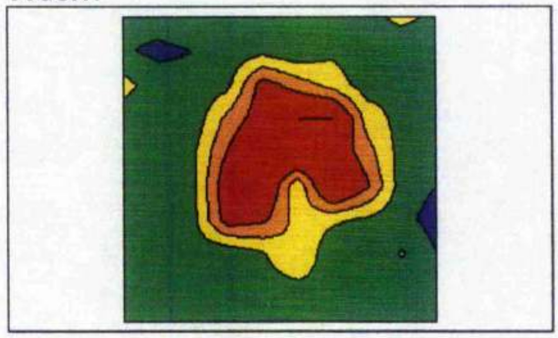


PLOT 6 (Treatment HP, Rep 3)
Quadrat 1

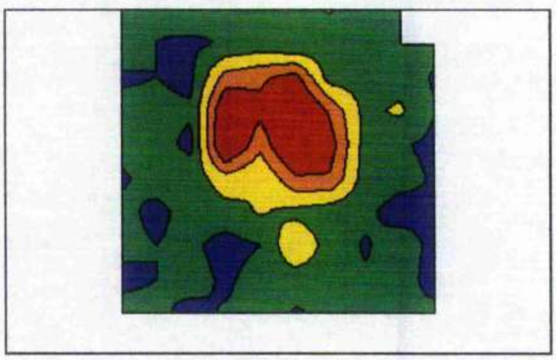
Week 0



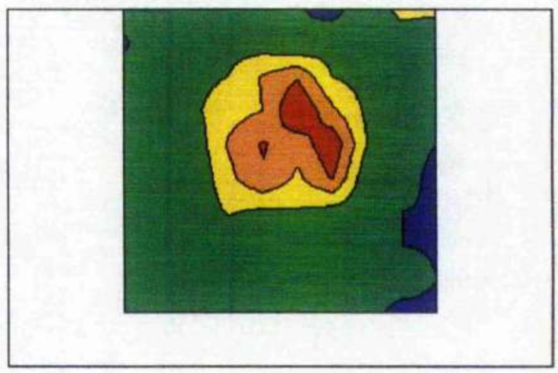
Week1



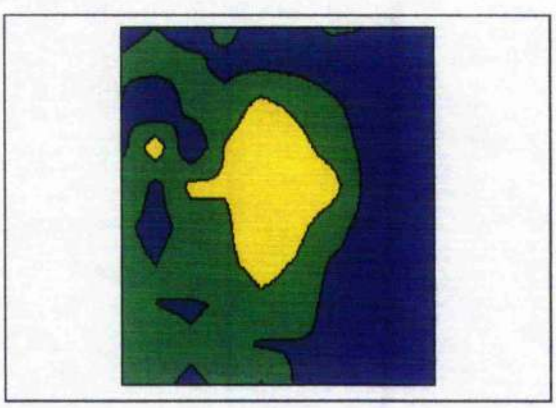
Week 2



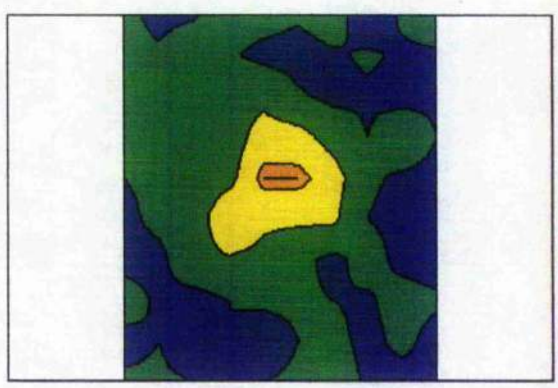
Week 3



Week 4

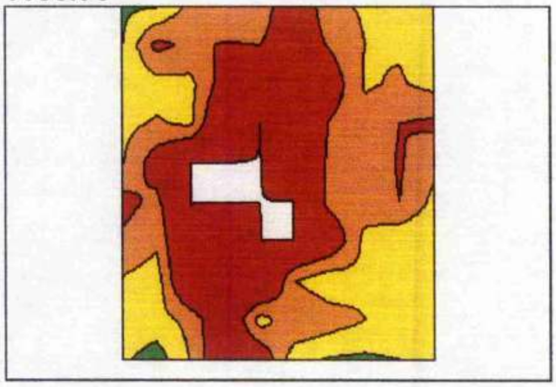


Week 5

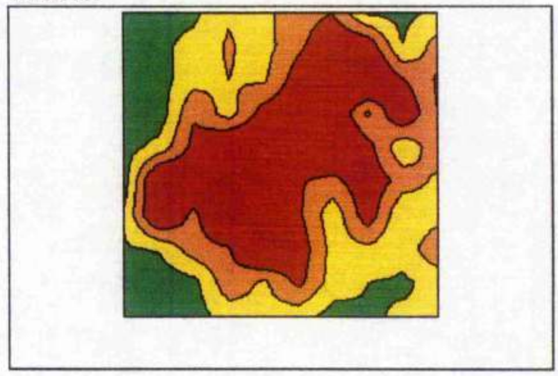


PLOT 6 (Treatment HP, Rep 3)
Quadrat 2

Week 0



Week1



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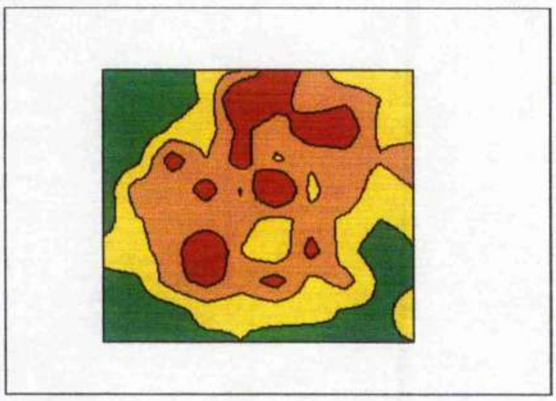
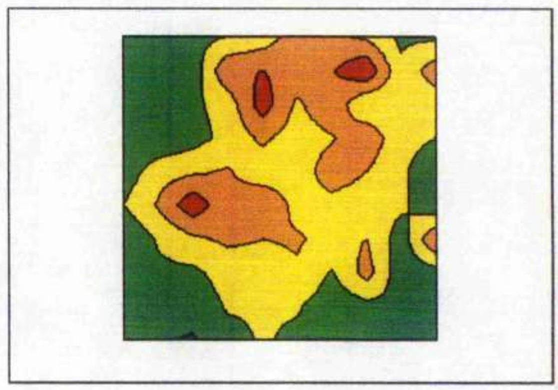


Week 3



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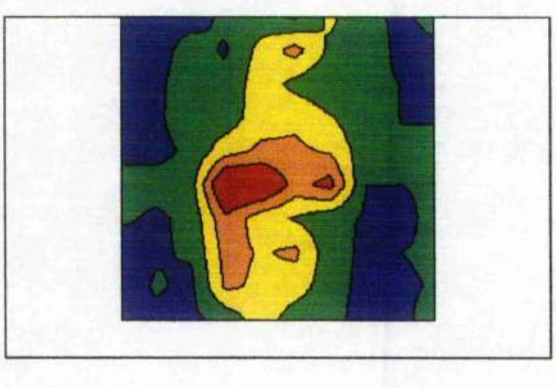
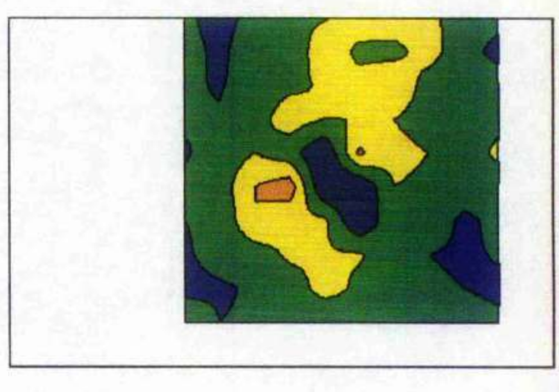
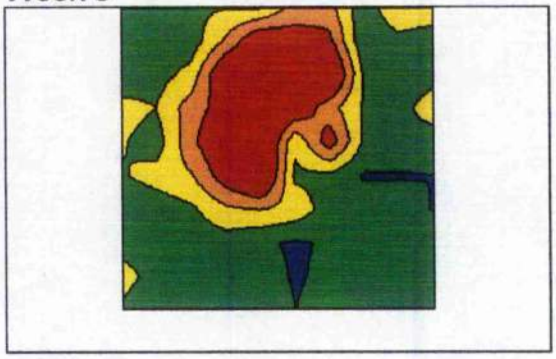


Week 5

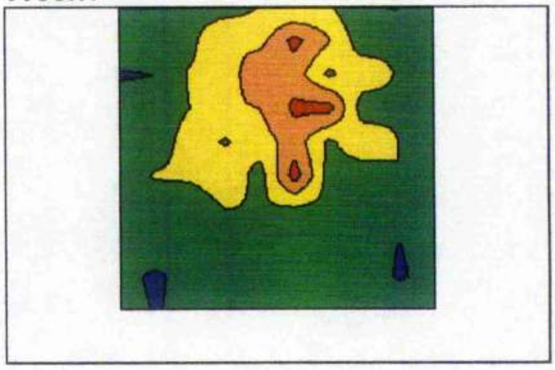


PLOT 6 (Treatment HP, Rep 3)
Quadrat 3

Week 0



Week1



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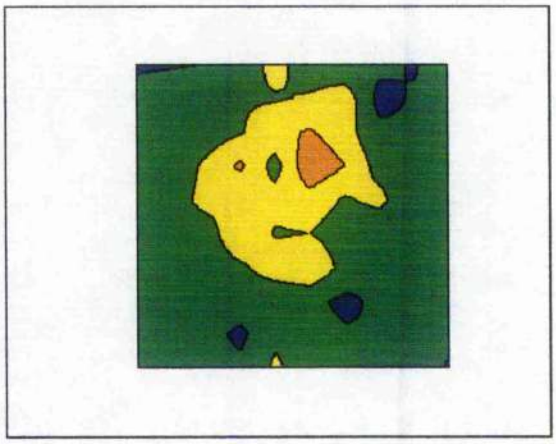

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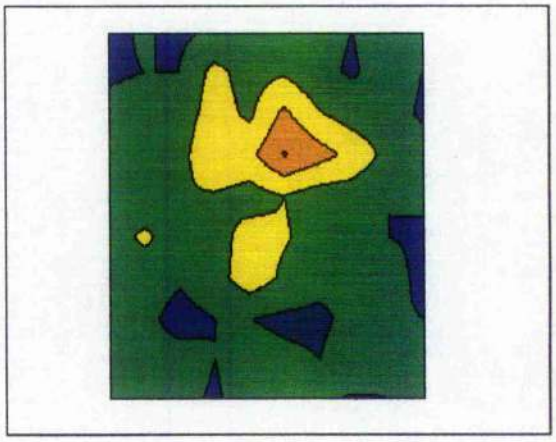
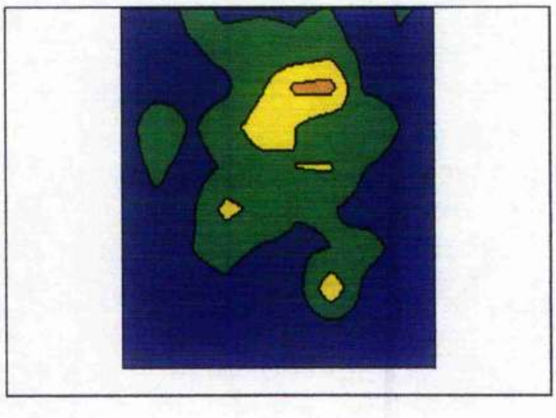
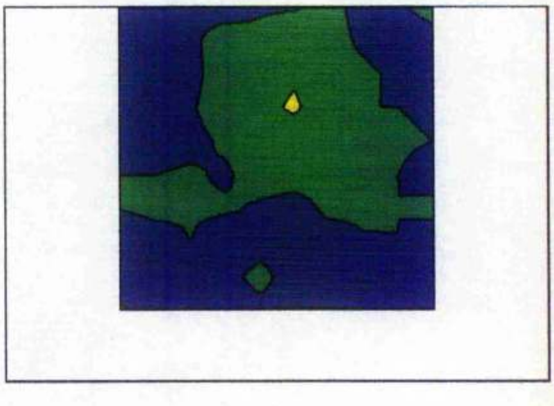


Week 4



Week 5



Appendix 3. Chemical analysis (by Near Infra-Red Spectroscopy) of infrequently grazed patches within swards at the beginning and end of the experimental period for Experiment 2

	Treatment	Week 1	Week 4
ME MJ/kgdm	6	10.5	10.3
	8	10.3	10.2
	10	10.5	10.3
	s.e.d / *P*	0.17 ns	0.3 ns
D-Value %	6	70	68
	8	68.7	68
	10	70	68
	s.e.d / *P*	1.2 ns	0.5 ns
NDF g/kgdm	6	562	546
	8	576	590
	10	575	546
	s.e.d / *P*	11.5 ns	8.9 **
CP g/kgdm	6	150.7	111
	8	165.3	113
	10	140.0	117
	s.e.d / *P*	17.2 ns	34.3 ns
WSC g/kgdm	6	98.3	134.0
	8	73.0	111.0
	10	94.0	123.0
	s.e.d / *P*	12.1 ns	44.9 ns

**=$P \leq 0.01$, ns = non significant

Appendix 4: Fat composition of milk (g kg^{-1}) for Experiment 2

Week	TREATMENT			P at week	P accumulated up to week
	6	8	10		
1	45.7	39.4	39.8	ns	ns
2	39.6	36.7	40.0	ns	ns
3	39.6	36.9	37.6	ns	ns
4	38.8	38.3	38.2	ns	ns

ns = non significant

Appendix 5: Protein composition of milk (g kg^{-1}) for Experiment 2

Week	TREATMENT			P at week	P accumulated up to week
	6	8	10		
1	32.7	31.3	31.8	ns	ns
2	31.4	31.5	31.3	ns	ns
3	31.0	30.9	31.6	ns	ns
4	30.7	31.4	31.5	ns	ns

ns = non significant

Appendix 6: Lactose composition of milk (g kg^{-1}) for Experiment 2

Week	TREATMENT			P at week	P accumulated up to week
	6	8	10		
1	45.9	44.7	44.7	ns	ns
2	45.3	45.3	45.0	ns	ns
3	45.3	44.7	45.0	ns	ns
4	44.5	44.6	44.7	ns	ns

ns = non significant

Appendix 7: Live weight (kg) and Condition score (1-5 scale, 1= poorest) for Experiment 2

	Live weight					Condition score				
	Treatment					Treatment				
Week	6	8	10	*P* *At week*	*P* *up to week*	6	8	10	*P* *at week*	*P* *up to week*
1	580	585	585	ns	ns	2.45	2.45	2.30	ns	ns
2	573	582	580	ns	ns	2.40	2.20	2.20	ns	ns
3	576	584	574	ns	ns	2.2	2.2	2.1	ns	ns
4	580	595	589	ns	ns	2.25	2.10	2.10	ns	ns

ns = non significant