The effect of pre-mowing pasture on milk, pasture, and nitrogen partitioning of dairy cows in the autumn

---

A dissertation

submitted in partial fulfilment

of the requirements for the Degree of

Bachelor of Agricultural Science with Honours

at

Lincoln University

by

Larissa Ashleigh Kingsbury

Lincoln University

2014

Abstract of a dissertation submitted in partial fulfilment of the requirements

for the Degree of Bachelor of Agricultural Science with Honours

The effect of pre-mowing pasture on milk, pasture, and nitrogen partitioning of dairy cows in the autumn

By

Larissa Ashleigh Kingsbury

The effect of pre mowing on pastures of high or low mass was investigated to determine whether herbage quality, intake, milk yield and nitrogen use efficiency (NUE) of dairy cows could be increased. The experiment was carried out using tetraploid perennial ryegrass and white clover pastures in autumn at the Lincoln University Research Dairy Farm. Forty eight lactating, pregnant, spring calving Friesian x Jersey cows were used. A 2 x 2 non-replicated factorial design was used to explore the effect of high (HM, 2800 kg DM/ha) versus low (LM, 2200 kg DM/ha) mass on standing (S) versus pre mown (P) pasture. Pastures prepared by manipulating regrowth interval or mowing had little effect on the chemical composition of the herbage of offer. However pre-mowing 3 hours ahead of grazing increased the proportion of neutral and acid detergent fibre (NDF, ADF) and reduced water soluble carbohydrate (WSC) in the diet. Increasing pasture mass increased the proportion of WSC in the diet. In pre-mown treatments the apparent DMI was reduced by 1.4 kg DM/cow/day and 1.2 kg DM/cow/day for low and high pastures, respectively. The daily milk yield was lower ($P < 0.001$) in P compared with S treatments and lower ($P = 0.003$) at HM compared with LM treatments. There was a tendency for lower milk protein yield in the P compared with S treatments ($P<0.10$). While herbage remained digestible after mowing, the increase in crude fibre in P treatments may have reduced rate of energy availability to rumen microbes resulting in reduced microbial protein synthesis. There were interactions between pasture mass and mowing on grazing behaviour. On S pastures cows spent similar amounts of time grazing during the first 6 hours after feeding while P reduced time grazing at LM compared with HM. The N intake was not significantly affected by pasture mass, this resulted in the NUE values being very similar between treatments. When offered the same allowance of herbage, pre-mowing did not improve dairy cow performance. It is likely that loss of DM occurred following mowing – reducing the availability of the diet allowance on pre-mown treatments. The benefits of pre-mowing may be to increase dry matter intake through shifting cows to a new pasture allocation and enabling a higher allowance to be offered.

Keywords: defoliation, diet, tetraploid, *Lolium perenne*, synchrony, manipulation, urine N, utilisation

Acknowledgements

I would like to extent my gratitude to my supervisor Doctor Racheal Bryant, for her guidance, and constructive criticism throughout my course of study. I would like to further extend my appreciation and gratitude to the members of Lincoln university staff and students that went out of their way to help in the completion of my study of which include: Helen Hague, Adam Caldwell, Sam Harvey, Josh Norton, Simon Chamberlain, Rob Fraser, Rebekah Brosnahan, Emma McDonald, Aimee Kingsbury, Aimi Hussein, Kurt Engelbrecht, Jonathon and Jeff Curtis.

Table of Contents

List of tables

List of figures

List of plates

1 Introduction

The New Zealand dairy system is primarily pasture based, where pasture growth is seasonal, peaking in spring and declining to a minimum during the winter (Rickard & Radcliffe, 1976). The farming system attempts to match the seasonal supply of pasture, to the herd intake demand. In temperate environments, mixed perennial ryegrass white clover pastures provide the majority of the diet for grazed dairy cows throughout the greater part of the lactation period (Bryant, Dalley, Gibbs, & Edwards, 2013). The profitability and sustainability of pasture-based dairy systems depend on efficient use of available pasture coupled with reasonable milk production per cow (Perez-Prieto & Delagarde, 2013). Milk production is limited by energy intake (Bryant et al., 2013), which is limited by dry matter intake. Factors such as grazing behaviour, pasture allowance, pasture composition and quality all influence dry matter intake and therefore have follow-on effects on animal production.

Pasture is a cheap, high quality feed which can be utilised for efficient milk production. Dillion (2006) reported a reduction of NZ$0.60 in the cost to produce 1 kg of milksolids (MS) when the proportion of pasture harvested by the cows was increased by 10%. Achieving maximum daily intake of highly digestible pasture to produce high milk yields per cow and per hectare is the objective of pasture-based systems (Tunon et al., 2011). The strict management of grazing residuals in spring, between 1400 and 1600 kg DM/ha (Boyce & Kerr, 2013; Irvine, Freeman, & Rawnsley, 2010), have been shown to improve milk production in the summer months through improving pasture quality. Spring management of ryegrass dominant pasture to control reproductive development of the sward may be a more important criterion than management to control leaf area and light interception (Korte, Watkin, & Harris, 1984). Mowing, pre- or post-grazing, has been used as a grazing management practise to maintain consistent post-grazing residuals and remove reproductive material from the sward. In doing so this increases pasture quality, through reductions in senescent material, and increases in leafy material (Kolver, Penno, MacDonald, McGrath, & Carter, 1999). A balance between optimum sward production and quality will dictate the height of pre-grazing pasture mass (Tunon et al., 2011).

During the late spring, early summer pasture growth is greater than animal demand. The quality of herbage offered to grazing dairy animals has a major effect on milk production and animal performance over the length of the milking season. In order to maintain desirable pre- and post-grazing pasture masses, rotation length can be altered to manage the regrowth interval. If there is surplus feed, the rotation length can be sped up by increasing the pasture allowance. However, increasing pasture allowance may result in higher post-grazing residuals. Alternatively, stocking rate could be increased to restrict allowance, to reduce post-grazing residuals. If low stocking rates do not allow, mowing could be used as management practise to maintain desired residuals and increase pasture allowance to utilise the pasture surplus without adverse effects on pasture quality. An increase in the regrowth length, results in increased herbage accumulation and therefore greater pasture masses.

Mowing results in low post-grazing residuals (~1500 kg DM/ha), where growth rates will be slowed as it takes longer for the plant to begin photosynthesis due to the low leaf area available. The tiller production is thought to increase and as a result may result in increased pasture production providing that defoliation occurs after the plant reaches the three-leaf stage (Lee, Donaghy, & Roche, 2008). Herbage composition of mown pastures is thought to result in a reduction in the amount of dead material in the sward. It may there be a beneficial management practise to increase pasture quality.

In New Zealand, the majority of dairy cows are fed on perennial ryegrass/white clover pastures, which have a greater nitrogen concentration than what is required by the cows. One of the major challenges associated with diets consisting of grazed grass is the low efficiency of protein utilisation. Ryegrass/white clover pastures have ME concentrations typically greater than 11.5 MJ of ME/kg of DM and a CP content of up to 30% (Totty, Greenwood, Bryant, & Edwards, 2013), where high producing cows only require 15-16% CP (Pacheco & Waghorn, 2008). The majority of excess N not utilized for growth or production is excreted in the urine (Broderick, 2007). There is an energetic cost associated with the elimination of excess nitrogen (Pacheco & Waghorn, 2008). As a consequence, excess nitrogen is excreted as dung (~25% of total N consumed) or urine (~50% of total N consumed)(Kemp, Condron, & Matthew, 1999). A possible mitigation strategy is through increasing the regrowth interval, in doing so this results in nitrogen metabolism, therefore has a lower CP and but more senescent tissue within the pasture (Hortensteiner & Feller, 2002). Pre-mowing could be used as a tool to maintain pasture quality, while minimising N excretion via urine.

1.1 Objectives

The objectives of the experiment were to:

- Determine the effect that pre-mowing has on the herbage composition and pasture quality
- Establish the effect of pre-mowing on apparent dry matter intake and consequently milk production
- Describe the effect that pre-mowing has on animal behaviour in terms of rumination, grazing and time spent idle
- Evaluate the effects of diet on the nitrogen partitioning of the high and low mass pastures which were left standing or pre-mown.

2 Literature review

The objective of the literature review is to assess grazing management practises, mowing pre- and post-grazing in particularly, and their effects on pasture quality. Factors which may influence dry matter intake, and any milk production effects these may have are also discussed. This review is not intended to be a complete account of all available literature, but an indication of what has been looked into.

2.1 Canterbury Plains pasture production

2.1.1 Dry matter production

As a result of a temperate climate New Zealand has seasonal variations in pasture growth, this has resulted in a bell shaped growth pattern (Figure 1). Consequently livestock farmers aim to match animal demand with pasture growth rates and feed supply. For example most dairy farms in Canterbury calve cows in the spring in order to match dry matter production with animal energy requirements. In Canterbury farmers use irrigation to maximize production and ensure pasture supply throughout the milking season. A large proportion of pasture growth occurs in spring, this growth accounts for approximately 40% of annual growth for irrigated pastures on the Canterbury Plains (Rickard & Radcliffe, 1976). During the summer months irrigation maintains pasture growth, as a result 48% of the annual pasture growth occurs during this period (Rickard & Radcliffe, 1976).

Growth rates are at a maximum from October to December, this often results in a pasture surplus, which must be managed to ensure high pasture quality. The average yearly pasture production on an irrigated Canterbury dairy farm is 17.6 t DM/ha. The average Canterbury stocking rate for a dairy farm is 3.21 cows/ha (DairyNZ, 2012), their annual demand is ~17 t DM/ha (Jersey x Friesian cow, producing 400 kg MS/cow/year) (DairyNZ, 2010). Pasture growth rates for irrigated Canterbury range between 10 and 117 kg DM/ha/day (DairyNZ, 2010), this means that in the spring and early summer high growth rates exceed animal demand resulting in a surplus. A common practice for the management of a pasture surplus is the making of supplement, this is often used in a deficit period, such as autumn or winter, when pasture production is low. Other management practices to maximize pasture quality in the spring and early summer to manage the surplus and reproductive activity of perennial ryegrass is 'topping' or 'pre-mowing' of pastures, this is to maintain desired post-grazing residuals and retain pasture quality.

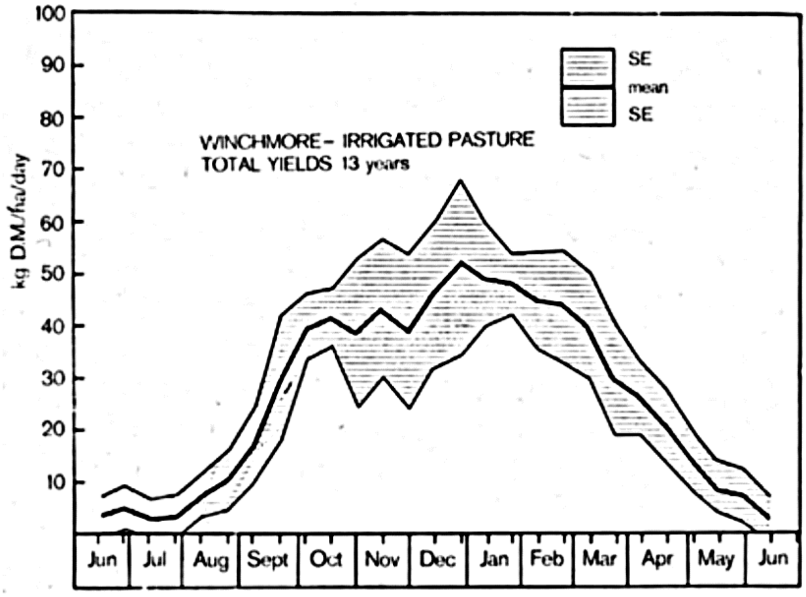

Figure 1: Irrigated pasture: seasonal distribution of pasture growth rates and standard errors. Sourced from (Rickard & Radcliffe, 1976).

2.1.2 Tiller density

Tiller density is driven by grazing intensity and frequency. The tiller density influences the pasture production and quality (Bircham & Hodgson, 1983; Motazedian & Sharrow, 1990). Tiller population densities are greater under hard than lax grazing (L'Huillier, 1987; Xia, Hodgson, Matthew, & Chu, 1990) due to increased light interception at the base of the sward promoting tiller initiation (Hunt & Field, 1979; Korte, Watkin, & Harris, 1985). Under a mowing regime, topping or pre-mowing, would affect pasture in a similar way as hard defoliation grazing management practises due to similar post-grazing residuals (Lee et al., 2008). This is due to mowing pasture, either pre- or post-grazing, resulting in a low post-grazing residuals. Typically low post-grazing residuals are characterised by low leaf area indexes (LAI) where the majority of the leaf area has been removed by defoliation, or is defined as having a low herbage mass (<1500 kg DM/ha).

Korte *et al.* (1984) also found increases in tiller number as a result of hard grazing (LAI = 0.0 - 0.7) with significantly larger tiller populations from December to May of the experimental period, in comparison to the lax grazing (LAI = 0.8 - 2.2). The increased tiller density resulted in 14.7% greater (1900 kg DM/ha) pasture production across the experimental period (October to May) (Korte et al., 1984). There is limited research available around the direct effects mowing, topping and pre-mowing, have on pasture production. Comparisons can be drawn between hard grazing practises and mowing as a result of similar post-grazing residuals. With mowing we would expect increases in tiller density and as a result pasture production.

2.2 Pasture composition

Grazing management during the spring months is important due to the effect on pasture composition and therefore quality. Pasture composition is affected by pre-grazing herbage mass. Pasture quality is affected by the amount of green leaf, grass stem, clover and senescent material (Hoogendoorn, 1992). High quality swards will be high in digestible energy and protein and are characterised by low proportions of senescent material and a high leaf area (LAI). Low proportions of senescent material reduce the neutral detergent fibre (NDF) and acid detergent fibre (ADF) in the forage. Figure 2 shows that increases in ADF result in relatively more indigestible components in the feed, reducing the digestibility and subsequently quality.

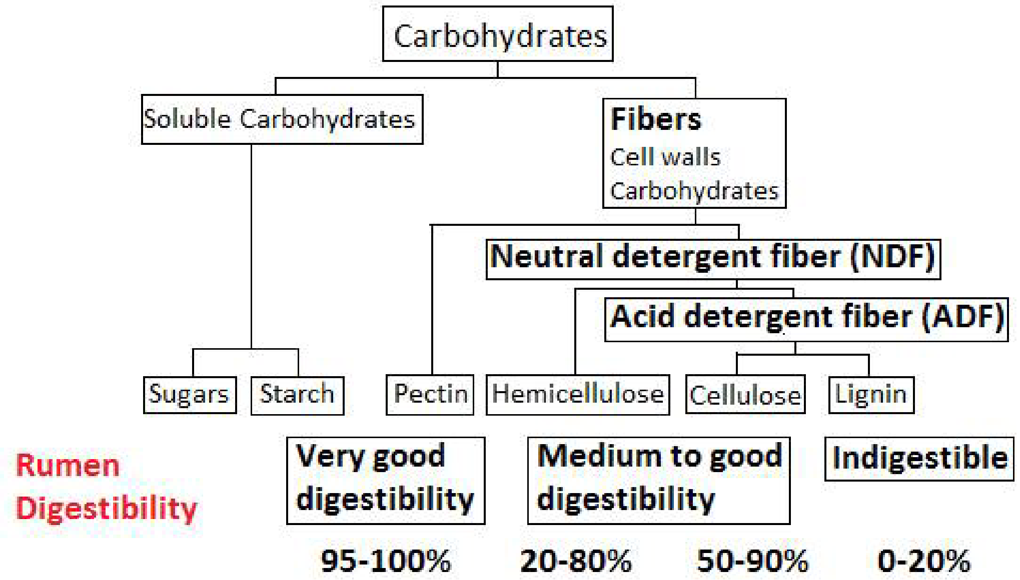

Figure 2: Constituents of plant fibre and relative digestibility

Increased grazing intensity during spring (including the period of reproductive development in ryegrasses) produced swards in early summer with lower pre-grazing herbage masses, with improved sward quality (Hoogendoorn, 1992; O'Donovan & Delaby, 2008). Laxly grazed swards in spring have a higher stem and dead material proportions in summer compared to swards grazed to a lower post-grazing residual (Holmes, Hoogendoorn, Ryan, & Chu, 1992; Korte et al., 1984).

Pasture composition influences pasture quality through changes in the senescent material. The composition of the pasture was significantly different between high and low pasture mass treatments (Hoogendoorn, 1992). In the high mass (5310 kg DM/ha) treatment the grass leaf proportion was 57% lower than that of the low mass (2480 kg DM/ha) treatment. There was also a significant difference in the amount of grass stem between treatments, high mass had 41% more grass stem than low mass. Senescent material is 44% greater in high mass swards compared to low mass swards (Hoogendoorn, 1992). These results support that sward composition changes as a result of different grazing intensities.

Table 1: Pre-grazing herbage mass and herbage composition measured during the experimental period in early summer

	Treatment		
	High mass	**Low mass**	**s.e. mean**
Composition of DM (g/kg)			
Grass leaf	295	462	26 **
Grass stem	401	235	21 **
Clover	119	167	18 NS
Senescent material	176	98	13 **

** P<0.01; NS, not significant. Sourced from (Hoogendoorn, 1992).

Increased grazing intensity during spring produced swards in early summer with lower pre-grazing herbage masses (Hoogendoorn, 1992; L'Huillier, 1987; O'Donovan & Delaby, 2008). Hoogendoorn *et al.* (1992) experiment was carried out in early summer rather than in the spring months, this means that in order to compare Hoogendoorn *et al.* (1992) to that of L'Huillier *et al.* (1987), late spring will be the most appropriate. Through higher stocking intensity (HSR), in the spring there is a 29% increase in green material, this shows the benefits of high pasture utilisation during the spring period.

Table 2: Rate of total, dead, and green herbage accumulation (kg DM/ha per day) for low (LSR; 2.77 cows/ha) and high (HSR; 4.28 cows/ha) stocking rate swards for the 28-day regrowth interval.

		LSR	**HSR**	**SED**	**Sig.**
Early Spring	Total	77.5	76.5	6.8	NS
	Dead	7.1	8.4	3.8	NS
	Green	70.4	68.1	3.5	NS
Late Spring	Total	103.6	84.6	5.7	*
	Dead	7.8	16.4	14.2	NS
	Green	95.8	68.2	11.2	*

*P<0.05; NS, not significant. Sourced from (L'Huillier, 1987).

Increasing pasture allowances result in differing sward compositions throughout the season. At high pasture allowances grazing becomes increasingly lenient and residuals are increased. L'Huillier (1987) compared the consumption of 10, 35, or 60% of the pre-grazing herbage mass grazed over a 24 hour period. This represented lax, moderate, and hard grazing respectively. Herbage accumulation data were summed over 28 and 70 days (56 days in autumn) after grazing to give a short and long regrowth interval. L'Huillier (1987) found that the severity of defoliation influences total herbage accumulation through senescence of residual herbage. Total herbage accumulation measures harvestable production. The effects of defoliation level on herbage accumulation depended on the length of the regrowth period, where the rates of green herbage and grass leaf accumulation were not significantly different between levels of defoliation over the short regrowth interval (28 days). However, after a 70 day regrowth (56 day for autumn) regrowth interval the rate of green herbage accumulation was higher (significant in early spring, late spring, and autumn) and that of dead herbage lower (significant in late spring and autumn) in hard than in lax-grazed swards (L'Huillier, 1987).

Pasture composition and production is affected by herbage mass in the late spring as opposed to the early spring (Hoogendoorn, 1992; L'Huillier, 1987). In high mass or laxly grazed swards there was a greater proportion of senescent or dead material than in that of low mass or hard grazed swards. Pasture allowance and stocking rate had significant effect on green herbage accumulation in subsequent rotations. From the literature available some conclusions can be drawn as to the effect that mowing will have on pasture composition. It is expected that as a result of a reduction in the ability of animal's to show grazing preference there will be reductions in the amount of dead material found in the sward, with amounts being similar to grazing practises which limit grazing behaviour such as high stocking rates or pastures with low pre-grazing pasture masses.

2.3 Pasture Quality

As mentioned previously high quality is associated with high digestible energy and protein which support the metabolisable energy and protein requirements of the grazing livestock. The quality of herbage offered to grazing dairy animals has a major effect on milk production and animal performance over the length of the milking season. The regrowth length of the pasture before the next grazing (rotational grazing) affects the pasture quality through changes in herbage composition and digestibility. Rotation length can be altered to manage the regrowth interval. If there is surplus feed, the round can be sped up by increasing the pasture allowance. However, increasing pasture allowance may result in higher post-grazing residuals. Alternatively, stocking rate could be increased to restrict allowance, to reduce post-grazing residuals. If low stocking rates do not allow, mowing could be used as management practise to maintain desired residuals and increase pasture allowance to utilise the pasture surplus without adverse effects on pasture quality. An increase in the regrowth length, results in increased herbage accumulation and therefore greater pasture masses. Swards with high herbage mass can reduce feeding value and dry matter intake of grazing dairy cows (O'Donovan & Delaby, 2008). This is largely influenced by organic matter digestibility of grass leaf and stem which is reduced with increased regrowth age due to a higher proportion senescent material in the grazing sward (Hoogendoorn, Holmes, & Chu, 1992; Korte et al., 1984). Holmes *et al.* (1992) found higher digestibility in pastures with low herbage mass (L HM; 2.86 t DM/ha) compared with high herbage mass (H HM; 4.79 t DM/ha) swards.

The pre-grazing herbage mass has a more significant effect on the chemical composition of the feed, than that of pasture allowance. Crude protein content (g/kg) decreased by 12% and 7% for the 15 and 20 kg DM/c/d respectively with increasing herbage mass. Organic matter digestibility was reduced in the 2400 kg DM/ha swards (O'Donovan & Delaby, 2008), as a result of a significant increase in NDF (Curran et al., 2010).

Table 3: The effect of pre-grazing herbage mass and daily herbage allowance on chemical composition of selected pasture samples from July 21 to October 31.

Herbage mass (kg DM/ha)	1600		2400		SED	HM	PA
PA (kg DM/cow per day)	15	20	15	20			
DM composition (g/kg)							
OM digestibility	826.7	829.4	818.3	824.3	4.2	< 0.05	0.181
Crude Protein	209.8	213.3	184.9	199.0	8.42	< 0.05	0.369
ADF	272.7	286.5	262.0	278.5	14.9	0.427	0.189
NDF	409.7	408.5	424.0	419.4	7.15	< 0.05	0.603

SED = SE of the difference, HM = herbage mass, PA = Pasture Allowance, DM = Dry matter, OM = Organic matter, ADF = Acid detergent fibre, and NDF = Neutral detergent fibre. Sourced from (Curran et al., 2010).

Compared with standing pasture measured before mowing, the wilted pasture had a higher DM content, increasing on average by 30% during spring and summer. The in-vitro organic matter digestibility (IVD) was higher before the pasture was wilted during the spring and summer. On average the IVD decreased by 5%. Neutral detergent fibre (NDF) increased in wilted pastures, on average by 4%. NDF in mown pastures compared to the control were lower. Compared with the control, mowing before grazing did not change ME content in spring, but increased pasture quality by an average of 0.2 MJME/kg DM during summer. Topping pasture after grazing consistently increased the quality of pasture by 0.6 MJ ME/kg DM during spring and summer (Kolver et al., 1999). The non-structural carbohydrate (NSC) would be expected to be higher for the control than that of the pasture which had been mown (Lee, Donaghy, Sathish, & Roche, 2009). The increase in crude protein and metabolisable energy by mown pastures is likely an increase of green leafy material (Kolver et al., 1999).

Table 4: Chemical composition as a % of dry matter. Measure of variability available only for DM%.

	Spring			Summer		
	September	October	November	December	January	February
DM %						
Control	14.1^{a}	12.7^{a}	15.2^{a}	21.4^{a}	23.4^{a}	42.1^{a}
Mown before grazing 1	14.1^{a}	12.6^{a}	14.2^{a}	19.4^{a}	27.5^{a}	35.9^{b}
Mown before grazing 2	17.1^{b}	17.8^{b}	23.4^{b}	31.5^{b}	35.5^{b}	-
Topped after grazing	13.9^{a}	11.9^{a}	14.7^{a}	19.3^{a}	24.4^{a}	35.3^{b}
Estimated ME (MJ ME/kg DM)						
Control	11.2	11.0	10.7	10.1	9.9	8.5
Mown before grazing 1	11.3	11.6	11.3	11.5	10.4	9.0
Mown before grazing 2	11.0	11.5	10.7	10.5	9.5	-
Topped after grazing	11.3	11.5	11.3	11.1	10.3	9.0
IVD						
Control	75.0	73.6	71.8	67.8	66.5	57.1
Mown before grazing 1	75.6	78.2	75.7	77.0	70.0	60.3
Mown before grazing 2	73.7	77.5	71.5	70.7	64.0	-
Topped after grazing	76.0	77.0	75.7	74.7	69.1	60.4
CP						
Control	16.8	18.9	15.0	11.6	14.5	12.4
Mown before grazing 1	18.2	24.1	19.2	16.3	12.6	14.4
Mown before grazing 2	18.7	23.8	17.9	16.3	12.9	-
Topped after grazing	16.9	23.5	19.6	15.5	12.9	13.9
NDF						
Control	49.5	50.8	53.2	56.1	53.1	57.7
Mown before grazing 1	48.9	45.5	49.4	47.1	51.4	52.6
Mown before grazing 2	48.2	48.2	52.2	50.8	53.5	-
Topped after grazing	48.6	48.7	49.8	49.6	51.5	55.1
NSC						
Control	7.3	5.4	6.9	6.7	6.1	3.8
Mown before grazing 1	6.8	6.3	7.3	10.2	8.8	5.7
Mown before grazing 2	6.4	4.7	5.0	7.0	8.6	-
Topped after grazing	8.0	4.2	6.4	9.3	8.6	4.7

1 Standing pasture before mowing. 2 Wilted pasture 24 hours after mowing. a,b,c,d Values in the same column with different superscripts are significantly different, P<0.05. Sourced from (Kolver et al., 1999)

Topping pastures pre-grazing reduced the herbage quality, with increased (P <0.05) NDF and reduced (P <0.01) digestibility and ME content (Table 5), this was similar to the results that Kolver *et al.* (1999) received. There was no significant (P >0.05) difference between treatments in the percentage crude protein of the pasture diet (Irvine et al., 2010).

Table 5: Pre- and post-grazing biomass (kg DM/ha), dry matter content (DM, %) and pasture quality. ME = Metabolisable energy; DMD = Dry matter digestibility; CP = Crude protein; NDF = Neutral detergent fibre.

	Treatment					
	Pre-top	**Post-top**	**Regraze**	**Control**	**LSD**	**F.pr.**
DM%	36.6	19.9	19.4	19.7	0.92	< 0.01
ME (MJ/kg DM)	11.00	11.8	11.9	11.8	0.16	< 0.01
DMD (%DM)	73.2	77.9	78.5	77.8	0.87	< 0.01
CP (%DM)	15.6	16.2	16.5	16.3	0.81	NS
NDF (%DM)	50.8	48.6	48.0	48.8	1.22	0.01

Sourced from (Irvine et al., 2010).

The quality of the pasture consumed by the animal may differ to what is on offer due to grazing preference (Dalley, Roche, Grainger, & Moate, 1999; Kennedy, O'Donovan, Murphy, Delaby, & O'Mara, 2007). Experiments such as O'Donovan *et al.* (2008) which use stocking rate as a factor, and Kolver *et al.* (1999) or Irvine *et al*. (2010) which pre-mow, may remove grazing preference, and reduce the diet quality. Mowing prior to grazing may increase crude fibre contents in the diet, this has potential to reduce pasture quality, through reductions in digestibility. However, the reduction in dead material and subsequent increase in leaf material may offset this.

2.4 Grazing behaviour and intake

The grazing of pasture is a complex series of relationships between the animal and the pasture. The decisions around bite rate, depth and mass not will only affect the intake but the performance of the animal (Cosgrove & Edwards, 2007). High herbage mass swards, may limit intake through increases in the stem and senescent material (O'Donovan & Delaby, 2008). Mowing prior to grazing may be a management practise which could be utilised to minimise the effect of high herbage mass limiting dry matter intake (DMI). Daily dry matter intake is influenced by a variety of factors. Rook (2000) defined intake of herbage as the product of bite mass and bite rate, and time spent grazing as the product of meal duration and number of meals per day:

Daily intake = (bite mass x bite rate) x (meal duration x number of meals)

Similarly Burns and Sollenberger (2002) described animal response to pasture as a process, which includes factors such as the pasture canopy, digestibility and animal behaviour as being the key determinants of short term animal intake and subsequent performance.

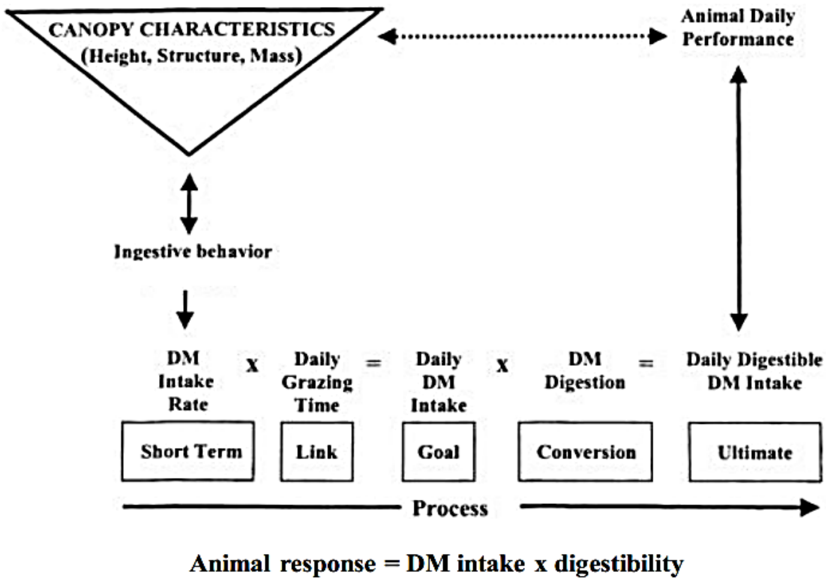

Figure 3: The process to achieve the goal of estimating daily dry matter intake from short term intake rate and daily animal performance. Sourced from (Burns & Sollenberger, 2002).

Optimal dry matter intake rates are achieved by increasing bite mass and bite rate. Grazing ruminants can vary bite dimensions, bite rate and grazing time in response to changes in sward conditions (Dillon, 2006), to maximise daily dry matter intake. There is a confounding relationship between the affect of sward height and sward maturity on bite depth. Bite depth is thought to be primarily a function of sward height (Griffiths & Gordon, 2003). Bite depth showed a strong and positive relationship with sward height (figure 2). The proportional increase in bite depth diminished with increasing sward height (Griffiths, Hodgson, & Arnold, 2003b).

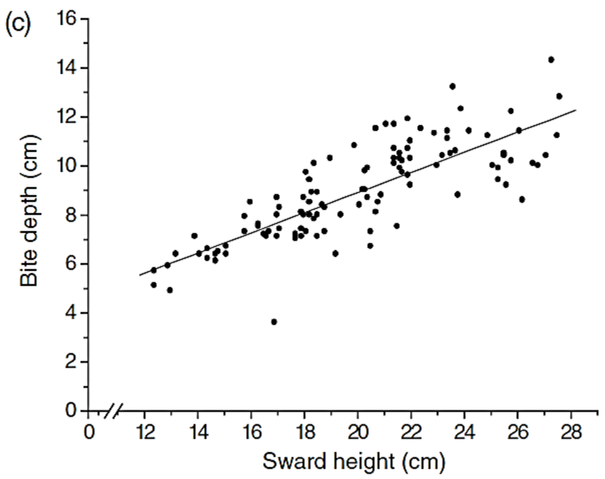

Figure 4: Relationship between bite depth (cm) and pre-grazing sward height. Sourced from *(Griffiths et al., 2003b)*.

Bite rate has a significant effect on dry matter intake (Burns & Sollenberger, 2002). The post-grazing residual influences bite rate in the subsequent rotation. The number of bites was positively related to regrowth depth and negatively related to sward height, as seen in figure 3. The relationships between sward height and number of bites was more apparent in the taller swards (6.4 and 9.6 cm) than in the short sward (1.7 cm) where there was no indication of a negative relationship with increasing sward height (figure 2) (Griffiths, Hodgson, & Arnold, 2003a).

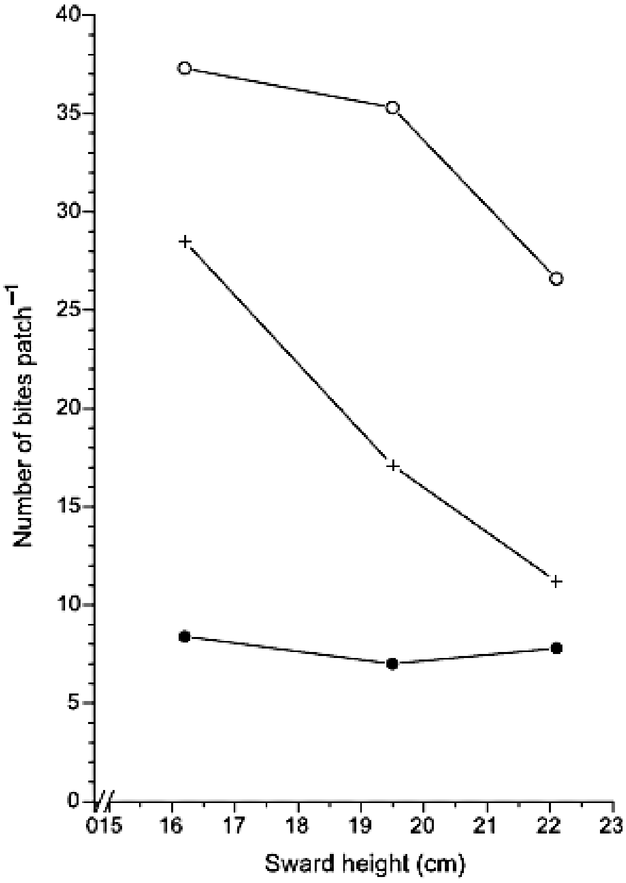

Figure 5: Relationship between sward height and bite number for 1.7 cm (●), 6.4 cm (+) and 9.6 cm (○) regrowth depths. Sourced from (Griffiths et al., 2003a).

Bite depth, has been widely accepted as the primary determinant of the short-term rate of herbage intake (Griffiths et al., 2003b). It is argued that pseudo-stem acts as a barrier to bite depth, which is particularly evident in small ruminants (ref). Larger ruminants however, have the potential to exert greater force, thereby penetrating deeper into the canopy, and may not be as sensitive to constraints imposed by a sward with pseudo-stem or reproductive stem (Griffiths et al., 2003b; Illius, Gordon, Milne, & Wright, 1995). An animal's intake may be constrained by the ease of prehension, with intakes becoming more limiting with increased proportions of the sward being consumed. The force required for prehension increases from the top to the bottom of the sward. Griffiths *et al.* (2003b) found a 49% increase in force required to tear the lower part of the sward stratum, using a Warner Bratzler meat shear test apparatus to measure shear force.

Table 6: Mean values for maximum force in shear

	Maximum force in shear (N)		
	Upper Stratum	Middle Stratum	Lower Stratum
Stratum mean (s.e.m)	37.8	62	73.4

Sourced from (Griffiths et al., 2003b)

Dry matter intake is often constrained at low herbage mass despite increased bite number and grazing time, indicating that there is an greater energetic cost of harvesting on short, low mass swards (Tunon et al., 2011). Although Tunon et al. (2011) were unable to show a significant effect of mass on DM intake, other studies have demonstrated the effect of moderate pasture mass and high quality on milk response (Curran et al., 2010; Hoogendoorn, 1992).

Table 7: Grazing behaviour, herbage dry matter intake (DMI) and daily milksolid (MS) yield for the Autumn (26 July to 17 October 2010) of cows the grazing low (978 kg DM/ha), medium (1521 kg DM/ha) and high (2330 kg DM/ha) herbage masses above the 4 cm horizon.

Measurement	Pre-graze herbage mass				
	Low	Medium	High	Standard error	P value
Grazing time (h/day)	10.8^{a}	9.3^{b}	9.3^{b}	0.7	0.01
Rumination time (h/day)	8.4^{a}	9.0^{b}	9.9^{c}	0.8	0.03
Bites (n/day)	42148^{a}	36180^{b}	35543^{b}	3614	0.01
DMI (kg/cow/day)	15.2	16.5	15.7	0.5	0.09
MS yield (kg/cow/day)	1.42	1.43	1.31	0.06	0.24

Sourced from (Tunon et al., 2011)

Pre-grazing herbage mass and pasture allowance have a significant effect on grazing behaviour. Increasing herbage mass from 978 kg DM/ha to 2330 kg DM/ha (above the 4 cm horizon) increased time spent grazing by 14% (Table 7) (Tunon et al., 2011). Similarly grazing time also increased with increasing pasture allowance. Grazing time increased by 3.0 and 0.9 min/d per kilogram of pasture allowance from low (21 kg DM/d) to medium (32 kg DM/d) and from medium to high (43 kg DM/d) pasture allowance, respectively (Perez-Prieto & Delagarde, 2013). Grazing time appears to be both a function of herbage mass, as well as allowance with grazing time reducing as either, or both, increase. Increasing pre-grazing herbage mass increases the rumination time. By increasing the pasture mass from 978 kg DM/ha to 2330 kg DM/ha (above the 4 cm horizon) rumination time increased by 15% (Table 7) (Tunon et al., 2011). Perez-Prieto & Delagarde (2013) found that increased pasture allowance had no significant effect on rumination time. From this it can be assumed that rumination is more affected by pre-graze herbage mass, with greater pasture masses requiring greater rumination as a result of increased fibre length and reduced digestibility (Van Soest, 1965; Weiss, 1998).

Animal behaviours such as bite rate, bite depth and grazing and rumination time largely determine short term animal intake rates. Intake rate is maximised when sward height and post-grazing residuals are correctly managed to ensure that the harvest cost is not over and above what the animal requires for optimal intake and therefore production. The feeding value of herbage for animal production is a function of the quantity eaten and the concentration of nutrients consumed in the dry matter. The composition of herbage consumed by grazing animals can differ markedly from that on offer due to selection within the sward (Dalley et al., 1999; Kennedy et al., 2007). By removing the animals grazing preferences by mowing the pasture prior to grazing, this may have effects on milk production and composition.

2.5 Pasture allowance and animal intake

To maximize intake, animals need to consume plants that have characteristics that allow rapid consumption and lead to fast rates of passage through the rumen (Dillon, 2006). Herbage intake of individual grazing cows is positively correlated with herbage allowance. Generally voluntary intake increases by 14% from low to high pasture allowance adult dairy cows (Peyraud, Comeron, Wade, & Lemaire, 1996). The increased mass of the sward increases intake because cows have access to a greater proportion of easily harvestable material before they had to graze the lower horizons (Peyraud et al., 1996). Lee *et al*. (2008) found that increasing pasture allowance would result in an increase in post-grazing pasture residual and therefore a reduction in pasture quality in subsequent rotations. Peyraud *et al.* (1996) was a short term study, only carried out in the spring, which does not reflect of the effect of pasture allowance on subsequent rotations.

Table 8: Effect of herbage allowance and lactation number of cows on milk production and herbage intake

Herbage allowance	**Low (20 kg DM/d)**		**Medium (30 kg DM/d)**		**High (40 kg DM/d)**		
Lactation number	**Primary[a]**	**Adults[b]**	**Primary[a]**	**Adults[b]**	**Primary[a]**	**Adults[b]**	**Linear Sig.**
Herbage intake (kgOM/day)	12.4	15.2	14.7	17.6	15.8	17.7	**

[a] Dairy cows in their first lactation; [b] Adult dairy cows; ** P<0.01. Sourced from (Peyraud et al., 1996).

The relationship between herbage allowance and subsequent intake is important as it influences pasture utilisation. Pasture utilisation directly effects pasture composition through changes in post-grazing residual. Delagarde *et al*. (2001) found that there is a strong curvilinear relationship between herbage intake and herbage allowance. Figure 5 shows that daily herbage intake reaches a plateau for an herbage allowance higher than 60 kg/day. This indicates the maximum daily voluntary intake has been reached. Post-grazing residual is a direct function of the daily herbage allowance, greater allowance results in greater residuals, this is a result of reduced utilisation. Increased post-grazing residuals result in reduced pasture quality and strongly influence subsequent milk production (Lee et al., 2008).

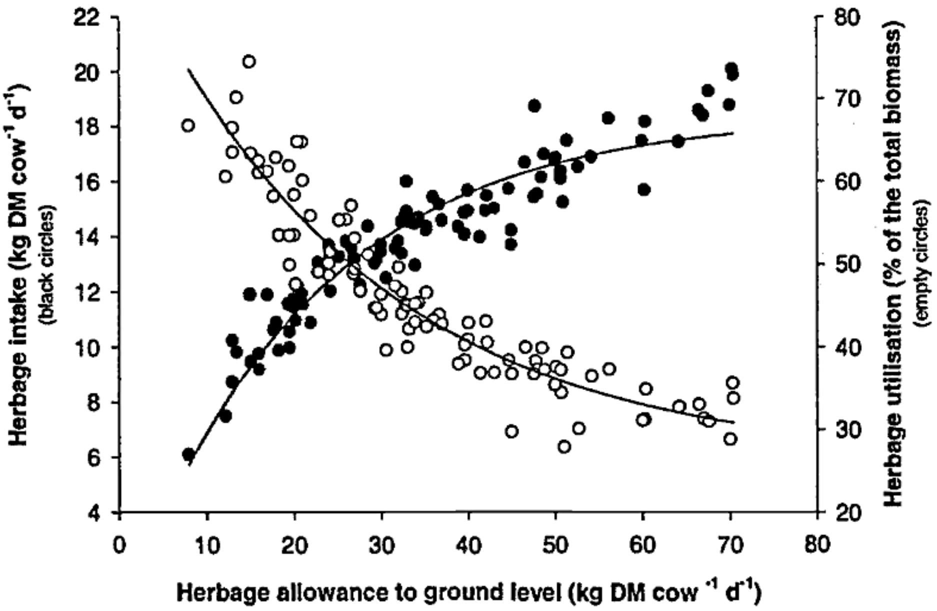

Figure 6: Influence of daily herbage allowance to ground level on daily herbage intake in rotationally grazed dairy cows. Sourced from (Delagarde, Prache, D'Hour, & Petit, 2001).

Increasing pasture allowance resulted in higher levels of dry matter intake. The dry matter intake response beyond a certain level of pasture allowance reduces the benefits of higher allowances due to higher post grazing residuals (Lee, et al., 2008) and deteriorating sward quality in subsequent grazing rotations.

2.6 Effect of mowing

2.6.1 Dry matter production

Despite pre-mowing or topping being used as a tool to increase pasture quality, previous studies relating to the effects of mowing pasture reported reduced pasture growth rates and lower pre- and post-grazing pasture masses (Irvine et al., 2010; Kolver et al., 1999). Kolver *et al.* (1999) found that pasture masses which had been pre-mown or topped, through the spring and summer, were 20% lower than pastures which had not been mown (Kolver et al., 1999). Irvine *et al.* (2010) reported post-grazing masses were also 20% lower when they were either pre-mowed or topped, but did not find pre-graze pasture masses were significantly different. Irvine *et al.* (2010) also found that pastures which had been pre-mown had significantly lower post-grazing residuals than those that had been topped after grazing (Irvine et al., 2010). Reduced pasture growth rates were also reported (Kolver et al., 1999), this is most likely a result of the low post-grazing residual (Lee et al., 2009). This is due to pastures with low-post grazing residuals (< 1500kg DM/ha), having little or no leaf area and are therefore unable to meet energy demands for growth. Severely defoliated plants are likely to have a greater dependence on their stored energy reserves, such as water soluble carbohydrates (WSC) to provide the energy required for regrowth. As a result the WSC reserves are likely to be reduced, with varying amount of stores used depending on the defoliation height (Lee et al., 2009). Fulkerson and Michell (1987) reflected that in the spring the regrowth interval before the next defoliation had the biggest effect on herbage yields, while in the autumn the mowing height was more significant (Fulkerson & Michell, 1987). High herbage yields may be achieved from severely defoliated pastures providing that the regrowth interval is long enough for the pasture to achieve the 'three leaf' stage (Lee et al., 2009). Pasture that was initially infrequently cut through the spring and summer resulted in increased pasture production in the late summer and autumn which was then more frequently cut (Harris & Thomas, 1970).

2.6.2 Milk production

If sward quality is improved by spring grazing management practises, such as those experienced through mowing practises, the benefits in improved sward quality should result in increased per cow performance and higher total energy intake (O'Donovan & Delaby, 2008). The feeding value of herbage for animal production is a function of the quantity eaten and the concentration of nutrients consumed in the dry matter. The composition of herbage consumed by grazing animals can differ markedly from that on offer due to selection within the sward (Dalley et al., 1999; Kennedy et al., 2007). The cows grazing on low-mass swards in early summer produced larger daily yields of milk, fat and protein than those grazing on the high-mass swards (Hoogendoorn, 1992). A consequence of increasing pasture allowance to raise milk production is an equivalent rise in the post-grazing pasture residual. This is likely to decrease the quality of the pasture in subsequent rotations because of increased stem production and accumulation of dead material (Lee et al., 2008).

Increasing pasture allowance has an exponential effect on pasture intake, milk production, and milk solids production. A meta-analysis carried out by Perez-Prieto and Delagarde (2013) compared the effects of pasture allowances (PA) above ground, of low (20 kg DM/d), medium (40 kg DM/d), and high (60 kg DM/d). Pasture intake (0.21 c. 0.07 kg/kg of PA) and milk production (0.19 c. 0.05 kg/kg of PA) increased more from low to medium PA than from medium to high PA (exponential effect, figure 6). Production of 4% FCM, milk solids, milk fat, and milk protein per kilogram of PA also increased at a declining rate with increasing pasture allowance (Perez-Prieto & Delagarde, 2013).

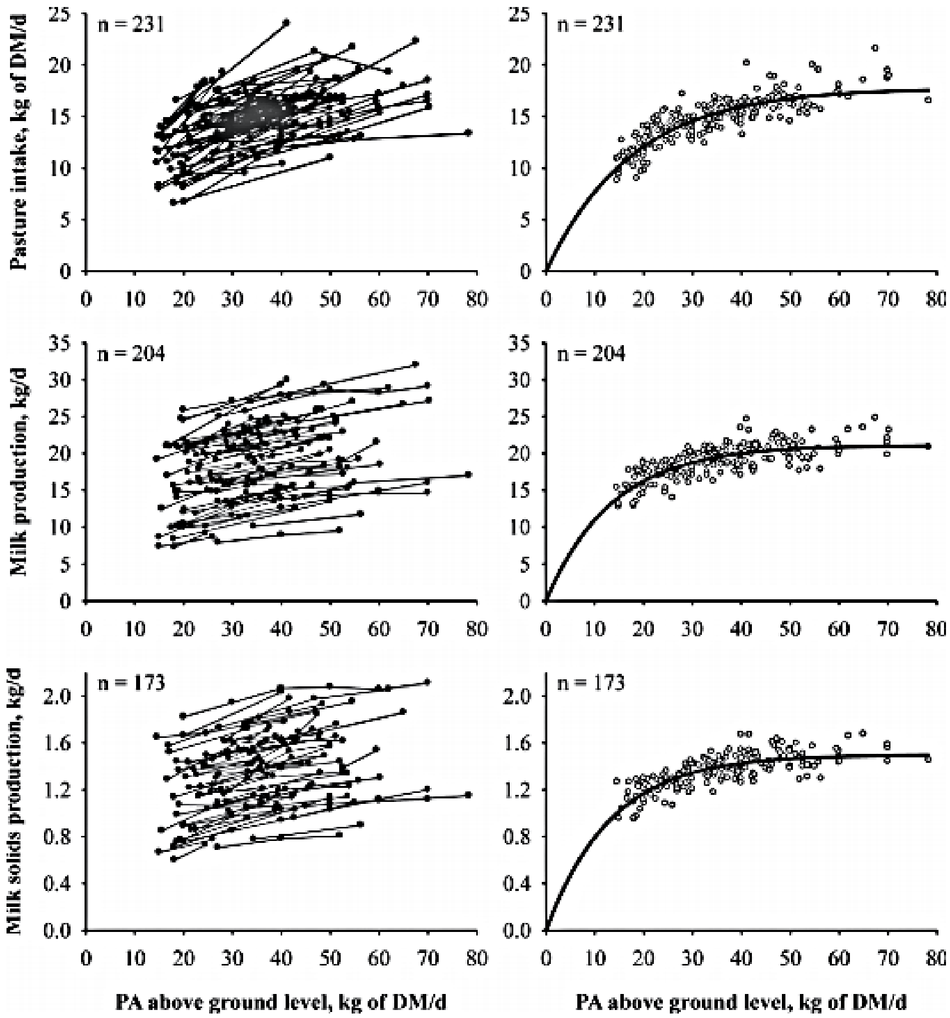

Figure 7: Effect of pasture allowance (PA) on pasture intake, milk production, and milk solids production in grazing dairy cows. Plots on the left report raw data (●) from each study included in the meta-analysis (1 line = 1 PA comparison). Plots on the right report adjusted observations (○) and the mean regression line from the mixed model analysis if P < 0.10. Sourced from (Perez-Prieto & Delagarde, 2013).

Apparent daily dry matter intake has an influence on daily milk yield and composition. Hoogendoorn (1992) found the highest apparent daily dry matter intakes were achieved on low mass pasture with high pasture allowances. Due to the increased intake rate this has resulted in increased milk production. Hoogendoorn (1992) results support that of Peyraud et al. (1996) where milk yield was increased in high herbage mass through increasing pasture allowance. This further proves that animals are able to demonstrate greater grazing selection.

Table 9: Yields of milk and milk solids by cows grazing on the two swards, measured in the second week of the experimental period in early summer

	Treatment				
	High mass		Low mass		
	High allowance	Low allowance	High allowance	Low allowance	s.e. mean
Herbage mass (t DM/ha)	5.31		2.48		
Daily herbage allowance (kg DM/c)	47.5[b]	12.3[a]	48.1[b]	12.1[a]	0.3
Apparent daily DM intake (kg DM/c)	16.1[b]	7.9[a]	26.5[d]	6.7[b]	0.5
Daily yield (kg/cow)					
Milk	13.6[b]	10.5[a]	15.5[c]	13.1[b]	0.6
Milk fat	0.63[a]	0.54[a]	0.79[c]	0.68[b]	0.04
Milk protein	0.58[b]	0.41[a]	0.64[c]	0.50[b]	0.03

Sourced from (Hoogendoorn, 1992).

In a long term study carried out in spring, Peyraud *et al.* (1996) found that from high to low herbage allowances adult cow's milk yield increases significantly by 3.6 kg per day. Increasing herbage allowance significantly increases intake and digestibility resulting in increased milk production (Peyraud et al., 1996). However, increased milk yield in high herbage allowance cows could be a result of increased pasture to exhibit grazing preference (Dalley et al., 1999; Kennedy et al., 2007).

Table 10: Effect of herbage allowance on the cow milk production and herbage intake

Herbage allowance	Low (20 kg DM/d)	Medium (30 kg DM/d)	High (40 kg DM/d)	Linear Sig.
Milk Yield (kg/day)	24.2	26.2	27.8	**
Fat content (g/kg)	36.9	36.2	36.6	NS
Protein content (g/kg)	28.5	29.3	30.1	**
Fat-corrected milk (kg/day)	22.8	24.4	26.3	**

Sourced from (Curran et al., 2010).

Herbage mass has a significant effect on the milksolid production, particularly at the end of the milking season. Tunon *et al.* (2011) found a significant (represented by *** in figure 5) effect of herbage mass on milk solid production in the autumn. Figure 5 describes the importance of maintaining a suitable herbage mass through the duration of the season so as to maximise milk production at the end of the season.

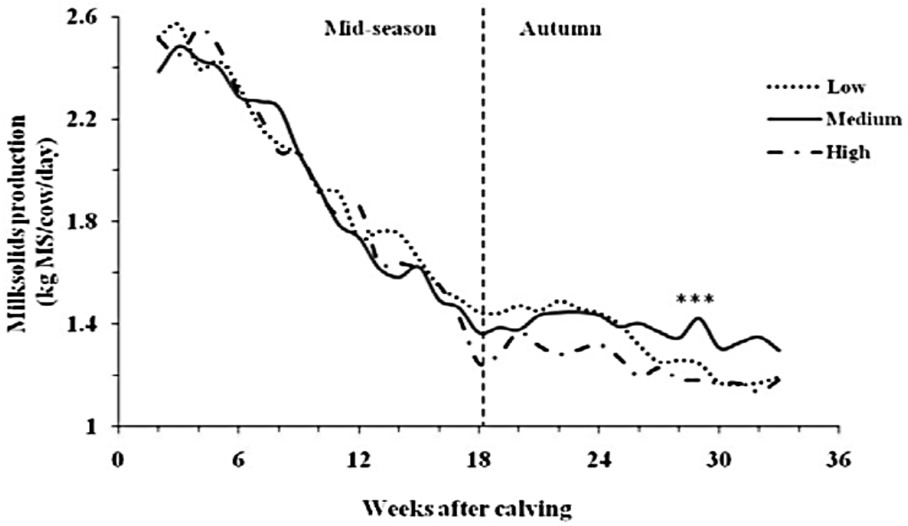

Figure 8: Mean weekly milksolid (MS) production of cows during each week of the trial while grazing low (978 kg DM/ha), medium (1521 kg DM/ha) and high (2330 kg DM/ha) pre-grazing herbage masses, measured at 4 cm above ground level. Sourced from (Tunon et al., 2011).

Mowing pasture results in reduced milk production in the spring and increased milk production during the summer. Compared with the control, mowing pasture before grazing reduced the milk yield and milksolids during spring by an average of 1.55 l/cow/day (P< 0.05) and 0.12 kg MS/cow/day (P<0.05), respectively (Table 11). Similar to topping pastures before grazing, topping pastures after grazing produced milk yields and milksolids during October were that reduced by 1.55 l/cow/day (P< 0.05) and 0.11 kg MS/cow/day (P< 0.05), respectively. However, milk yields and milksolids were increased during summer by an average of 1.75 l/cow/day (P< 0.05) and 0.13 kg MS/cow/day (P< 0.05), respectively, compared with the control. Topping pastures after grazing resulted in a mean milksolids production of 1.28 kg MS/cow/day across the six 14 day experimental periods. This mean milksolids production was greater (P< 0.05) than that for the control (1.22 kg MS/cow/day) and the pre-mown (1.21 kg MS/cow/day) treatments. Dry matter intakes were significantly (P< 0.05) lower compared with the control and mown after grazing in October and November. Dry matter intakes were significantly (P< 0.05) higher compared with the control and mown after grazing in December and January (Kolver et al., 1999).

Table 11: Milk yield (l/cow/day), milk composition (fat% and protein%), milksolids yield (kg/cow/day), and dry matter intake (kg/cow/day) determined using the alkane technique, of cows grazing control pasture, pasture mown before grazing, and pasture topped after grazing.

	Spring			Summer		
	September	October	November	December	January	February
DM Intake						
Control	13.2^{a}	16.2^{a}	18.3^{a}	12.7^{a}	16.4^{ab}	12.1^{a}
Mown before grazing	12.8^{a}	20.2^{b}	15.9^{b}	16.9^{b}	17.6^{a}	12.9^{a}
Topped after grazing	13.3^{a}	16.8^{a}	17.8^{a}	14.6^{c}	13.6^{b}	12.9^{a}
Milk yield						
Control	19.48^{a}	18.98^{a}	17.81^{a}	14.97^{a}	13.06^{a}	8.18^{a}
Mown before grazing	18.59^{b}	16.19^{b}	16.84^{b}	15.7^{a}	14.73^{b}	10.17^{b}
Topped after grazing	19.57^{a}	17.43^{c}	18.2^{a}	16.57^{b}	14.99^{b}	9.91^{b}
Fat%						
Control	4.29^{a}	4.42	4.46	4.63^{a}	4.59^{a}	5.13^{a}
Mown before grazing	4.32^{a}	4.50	4.52	4.50^{b}	4.65^{ab}	4.96^{b}
Topped after grazing	4.46^{b}	4.48	4.42	4.61^{ab}	4.74^{b}	4.87^{b}
Protein%						
Control	3.40^{a}	3.46^{a}	3.42^{a}	3.35^{a}	3.35^{a}	3.29^{a}
Mown before grazing	3.42^{a}	3.31^{b}	3.38^{a}	3.41^{ab}	3.49^{b}	3.26^{a}
Topped after grazing	3.37^{a}	3.41^{a}	3.4^{a}	3.46^{b}	3.44^{b}	3.28^{a}
Milksolids						
Control	1.49^{ab}	1.49^{a}	1.41^{a}	1.18^{a}	1.02^{a}	0.71^{a}
Mown before grazing	1.43^{a}	1.26^{b}	1.33^{b}	1.24^{a}	1.19^{b}	0.81^{b}
Topped after grazing	1.54^{b}	1.38^{c}	1.41^{a}	1.33^{b}	1.22^{b}	0.78^{ab}

a,b,c,d Values in the same column with different superscripts are significantly different, P<0.05. Sourced from (Kolver et al., 1999).

With the same target a daily pasture intake of 15 kg DM/cow for all treatments, Irvine *et al.* (2010) found that topping pastures pre-grazing significantly (P <0.01) reduced cow dry matter intake compared to all other treatments, by 2.3 kg DM/cow/day compared to the control (Table 12). Daily energy (ME MJ/day) intake was also significantly (P <0.05) reduced in the pre-top treatment than all other treatments. There was no significant (P >0.05) difference between treatments in milksolids production or milk fat percentage but the pre-top treatment did have a significantly lower milk yield (3.07 L/cow/day; P <0.05) and milk protein percentage (3.12% c. average 3.25%; P <0.05) than all other treatments. There was no significant (P >0.05) difference in intake and milk production between the post-top, regraze and control treatments (Irvine et al., 2010).

Table 12: Pasture dry matter (kg DM/cow/day) and metabolisable energy (MJ ME/cow/day) intake, milk yield (L/cow/day), milk solids yield (kg MS/cow/day) and milk composition (%).

	Treatment					
	Pre-top	**Post-top**	**Regraze**	**Control**	**LSD**	**F.pr.**
Pasture Intake	10.0	13.1	12.5	12.3	0.89	0.002
Metabolisable energy intake	107.5	151.6	148.1	141.9	15.61	0.04
Milk Production	18.1	21.6	20.9	21.0	2.29	0.04
Milksolids	1.26	1.51	1.51	1.49	0.2	NS
Fat %	3.86	3.82	4.03	3.82	0.38	NS
Protein %	3.12	3.24	3.23	3.27	0.07	0.02

Pre-grazing pasture mass and pasture allowance have significant effects on milk yield (Hoogendoorn, 1992; Kennedy et al., 2007; Perez-Prieto & Delagarde, 2013; Tunon et al., 2011). However, Peyraud *et al.* (1996) research showed that increased pasture allowance results in increased milk yield with no implication in milk yield being received by lower quality pasture as a result of increased post-grazing pasture residual.

2.7 N in diet and N partitioning

To understand the effect dairying has on nitrogen (N) loss and subsequent environmental effects, it is important to recognize the relationship between nutrition and N partitioning. Nitrogen in the feed of lactating dairy cows is transformed through a series of pathways in the gut and tissues and ultimately appears either in milk, faeces and urine or is involved in interchange with the body's reserves of N (Dewhurst & Thomas, 1992). The majority of excess N not utilized for growth or production is excreted in the urine (Broderick, 2007). There is an energetic cost associated with the elimination of excess nitrogen (Pacheco & Waghorn, 2008). An increase in dietary soluble N intake, appears to be the major factor influencing milk urea N (MUN) and faecal N concentration (Haig, Mutsvangwa, Spratt, & McBride, 2002). Therefore, the nutrition of a dairy cow is an integral part of the sustainability of dairying on the environment.

In New Zealand, the majority of dairy cows are fed on perennial ryegrass/white clover pastures, which have a greater nitrogen concentration than what is required by the cows. One of the major challenges associated with diets consisting of grazed grass is the low efficiency of protein utilisation. Ryegrass/white clover pastures have ME concentrations typically greater than 11.5 MJ of ME/kg of DM and a CP content of up to 30% (Totty et al., 2013), where high producing cows only require 15-16% CP (Pacheco & Waghorn, 2008). Rumen function is impaired due to the relatively high concentration of soluble protein (Hoekstra, Schulte, Struik, & Lantinga, 2007). As a consequence, excess nitrogen is excreted as dung (~25% of total N consumed) or urine (~50% of total N consumed)(Kemp et al., 1999). There are three pathways which have been identified through which N utilisation efficiency can be increased by grazing dairy cows. By manipulating the chemical composition of the pasture there is potential to match protein supply to animal requirements. Also by synchronising carbohydrate and N supply in the rumen. Lastly efficiency can be increased by increasing the proportion of rumen undegradable protein (RUP), this is seen in figure 9 below (Hoekstra et al., 2007).

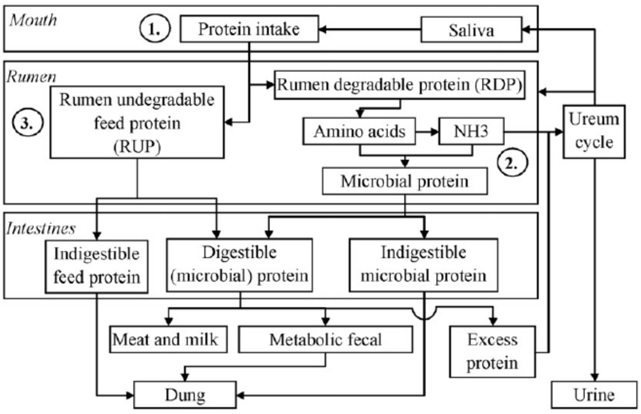

Figure 9: Simplified schedule of nitrogen digestion by bovines and pathways to improve nitrogen efficiency. (1) Matching protein supply to animal requirements; (2) balancing and synchronising carbohydrate and N supply in the rumen; (3) increasing the proportion of rumen undegradable protein (RUP) (Hoekstra et al., 2007).

When supplies of readily available energy (mainly water soluble carbohydrates, WSC) in the rumen are sufficiently high, amino acids taken up by the microbes can be incorporated into microbial protein. However, when the availability of water-soluble carbohydrates is relatively low, either amino acids or structural carbohydrates of the plant are used by rumen microbes for the bulk of their energy supply. These compounds are relatively slowly degradable and, as a result, there can be a lack of both balance and synchronisation of N and energy release in the rumen. This leads to ammonia accumulation in the rumen, which is absorbed across the rumen wall and subsequently converted into urea (Hoekstra et al., 2007) Depending on prevailing dietary conditions, 40 to 60% of liver urea output is excreted in urine (Higgs, Chase, & Van Amburgh, 2012).

Figure 10 below, describes the relationship between N intake and N partitioning. Changes in dietary N intake have relatively little effect on faecal and milk N, and most change is seen in urinary N excretion which can exceed 500 g N/day at high N intakes (Pacheco & Waghorn, 2008). Increasing N intake results in greater N excretion, therefore the best way to reduce N excretion is by minimising N intake.

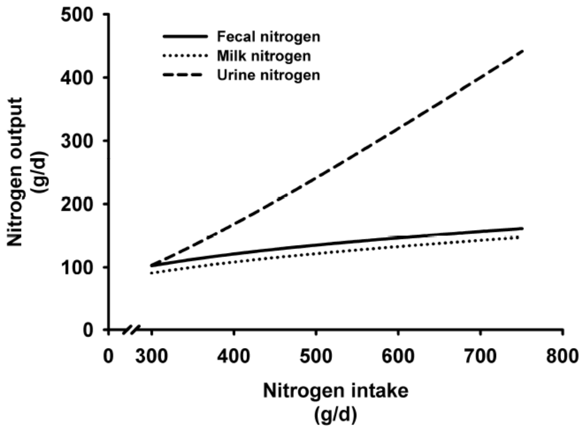

Figure 10: Partition of the dietary nitrogen (N) intake between milk, faeces and urine, for cows fed pasture with 85% N rumen degradability and 10.5 MJ of fermentable metabolisable energy per kg DM (equivalent to 12 MJ ME per kg DM) (Pacheco & Waghorn, 2008).

Nitrogen use efficiency (NUE) is significantly affected by the dietary energy and crude protein (CP) content of the feed (Rius, 2010). A high energy and low crude protein diet results in increased efficiency of N utilization. Similarly, Broderick (2003) found that with increasing CP the NUE decreases linearly ($P < 0.01$) (Broderick, 2003; Gourley, Aarons, & Powell, 2012). Rius *et al.* (2010) had NUE values ranging from 31 to 43% depending on available dietary energy and crude protein (Rius, 2010). Efficiency of N utilization in milk typically ranges from 15 to 25% (Tamminga, 1992), which is in close agreement with Haig et al. (2002) results. However, this efficiency was lower than data Chalupa and Ferguson (1995) received, where they achieved values of 30 to 35% by balancing the diet to maximize microbial capture of rumen NH_3-N and increasing MP reaching the small intestine from undegradable intake protein (UIP) sources (Chalupa & Ferguson, 1995).

2.8 Conclusions

The dry matter production by mowing pasture has been compared to hard grazing management practises due to the lack of information in this area. It is thought that as mowing results in low post-grazing residuals (~1500 kg DM/ha), because of this growth rates will be slowed as the as it takes longer for the plant to begin photosynthesis due to the low leaf area available. This means that the plant has to mobilise its water soluble carbohydrate reserves to grow. The tiller production is thought to increase and as a result may result in increased pasture production providing that defoliation occurs once the plant reaches the three-leaf stage. Herbage composition of mown pastures is thought to result in a reduction in the amount of senescent material in the sward. The reduction in senescent material results in increased pasture quality through increases in digestibility. Contrary to this, is evidence that pre-mowing results in an increase in NDF, which may affect the digestibility adversely and therefore dry matter intakes. Dry matter intakes can be optimised in dairy cattle by controlling herbage mass or height. Increases in pasture mass result in reductions in bite depth, bite number and time spent grazing. However, there are many benefits by increasing the regrowth interval which includes, reducing nitrogen excretion via urine. By pre-mowing the high mass pastures, there is potential to reduce harvest costs, so that trade off of higher pasture masses having reduced digestibility, is minimised through increases in dry matter intake. Pre-mowing may increase dry matter intake over a shorter period through removal of herbage harvesting cost and increases in bite volume. Although, pre-mowing has been found to reduce dry matter intakes at the same pasture allowance, by between 2 to 3 kg DM/cow/day in the spring, but potentially increases the dry matter intakes in the summer, however, results around pre-mown cows dry matter intakes were variable. Pasture allowance also has a significant effect on milk production with higher allowances generally resulting in higher intakes. However, with increased allowance there is potential to increase post-grazing residual which may adversely affect pasture quality. High post-grazing mitigation strategies include the use of mowing prior to grazing (pre-mowing) and after grazing (topping). However, each of these appears to reduce milk production in the spring months, but increase it during the summer. The increased milk production during the summer is mostly likely a result of increased pasture quality.

3 Materials and methods

3.1 Experimental site and design

The experiment was conducted between 20th and 29th of March 2014 at the Lincoln University, Research Dairy Farm, Lincoln, Canterbury (longitude 172°27'E; latitude 43°38'S; 10 m asl). The soil type is a Barhill loam over sandy loam (LandcareResearch, 2014). The experiment was a 2 x 2 factorial design, consisting of two pasture mass treatments: high (HM) (2768 ± 45 kgDM/ha) or low (LM) (2169 ± 45 kgDM/ha), and two mowing treatments: unmown, standing (S) pasture or mown before grazing (P). The experimental area was 4.9 hectares, of a tetraploid perennial ryegrass (*Lolium perenne L.*)(cv. Bealey) and managed with irrigation. The area was divided into four paddocks averaging 1.3 hectares. A temporary fence was positioned length ways down the paddock to separate high and low pasture mass areas (see figure 11). Prior to the experiment 60 kg N/ha of urea was applied in two split applications following grazing during the set up phase of the trial. During the set up phase from the 12th of February to the 10th of March, the trial area was grazed to create different pasture masses which would be able to be grazed at the same time during the trial period (20th to 29th of March). Low pasture masses were created by grazing the area allocated twice in the set up phase, while high masses were grazed only once (see table 10). 60 kg N/ha of urea (N:P:K:S ratio of 46:0:0:0) was applied in a split application, the first application was applied before grazing began, 30 kg N/ha was applied on the 5th of February. A second urea application of 30 kg N/ha of urea was then applied following grazing in high herbage mass treatments and after the second grazing in low herbage mass treatments (see table 10). The area being used for the mowing treatments, for both herbage masses, were mown during the setup phase, this was to help create treatment effects in the pasture. Average regrowth age of the pasture was 14 ± 1.0 days for the low pasture mass and 20 ± 3.0 days for the high pasture mass.

Table 13: Grazing and urea application dates for setup phase

Block	Treatment herbage mass	Date grazed	Date second urea application was applied
1	Low	12/02/2014	-
2	Low	15/02/2014	-
3	Low	18/02/2014	-
Lead in	High	23/02/2014	3/03/2014
1	High	25/02/2014	3/03/2014
2	High	28/02/2014	3/03/2014
3	High	3/03/2014	11/03/2014
1	Low	6/03/2104	11/03/2014
2	Low	7/03/2014	11/03/2014
3	Low	10/03/2014	14/03/2014

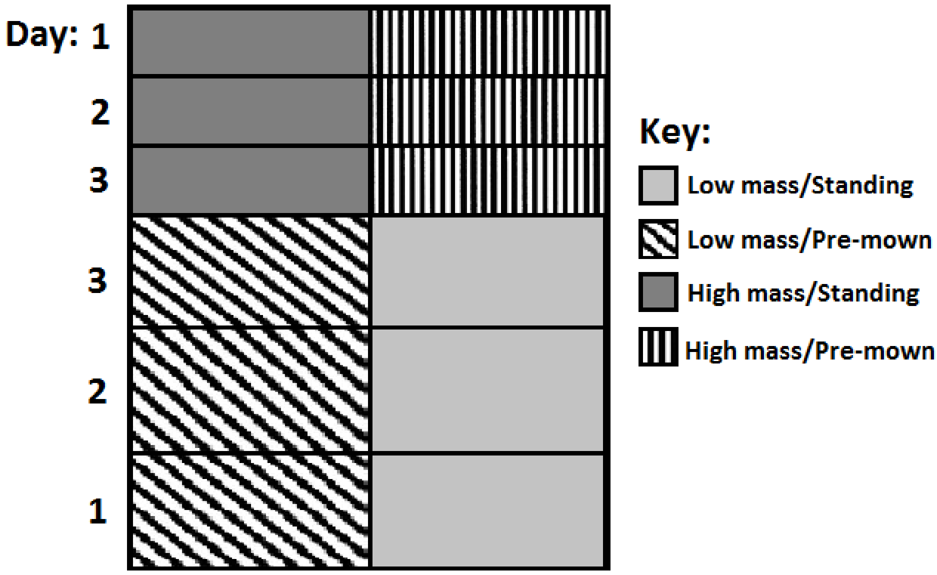

Figure 11: Division of each paddock into grazing allocations

3.2 Animals and management

Forty eight lactating, pregnant, spring calving Friesian x Jersey cows were blocked according to age (mean 4.9 years, range 3–10 years), milksolids (mean 1.38, range 1.95 - 0.97), calving date (mean 20th August 2013, range 17th July – 23rd September 2013), and live weight (mean 464 kg, range 334–581 kg), and randomly assigned to four groups of twelve cows. Cows were milked twice daily where they spent approximately one hour in the yards in the morning from 0700 h to 0800 h and in the afternoon from 1430 h to 1530 h.

The area to be grazed each day was determined using an electronic rising-plate meter (Jenquip F150 Electronic Pasture Meter, Fielding, New Zealand). The compressed height of the area immediately in front of each group of cows was recorded from fifty random plate meter readings, and pasture mass was estimated using the calibration (height cm x 280 + 500 kg DM ha^{-1}). Based from the pasture mass calculated, the break area was calculated so that each cow was allocated 15 kg DM per day above the grazing height of 3.5 cm. Dry matter intake (DMI) per cow was calculated as:

$$\text{DMI} = \frac{[\text{Pre grazing mass (kg DM ha}^{-1}) - \text{Post grazing mass (kg DM ha}^{-1})] \text{ x area (ha)}}{12 \text{ cows}}$$

Cows grazed each pasture allocation (break) for 24 hours, and were allocated a new break in the afternoon following milking. Pre-mown treatments were mown to 3.5 cm above ground level (~1500 kg DM/ha) three hours (~1130 h) before cows were put onto the break at 1530 h (plate 1). Cows were transitioned into the experiment over two days. Electric polywire fences were used to control pasture allowances, with the use of a back fence to prevent back grazing. Portable troughs were shifted daily so cows always had access to fresh water (plate 2).

Plate 1: Tractor mowing pasture prior to grazing

Plate 2: Cows have free access to water in movable water troughs

3.3 Pasture sampling

3.3.1 Pasture mass

Calibration cuts were taken pre and post-grazing from each of the three paddocks used during the trial period (lead in paddock was excluded) to calibrate the rising-plate meter. Ten calibration cuts were taken both pre and post-grazing for all four treatments. The rising-plate meter compressed sward height of herbage was taken first from within a 0.02 m^2 quadrat. All the plant material within the quadrat was cut to ground level using electric shears and removed to determine dry weight. Herbage was then washed and oven dried at 80°C to a constant weight. Pre- and post-grazing pasture masses for the trial were taken using a rising plate meter RPM. Calibrations for the treatments are as follows:

- High pasture mass – standing: $y = 47.7x^{1.3414}$ (R^2 =0.929)
- High pasture mass – mown: y = (1774.6 In(x))-2594 (R^2 =0.754)
- Low pasture mass – standing: $y = 96.71x^{1.162}$ (R^2 =0.821)
- Low pasture mass – mown: $y = 143.6x^{0.986}$ (R^2 =0.884)

3.3.2 Botanical composition and nutritive value

Snip cuts were taken at ground level using pasture shears. Snip cuts were taken in each paddock, on days 5, 7 and 9, for blocks 1, 2 and 3 respectively. Pre, mid and post-grazing snip cuts were taken from the same 'break' allocation. Snip cuts were taken in an x-pattern across the break. Pre-grazing snip cuts were taken at 1530 h prior to the cows being put onto their new pasture allocation, in un-mown treatments snips were taken in a x-pattern in the break, while mown treatments were taken along the fence line in front of the break. Mid-grazing snip cuts were taken at 0730 h prior to the cows coming back onto the break from the morning milking. Post-grazing snip cuts were taken at 1430 h, after the cows were taken away for the afternoon milking. 'Grab' samples of the mown pasture were randomly taken across the break pre-grazing at 1530 h. Snip cuts were mixed and ~30 g subsamples were taken for NIRS, DM% and botanical composition. Grab samples were also mixed and ~30 g subsamples were taken for NIRS and DM%. DM% subsamples had their fresh weight taken and oven dried at 80°C to a constant weight. Chemical composition of the snip sample and grab sample from each treatment group was determined by freeze drying and ground to pass through a 1 mm sieve (ZM200 rotor mill, Retsch Inc. Newtown, Pennsylvania, US). Digestibility of the organic matter in the dry matter (DOMD), crude protein (CP), water soluble carbohydrate (WSC), neutral detergent fibre (NDF) and detergent fibre (ADF) were analysed using near-infrared spectrophotometer (NIRS. Model: FOSS NIRSystems 5000, Maryland USA). Metabolisable energy (MJ ME/kg DM) was calculated as 14.55 - 0.155 ADF% (CSIRO, 2007). A botanical composition of a subsample was used to determine the proportion of sown grass species (Bealey tetraploid perennial ryegrass), white clover, senescence material and weed species.

3.4 Animal sampling

Animal sampling procedures were approved by Lincoln University Animal Ethics committee. After the morning and afternoon milking on days 7 and 9 faecal and urine samples were taken from each animal. Faecal samples were collected by manually stimulating defecation (plate 3). Urine was collected mid-stream by rubbing the vulva by hand (plate 2), and acidified with sulphuric acid to reduce pH and prevent volatilisation. Faecal and urine samples were stored frozen (-20°C). After thawing, each faecal sample was mixed thoroughly and a subsample of ~20 g was weighed, then was oven-dried at 100°C, this was to determine DM%. Another subsample (~30 g) was freeze-dried, then ground through a 1 mm grinder and analysed for N% by elementar (Vario MAX CN, Analysensysteme GmbH. Hanau, Germany). Urine samples were thawed at 4°C and analysed for urea, ammonia, N% and creatinine. Urinary N excretion was determined using the nitrogen and creatinine concentration in the urine and the live weight (LW) of the cows at the beginning of each sampling day. Milk yield was recorded (DeLaval Alpro Herd Management system, Hamilton, New Zealand) daily at both morning and afternoon milkings. Subsamples were obtained for composition of fat, protein, lactose and urea N (MUN) on days 0, 5, 7 and 9. Protein, fat and lactose concentrations were determined on whole milk by infrared analysis (MilkoscanTM, Foss Electric, Denmark). Milk urea was determined on skimmed milk, which after cooling was centrifuged at 1800 revolutions per minute (RPM) for 10 minutes to remove fat. Milk urea was then analysed by an automated Modular P analyser (Roche/Hitachi). MUN concentration was calculated on a molar basis by multiplying the molar concentrations of milk urea by two. Protein, fat, lactose and MUN were corrected for milk yield.

Plate 4: Collecting urine samples

Plate 3: Collecting faecal samples

3.5 Animal Behaviour

On days 4 and 7, animal behaviour was monitored for 6 cows in each of the treatment groups at 5 minute intervals for 24 hours. Animals were identified by with numbers spray painted on both their left and right sides (plate 5). Grazing, idling (not engaged in other activities), ruminating, sitting, standing, or walking were recorded for each cow. Each activity was calculated by multiplying each behaviour activity frequency by a five minutes interval, assuming the animal had exhibited that behaviour for the whole duration of that period.

Plate 5: Spray painted numbers for cow identification

3.6 Statistical Analysis

Variables for milk production, dry matter intake, and pasture variables were analysed for variance using general linear model procedure for completely randomised design in Genstat (VSN International Ltd, 16th edition). The analysis for animal measurements was for a nested experiment where cows were treated as internal replicates and paddocks were external replicates. Treatments of pasture mass and preparation and their interaction were used as fixed terms in the model. Paddocks were included as a random effect. Where means were significant different ($P<0.05$), LSD's were used to separate means. P values less than 0.05 were considered significant.

4 Results

4.1 Herbage yield and composition

The pre-grazing height and mass was greater (P < 0.001) for the high mass compared with the low mass treatment (Table 14). There was also a preparation effect observed in the pre-grazing pasture mass, pre-mown pasture were 8.6% and 6.8% lower than the standing pasture, in low and high pasture masses respectively (Table 14). There was no significant difference in post-grazing height or mass. All pasture treatments were dominated by perennial ryegrass (mean = 71.3 % of DM), with little clover (mean = 6.2% of DM) or weed (mean = 4.9% of DM) content. There was no effect of treatment on botanical composition at either pre-, mid- or post-grazing stages (Table 15).

Table 16 describes the chemical composition of unmown pastures of each of the four treatments, immediately before (pre) and after (post) grazing, from herbage sampled to ground level. Unmown herbage was similar in chemical composition across all treatments. However, differences in chemical composition were apparent in post-grazing residuals. Pre-grazing mowing resulted in lower proportion of water soluble carbohydrate (WSC, decrease of 36 g/kg DM) in the stubble. Increasing pasture mass resulted in a 2% increase in acid detergent fibre (ADF) present in the stubble which resulted in a lower post grazing ME content.

The chemical composition of the herbage consumed from standing and wilted mown samples in both the high and low pasture masses is presented in Table 17. To compare nutrient 'disappearance' across treatments, the standing treatments in Table 16, were corrected so that the pre-grazing chemical composition accounted for composition of the post-grazing residual. Additionally the nutrient 'opportunity' is included where nutrient disappearance is compared for both uncut mown herbage and mown wilted herbage. The dry matter content (DM%) of the herbage consumed is significantly (P = 0.047) greater in pre-mown compared standing pastures (mean = 13.2% c. 18.4%). The WSC content was also significantly (P < 0.001) greater in standing pastures, 28.8% higher (72.5 g WSC/kg DM) on average than the pre-mown. There was also a significant (P = 0.005) difference in WSC between the high and low pastures masses. The difference between in WSC in the wilted grass was greater at high pasture masses than low pasture masses (29% c. 10%). The proportion of ADF in the herbage consumed was significantly (P = 0.008) greater in the pre-mown samples by on average 11.6% and 22.3% greater in the low and high pasture mass treatments respectively. The amount of NDF was also significantly (0.008) greater in wilted pasture. The standing samples the crude protein contents were similar to the pre-mown, and were not significantly (P = 0.073) different.

Table 14: Pre-and post-grazing height and mass

	Low mass		High mass			P value		
	Standing	Pre-mown	Standing	Pre-mown	s.e.m	Pasture Mass	Preparation	M x P
Pre-grazing height (cm)	14.9	14.8	21.3	19.8	0.49	**<0.001**	0.092	0.156
Post-grazing height (cm)	7.81	7.11	8.30	7.66	0.34	0.138	0.057	0.933
Pre-grazing mass (kg DM/ha)	2233	2041	2896	2700	81.3	**<0.001**	**0.025**	0.979
Post-grazing mass (kg DM/ha)	1055	994	818	997	64.5	0.082	0.367	0.075

Table 15: Pasture Composition (% of total dry weight) to ground level of high (2768 ± 45 kg DM/ha) and low (2169 ± 45 kg DM/ha), pasture mass for standing and pre-mown treatments at pre-, mid- and post-grazing

	Low mass		High mass			P value		
	Standing	Pre-mown	Standing	Pre-mown	s.e.m	Pasture Mass	Preparation	M x P
Pre-grazing (1530 h)								
Grass	77.5	67.1	66.3	74.4	7.2	0.792	0.878	0.236
White Clover	5.0	7.3	6.4	6.2	2.1	0.934	0.633	0.552
Weed	4.1	4.3	5.9	5.4	1.3	0.313	0.926	0.790
Dead	10.5	15.2	13.5	8.1	4.2	0.631	0.936	0.253
Mid-grazing (0730 h)								
Grass	50.4	51.1	50.7	56.0	2.3	0.327	0.264	0.367
White Clover	3.4	3.5	4.5	4.0	1.5	0.640	0.908	0.856
Weed	5.0	5.8	3.2	5.0	1.6	0.448	0.464	0.765
Dead	30.8	27.3	24.7	26.0	6.9	0.617	0.885	0.743
Post-grazing (1430 h)								
Grass	61.3	54.9	55.3	57.1	7.1	0.794	0.750	0.577
White Clover	4.2	3.1	2.0	4.3	1.2	0.690	0.180	0.642
Weed	5.2	5.3	5.7	2.2	1.7	0.454	0.349	0.329
Dead	42.0	42.1	47.1	63.1	7.9	0.124	0.330	0.332

Table 16: Nutritive value (% of total dry weight) to ground level whilst standing, of high (2768 ± 45 kg DM/ha) and low (2169 ± 45 kg DM/ha), pasture mass for standing and pre-mown treatments at pre- and post-grazing

	Low mass		High mass			*P value*		
	Standing	**Pre-mown**	**Standing**	**Pre-mown**	**s.e.m**	**Pasture Mass**	**Preparation**	**M x P**
Pre-grazing (1530 h)								
DM	15.0	15.8	15.4	15.1	0.01	0.841	0.744	0.480
OM	90.0	89.2	89.8	89.5	0.37	0.866	0.166	0.506
WSC	20.5	20.6	21.7	21.9	0.96	0.237	0.923	0.970
NDF	41.3	40.8	42.1	39.0	2.14	0.826	0.431	0.558
ADF	23.4	23.3	24.2	22.9	0.84	0.854	0.432	0.511
CP	18.8	18.4	17.1	17.6	0.77	0.137	0.941	0.558
DOMD	76.89	76.95	77.59	78.24	1.26	0.453	0.788	0.819
ME (MJ/kg DM)	10.9	10.9	10.8	11.0	0.13	0.854	0.432	0.511
Post-grazing (1430 h)								
DM	17.7	18.8	19.6	18.6	2.41	0.717	0.974	0.687
OM	87.2	87.4	88.5	86.7	1.13	0.758	0.501	0.394
WSC	19.7	15.3	19.9	17.1	1.34	0.450	**0.020**	0.558
NDF	46.6	47.4	50.6	50.4	1.83	0.079	0.878	0.817
ADF	27.5	27.5	29.4	29.4	0.84	**0.043**	0.977	0.992
CP	13.7	15.5	12.2	12.9	0.99	0.061	0.235	0.625
DOMD	67.9	68.9	67.4	65.2	2.68	0.437	0.821	0.566
ME (MJ/kg DM)	10.3	10.3	10.0	10.0	0.13	**0.043**	0.977	0.992

Table 17: Nutritive value (% of total dry weight) of nutrient consumed (above grazing height) at high (2768 ± 45 kgDM/ha) and low (2169 ± 45 kgDM/ha), pasture mass for standing and pre-mown treatments at pre- and post-grazing

Pasture Mass	Low mass			High mass				P value		
Preparation	Standing	Pre-mown[1]	Pre-mown[2]	Standing	Pre-mown[1]	Pre-mown[2]	s.e.d	Pasture Mass	Preparation	M x P
DM	12.7	12.8	18.8	13.6	14.6	18.0	2.32	0.919	**0.049**	0.747
OM	91.8	91.3	89.9	90.6	92.6	90.0	0.51	0.934	0.618	0.100
WSC	23.0	21.0	17.4	27.4	25.4	18.5	0.95	**0.005**	**<0.001**	0.459
NDF	35.1	40.0	39.1	28.4	33.8	39.7	2.28	0.097	**0.021**	0.438
ADF	19.1	22.6	21.6	17.1	18.9	22.0	0.92	0.078	**0.008**	0.360
CP	23.3	19.3	24.4	21.2	22.3	23.3	1.25	0.951	0.073	0.274
DOMD	84.7	81.9	81.5	86.2	89.9	80.7	1.88	0.150	0.346	0.596

[1]Pre-mown pasture while still standing

[2]Pre-mown pasture after 3 hours wilting

4.2 Milk production and intake

On average apparent dry matter intake (DMI) was 15.3 kg DM/cow/day. Pre-mowing pasture decreased apparent DMI by 1.3 kg DM/cow/day (P = 0.037, Table 18). Apparent DMI was not affected by pasture mass. The metabolisable energy intakes between treatments were not significantly different, despite the pre-mown treatments consuming less DM than those on the standing treatments. The daily milk yield was significantly (P< 0.001) lower in pre-mown treatments and significantly (P = 0.003) higher in low pasture masses. The low mass standing treatment had significantly (LSD = 0.699) greater daily milk yield (14.80 kg/cow/day), 14% higher than that of the pre-mown (12.72 kg/cow/day). Similarly, in the high mass treatments, the pre-mown cows trended to have lower daily milk yields than that of the standing, however, the difference was not significant (LSD = 0.699). Daily milk lactose yield was significantly (P = 0.043) lower in the pre-mown treatment cows, the lactose was 14% and 15% lower for low and high mass pastures, respectively.

4.3 Nitrogen intake and excretion

The nitrogen content (N%) of pre-grazing herbage for the standing treatments was adjusted in the same way as described previously for Table 17. There was no difference in nitrogen content in the pre-mown treatments than the standing. However, pre-mowing pasture increased nitrogen in the herbage by 4.4% and 8.6% in low and high mass pastures respectively (Table 19). The nitrogen intake reflected the apparent dry matter intake and was largely driven by the herbage N%. The highest nitrogen intake from the low mass standing pastures (594.4 g/cow/day) and the lowest from the low mass pre-mown pastures (531.8 g/cow/day), these were also not significantly different. The nitrogen content (%) in the urine was greater (P = 0.042) from cows on low pasture mass treatments, corresponding with numerically higher N intakes. Faecal N content (g N/kg DM) was also greater (P = 0.002) in low mass treatments. The concentration of N in dung was reduced (P = 0.009) in cows consuming pasture which had been pre-mown. Cows on low mass pastures had significantly (P< 0.001) more milk urea-N (MUN) on average (19.6% greater) than cows on high mass pastures. Low mass pasture has 9.3 g N in milk more than high mass. As a result of having a high nitrogen in milk, the low mass pastures, the nitrogen use efficiency (NUE) was higher (16.9% c. 16.1%) though not significantly, a result of high N intakes. The NUE trended to being lower in pre-mown treatments, on average by 1.9%

Table 18: Intake, milk yield and milk composition of cows offered pastures following either high (2768 ± 45 kg DM/ha) or low (2169 ± 45 kg DM/ha), pasture mass for standing and pre-mown treatments.

	Low mass		High mass			*P value*		
	Standing	Pre-mown	Standing	Pre-mown	s.e.d	Pasture Mass	Preparation	M x P
Dry Matter Intake (kg/cow/day)	16.2	14.8	15.7	14.5	0.596	0.528	**0.037**	0.911
Metabolisable Energy Intake (MJ/cow/day)	168.7	155.4	167.0	156.3	9.78	0.975	0.254	0.897
Milk Yield (kg/cow/day)	14.80	12.73	13.00	12.43	0.36	**0.003**	**<0.001**	**0.034**
Milk Composition								
Fat (%)	5.54	5.72	6.15	5.54	0.25	0.705	0.728	**0.046**
Protein (%)	4.31	4.40	4.41	4.11	0.12	0.421	0.360	0.113
Lactose (%)	4.91	4.78	5.00	4.70	0.12	0.966	0.089	0.509
Milk fat yield (kg/cow/day)	0.79	0.78	0.80	0.68	0.06	0.422	0.248	0.365
Milk protein yield (kg/cow/day)	0.62	0.56	0.58	0.49	0.04	0.158	0.066	0.791
Milk lactose yield (kg/cow/day)	0.71	0.61	0.66	0.56	0.05	0.274	**0.043**	0.949
Total milksolids (kg/cow/day)	1.42	1.34	1.38	1.16	0.10	0.280	0.141	0.509

Table 19: Nitrogen use efficiency of cows offered pastures of either high (2768 ± 45 kg DM/ha) or low (2169 ± 45 kg DM/ha), pasture mass for standing and pre-mown treatments.

	Low mass		High mass			*P value*		
	Standing	Pre-mown	Standing	Pre-mown	s.e.d	Pasture Mass	Preparation	M x P
N% herbage consumed	3.73	3.90	3.40	3.72	0.20	0.951	0.073	0.274
N Intake (g/cow/day)	594	577	532	540	31.6	0.128	0.883	0.688
Urine N (%)	0.51	0.50	0.40	0.46	0.04	**0.042**	0.561	0.390
Faecal N (g/kg DM)	3.54	3.39	3.37	3.24	0.05	**0.002**	**0.009**	0.817
Faecal DM%	86.5	87.5	87.9	87.5	0.90	0.283	0.646	0.329
MUN (mg/dl)	14.5	14.6	11.2	12.2	0.36	**<0.001**	0.140	0.201
N excretion in milk (g N milk)	97.8	87.3	90.2	76.3	6.46	0.158	0.066	0.791
Nitrogen use efficiency (g N milk/g N intake)	17.6	16.1	17.3	14.9	1.60	0.636	0.258	0.777

4.1 Grazing behaviour

The first grazing bout was defined as the period from when the cows entered a new allocation to when they spent greater than 25 minutes either idle or ruminating (Figure 12). The standing pasture treatments cows spent less time grazing than the pre-mown cows in their first grazing bout, however, this result was not significant (P = 0.184). Pre-mown cows spent 212 and 214 minutes on average for the low and high pasture masses, respectively. While standing cows spent 226 and 236 minutes on average for the low and high pasture masses, respectively. The low mass standing cows have the smallest range, this shows that there is limited variation in the time spent grazing in the first bout. In comparison the other three treatments had a greater interquartile range.

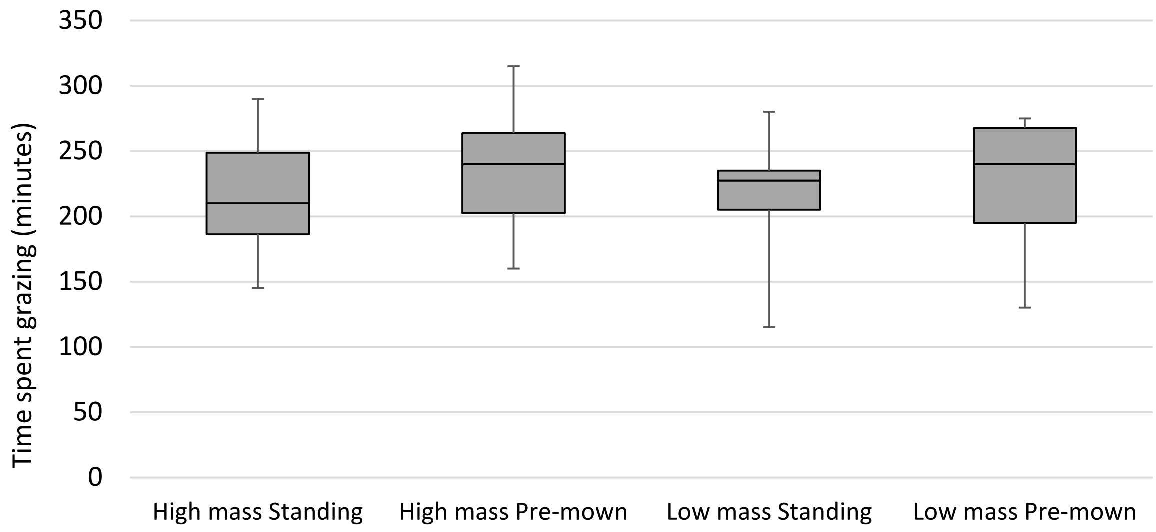

Figure 12: Box and whisker plot of the time spent (minutes) for the first grazing bout comparing either high (2768 ± 45 kgDM/ha) or low (2169 ± 45 kgDM/ha), pasture mass for standing and pre-mown treatments.

Proportion of time spent grazing also had a significant (P = 0.011) interaction between pasture mass and preparation (Figure 13). At high pasture mass there was no effect of mowing on time spent grazing whereas at low pasture mass cows on mown pasture spent less time grazing than cows on standing pasture. Pasture mass significantly affected the proportion of time spent ruminating and idle. On low mass pasture masses cow's spent significantly less time ruminating (P = 0.045) and proportionally more time idle (P = 0.020) than cows on high mass pastures. For proportion of time spent idle there was a significant (P = 0.030) interaction between pasture mass and subsequent preparation.

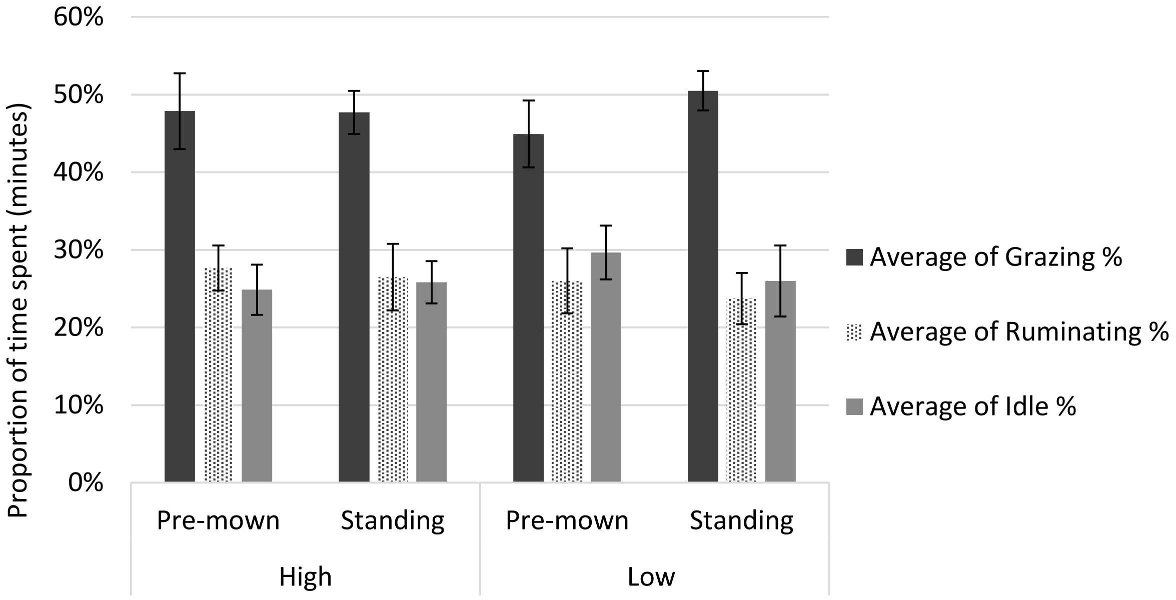

Figure 13: Proportion of total time (± SD) spent grazing, ruminating and idle for animals grazing either high (2768 ± 45 kgDM/ha) or low (2169 ± 45 kgDM/ha), pasture mass for standing and pre-mown treatments.

The total time spent standing had the tendency (LSD = 67.5) to be greater in the high mass pre-mown cows (Figure 14). High mass pre-mown cows had a standing to sitting ratio of 2.04, while standing cows at the same mass were only 1.70. The low mass pre-mown cows had a standing to sitting ratio of 1.60, while standing cows at the same mass spent more time standing, with a ratio of 1.73.

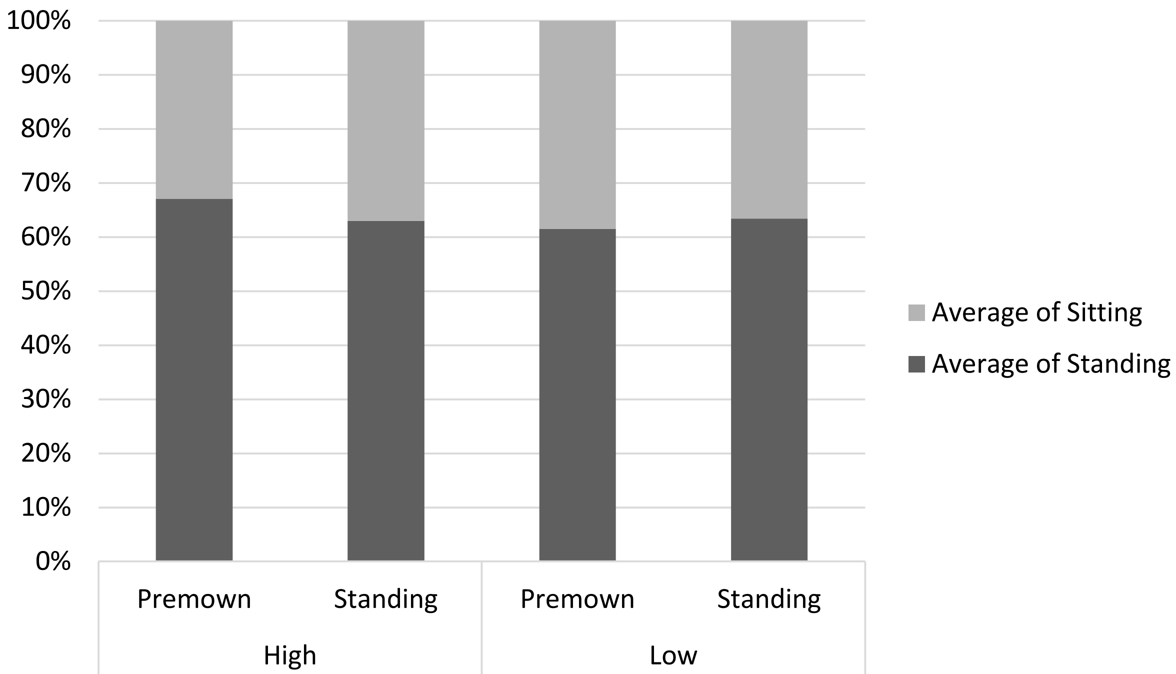

Figure 14: Proportion of total time spent standing and sitting for animals grazing either high (2768 ± 45 kgDM/ha) or low (2169 ± 45 kgDM/ha), pasture mass for standing and pre-mown treatments.

Figure 15, describes the grazing behaviour patterns of the four different treatments. Grazing occurs at night in distinct bouts, the first bout occurring from when the cows entered the break at 1530 h lasting until 1600 h. The next grazing bout occurs at around 2130 h, however, the low mass pre-mown cows appear to start the second bout later at around 2200 h. A large proportion of the cow's rumination appears to occur after the end of the second grazing bout from 0130 h onwards. The low mass standing cows appear to have another small grazing bout around 0400 h. During the day however, grazing bouts are not as defined. The grazing becomes more randomly dispersed as the day goes on after the cows are returned to the allocation after the morning milking. The high mass cows had more ($P = 0.015$) grazing bouts than the low mass (3.9 c. 3.2 grazing bouts). There was also an interaction effect ($P = 0.036$) between the number of grazing bouts at night the pasture mass and subsequent preparation.

There was no significant effects of either pasture mass or preparation, 3 or 6 hours after the cows were given a fresh pasture allocation. At night the time spent grazing is significantly ($P = 0.009$) effected by pasture mass (Table 20). The high mass cows spent 34 minutes on average grazing. However, there is also a significant ($P = 0.007$) interaction effect, where the high mass standing cows spend less time grazing than the pre-mown but the low mass standing spend more time grazing than the pre-mown. Low mass cows spent 48 minutes more ($P< 0.001$) idle than the high mass. During the day the low mass treatments spent significantly ($P = 0.003$) more time grazing, and significantly ($P= 0.027$) less time idle than the high mass treatments (Table 20)

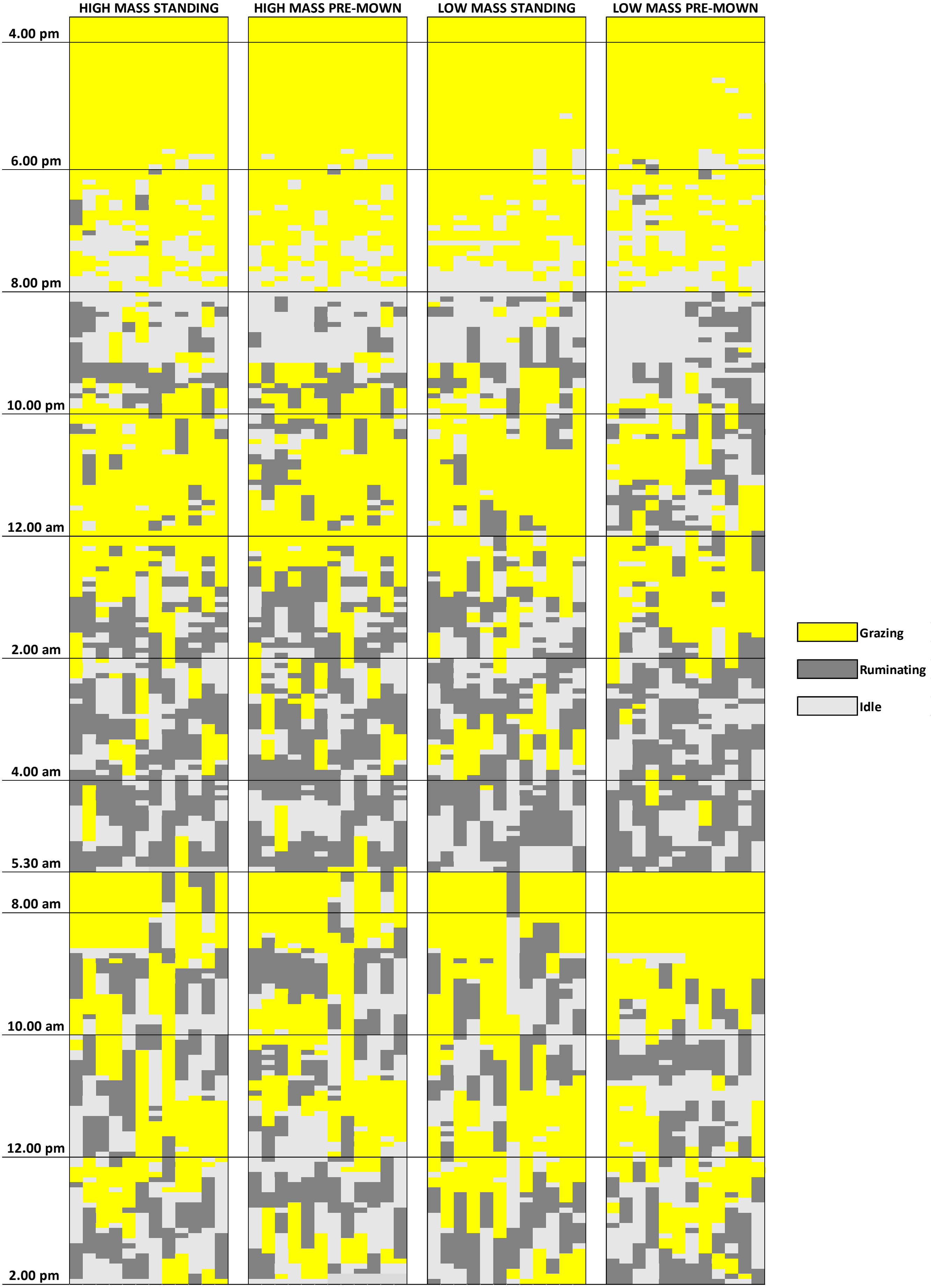

Figure 15: Behaviour patterns of cows offered pastures of either high (2768 ± 45 kgDM/ha) or low (2169 ± 45 kgDM/ha), pasture mass for standing and pre-mown treatments.

Table 20: Proportion of time spent (mins/cow) after 3 (1530 - 1830 h) and 6 (1530 - 2330 h) hours of being on the break, and during the night (1530 - 0700 h) and day (0800 - 1430 h) for cows on high and low pasture masses which was left standing or pre-mown.

Pasture Mass	**Low mass**		**High mass**			***P value***		
Preparation	**Standing**	**Pre-mown**	**Standing**	**Pre-mown**	**s.e.d**	**Pasture Mass**	**Preparation**	**M x P**
After 3 hours								
Grazing	176	165	172	172	3.30	0.707	0.084	0.108
Rumination	0.0	3.3	3.3	0.8	1.39	0.766	0.766	**0.042**
Idle	8.8	17	10	13	2.96	0.576	0.074	0.403
After 6 hours								
Grazing	234	214	225	237	13.6	0.313	0.527	**0.019**
Rumination	30	27	40	32	5.61	0.177	0.288	0.685
Idle	100	124	100	96	8.51	0.098	0.237	0.119
Night								
Grazing	416	360	415	430	12.3	**0.009**	0.108	**0.007**
Rumination	181	214	206	212	10.0	0.267	0.057	0.190
Idle	228	258	205	188	11.6	**<0.001**	0.555	0.052
Day								
Grazing	208	195	175	162	10.4	**0.003**	0.213	0.984
Rumination	112	107	121	130	7.03	**0.027**	0.791	0.363
Idle	93	108	114	119	10.2	0.129	0.334	0.599

5 Discussion

The aim of this study was to determine the effect of pre-mowing in the autumn on herbage composition, pasture quality, apparent dry matter intake, animal behaviour, milk production and to evaluate the impact on nitrogen use efficiency (NUE). Dry matter intake (DMI) appears to be the main driver of milk production. Herbage composition and the chemical characteristics of the pasture were not significantly affected by mowing. However, wilting changed the fibre component of the feed, which may have influenced the dry matter intake and subsequent nitrogen partitioning.

5.1 Herbage yield and composition

The pre-mown pasture masses were significantly lower than those that were not mown, on average pre-mown pastures were 194 kg DM/ha lower. This is a small difference in comparison to Kolver *et al.* (1999), who reported 696 kg DM/ha reduction in pasture production on average over the spring and summer periods (Kolver et al., 1999). This reduction may be due to repeated mowing throughout the season, in comparison to this experiment which only had one or two mowing's prior to the experimental period depending on whether it was low or high mass. Irvine *et al.* (2010) reported significant reduction in post-grazing herbage mass as a result of mowing. In this trial however, there were no significant reductions in post-grazing herbage mass, with post-grazing residuals being on average 966 kg DM/ha. The low post-grazing residuals, having little or no leaf area and were unable to meet energy demands via photosynthesis for growth (Lee et al., 2009). This may be why the pre-mown pre-grazing pasture masses were lower than the standing, due to longer lag phase resulting in slower growth rates (Brougham, 1956). Kolver *et al.* (1999), also reported pasture growth rates dropping from 52 kg DM/ha/day in the control to 34 kg DM/ha/day in pastures which had been pre-mown in October, at the start of the study. However, as mowing continued through the season there was an increase in pasture growth rates, from pastures which had been pre-mown, this is probably a result of increased tiller production by plants (L'Huillier, 1987; Xia et al., 1990). Fulkerson and Michell (1987) reflected that in the spring the regrowth interval before the next defoliation had the biggest effect on herbage yields, while in the autumn the mowing height had a more significant effect on herbage yields (Fulkerson & Michell, 1987). High herbage yields may be achieved from severely defoliated pastures providing that the regrowth interval is long enough for the pasture to achieve the 'three leaf' stage (Fulkerson & Donaghy, 2001; Lee et al., 2009).

One of the objectives of this study was to determine the effect that pre-mowing had on the herbage composition. Interestingly, pasture mass and mowing during the set up phase did not appreciably alter herbage composition. This was inconsistent with other literature, where high pasture masses have greater dead material present than that of the low pasture masses (Hoogendoorn, 1992;

Korte et al., 1984; L'Huillier, 1987). However, in the trial, the high (2798 kg DM/ha) pasture mass may not have been large enough to cause composition differences. For example, Hoogendoorn (1992) high pasture mass was 5310 kg DM/ha where it was being compared to a low mass pasture of 2480 kg DM/ha, a differential of 2830 kgDM/ha. In this experiment the differential was only 661 kg DM/ha, not enough to cause significant herbage composition differences. This may have been accentuated by the reduced growth rates which occur in autumn as a result of temperature declines (Rickard & Radcliffe, 1976), resulting in lower pasture production. Another possible explanation for lack of herbage composition differences may be due to the ploidy of the ryegrass that was used. The experiment used a tetraploid ryegrass, Bryant and Edwards (2012) found that in comparison to a diploid, a tetraploid has a lower crude protein content and higher crude fibre but is still highly digestible.

Severely defoliated plants are likely to have a greater dependence on their stored energy reserves, such as water soluble carbohydrates (WSC) to provide the energy required for regrowth (Fulkerson & Donaghy, 2001). As a result the WSC reserves are likely to be reduced, with varying amount of stores used depending on the defoliation height (Lee, et al., 2009). On average there was a 36 g WSC/kg DM reduction between post-grazing residuals which had been pre-mown and those that were left standing. This shows that a greater proportion of WSC may have been mobilized or utilized in the pre-mown pastures. Alternatively, another reason for the low WSC could be the due to the pasture being mown in the morning. This would mean that the increased WSC stores which build up as a result of photosynthesis through the duration of the day (Bryant, Gregorini, & Edwards, 2012), could not occur as the leaf area required for photosynthesis had already been removed via mowing (Brougham, 1956). This is also the most probable reason for significant increase in WSC content between the pre-mown pasture if it had been left standing and the pre-mown wilted pasture at 1530 hours when the cows were given the new pasture allocation. The pre-grazing WSC content while still standing was not significantly different between pasture masses, however, the WSC increased by 13 g WSC/kg DM from high to low pasture masses. This is most likely due to increased leaf area and regrowth interval (Brougham, 1956; Fulkerson & Donaghy, 2001; Lee et al., 2009). The increased WSC in high mass pastures may have increased the feeding value through subsequent increases in DOMD (Table 17).

Neutral detergent fibre (NDF) is a strong indicator of forage quality (Waghorn, Burke, & Kolver, 2007). Irvine *et al.* (2010) found that pre-mown pasture wilted for 12 to 24 hours resulted in a 3.9% increase in NDF content. In comparison, Kolver *et al.* (1999) found that the pre-mown pastures which had been wilted for 24 hours had consistently less NDF than that of the control, throughout the season. In this experiment, pre-mowing and wilting pasture for 3 hours increased NDF by 10% and 29% in comparison to low and high pasture masses that were not mown, respectively (Table 17), these increases were much greater than those of Irvine *et al.* (2010). However, these differences may be seasonal, with Kolver *et al.* (1999) reporting higher NDF in January and February in comparison to October and November.

The crude protein (CP) content between high and low herbage masses was not significantly different while the pre-grazing pasture was still standing (Table 16). However, the high mass CP was 1.3% lower on average than the low mass, showing a degree of nitrogen metabolism and tissue senescence within the pasture (Hortensteiner & Feller, 2002).

5.2 Dry matter intake and milk yield

Pre-mowing reduced apparent DMI and had a tendency for decreased milk protein yield. The reduction in apparent intake could be attributed to two possible factors. The first, is an increase in the fibre content in pre-mown herbage may have restricted intake, and secondly some loss of herbage availability following mowing may have inadvertently reduced allowance. Neutral detergent fibre (NDF) content is highly related to DMI of forage. NDF measures most of the structural components in plant cells such as lignin, hemicellulose and cellulose, but not pectin. DMI is positively correlated with NDF concentration when energy limits intake, but negatively correlated with NDF concentration when fill limits intake (Allen, 2000). The increase in NDF in wilted pastures/pre-mown pastures may be a limiting factor on DMI, in pre-mown pastures the apparent DMI was reduced by 1.4 kg DM/cow/day and 1.2 kg DM/cow/day for low and high pastures respectively. Similarly, Irvine *et al.* (2010) had the same target a daily pasture intake of 15 kg DM/cow, were they found that topping pastures pre-grazing significantly reduced cow dry matter intake by 2.3 kg DM/cow/day.

The pre-mowing cows ate more fibre as they were unable to exert selection pressure to alter diet composition. DMI increases with decreasing NDF, when NDF content of the diet exceeds 25% (Allen, 2000). Rates of fibre digestion can vary, generally decreasing as pasture matures (Waghorn et al., 2007). Burke et al. (2000) found that effective degradability was reduced from fresh perennial pasture to that which had been ensilaged, from 74% to 67% (Burke, Waghorn, Brookes, Attwood, & Kolver, 2000). Increases in ADF and NDF, are generally reflected in lower digestible organic matter content (DOMD). However, loss of digestibility was not apparent in the current study from the pre-mowing of the pasture as there was no effect on grazing and ruminating behavior, this means that the NDF is still very digestible, with no significant increases in rumination time by pre-mowing.

Increasing pre-grazing herbage mass increased the rumination time on average by 2% at high pasture masses. Similarly, Tunon *et al.* (2011) found that by increasing the pasture mass from 978 kg DM/ha to 2330 kg DM/ha (above the 4 cm horizon) rumination time increased by 15% (Table 7) (Tunon et al., 2011). In comparison to this trial Tunon *et al.* (2011) has a considerably greater differential between pasture mass treatments. Rumination is more affected by pre-graze herbage mass, with greater pasture masses requiring greater rumination as a result of increased fibre length and reduced digestibility (Van Soest, 1965; Weiss, 1998). In addition, grazing preference is also removed through pre-mowing. Indifference (where animals eat whatever is in front of them) is the lowest cost foraging option (Parsons, Thornley, Newman, & Penning, 1994).

Cows grazing standing pasture had the tendency to spend less time grazing than the pre-mown cows in their first grazing bout (Figure 12). This shows that pre-mowing pasture alters grazing behaviour and means that pasture can be consumed faster from a standing pasture, increasing the total intake rate. This may be a result of changes in the harvesting cost of grazing pasture, with sward height being removed as a limiting factor for bite depth and mass (Griffiths et al., 2003a, 2003b), bite volume can be maximised resulting in increased DMI, potentially prolonging the first grazing bout. Optimal dry matter intake rates are achieved by increasing bite mass and bite rate. Grazing ruminants can vary bite dimensions, bite rate and grazing time in response to changes in sward conditions (Dillon, 2006), to maximise daily dry matter intake. Bite rate and intake rate are limited by handling time, there is a fixed time cost associated with opening and closing the jaw to prehend a bite (Parsons et al., 1994). In this regard pre-mowing pasture, while minimising harvest cost may result in increased handling time as a result of increased bite mass. An animal's intake may be constrained by the ease of prehension, with intakes becoming more limiting with increased proportions of the sward being consumed (Griffiths & Gordon, 2003), pre-mowing removes this.

Interestingly there was no significant increase in grazing time by pre-mown cows during the night. However, it was observed that the majority (if not all the available) of the wilted grass mown the day prior had been consumed. This means that by pre-mowing, cows are capable of consuming similar pasture allocations in a shorter period of time in comparison to the standing cows. With this said, the DMI of the pre-mown cows was significantly lower, potentially a result of wilted pasture being lost to the ground. This does provide some provision for the idea that pre-mowing can increase intakes providing that after finishing the pre-mown grass they are moved onto a fresh allocation. It may also therefore be possible to increase milk production, by increasing DMI even at a high pasture mass.

The 24 hour break allocation area was calculated using manufactures calibrations for pasture mass to calculate the daily pasture allowance. However, the calibrations over calculated the available pasture mass at the high pasture masses, resulting in those cows getting a smaller allocation area and therefore lower pasture allowance. The allowance available to ground level between pasture masses was therefore very different (27.3 c. 36.8 kg DM/cow/day). Despite this, the DMI's were not greatly affected, with significant differences resulting between pre-mown and standing pastures.

5.3 Milk production

Pre-mowing significantly lowered the lactose concentration of the milk which drives volume and resulted in a reduction in milk yield (kg/cow/day). While there was a trend towards a reduction in milk protein yield caused by pre-mowing, this did not translate into significant effects of pre-mowing on total milk solids. Irvine et al. (2010) found that for cows which had pasture pre-mown, milk production was reduced by 1.9 kg/cow/day compared to the control. Kolver *et al.* (1999) found that pre-mowing reduced milk production in comparison to the control in spring (September to November), and increased it in the summer (December to February). The milk protein yield (kg/cow/day) from cows on the standing treatment tended to have greater milk protein % which is likely to be the result of increased intake and reduced fibre (Sutton, 1989). The lower fibre and greater DMI signaling improved rate of energy availability and synchrony for microbial protein synthesis. The milk lactose yield (kg/cow/day) was significantly lower for cows consuming wilted grass. It is generally accepted that it is difficult to influence dietary means apart from severe underfeeding (Sutton, 1989). The depression in milk lactose yield may therefore be due to the significantly lower DMI in pre-mown cows.

5.4 Nitrogen intake and excretion

It was intended that animals in the high pasture mass treatment would have a significantly lower N intake than the low mass pastures. However, the N intake in low mass pastures was only 49.5 g/cow/day higher. The N intake is driven by the N content in the herbage, which was also not significantly different. The N content in the herbage may not have been significantly different as the regrowth interval between pastures may have been too short, at only 6 days.

The nitrogen use efficiency (NUE) was higher in low mass pastures (16.9% c. 16.1%), though not significantly. Rius *et al.* (2010) had NUE values ranging from 31 to 43% depending on available dietary energy and crude protein (Rius, 2010). Efficiency of N utilization in milk typically ranges from 15 to 25% (Tamminga, 1992), which is in close agreement with Haig et al. (2002) results. However, this efficiency was lower than data Chalupa and Ferguson (1995) received, where they achieved values of 30 to 35% by balancing the diet to maximize microbial capture of rumen ammonia nitrogen (NH_3-N) and increasing MP reaching the small intestine from undegradable intake protein (UIP) sources (Chalupa & Ferguson, 1995). NUE received at both pasture masses was lower than the NUE received by Bryant and Edwards (2012) for the same ploidy. For an N intake off 447 g/d, cows had a NUE of 0.22 (Bryant & Edwards, 2012). Even though the end digestibility of the wilted pasture is the same, the greater NDF in the wilted pasture may slow the rate of degradation in the rumen and the therefore the rate of energy availability (Jung & Allen, 1995; Waghorn et al., 2007). The slower rate of energy available to rumen microbes will result in decreased N retention, and greater secretion in urine and faeces (Hoekstra et al., 2007). Despite the, the lack of rumen energy scynchrony was not apparent in the results, with pre-mown cows having significantly lower faecal N (g/kg DM) and no significant effect on urine N content compared to the standing.

A high energy and low crude protein diet results in increased efficiency of N utilization. Wilting pasture decreases the WSC and has high CP, this decreases the efficiency of N utilization. There is a negative relationship between NUE and WSC:CP (Hoekstra et al., 2007; Rius, 2010). With increasing CP the NUE decreases linearly ($P < 0.01$) (Broderick, 2003; Gourley et al., 2012). However, in the trial there was no significant differences in CP content, all treatments were high with an average of 23%, high producing cows only require 15-16% CP (Pacheco & Waghorn, 2008), this means that there is a high potential for losses through urine N excretion (Broderick, 2007). The high mass cows had significantly less N excreted in their urine, faeces and had a lower milk urea-N. This may be an indication, that while N intakes were not significantly different, high mass cows were consuming less N (Haig et al., 2002; Roseler, Ferguson, Sniffen, & Herrema, 1993).

Conclusions

- In the autumn, pre-mowing pasture and wilting it for 3 hours had no significant effects on pasture quality. However, there were significant increases in the NDF, ADF and WSC content of the wilted grass. Increased crude fibre has been associated with decreases in dry matter intake.

- Dry matter intake was reduced by pre-mowing for cows allocated the same allowance. Subsequently there was a resulting decrease in milk production. It may be possible to increase dry matter intake by shifting cows to a new pasture allocation once they have finished, as it was observed that the pre-mown cows had eaten all the wilted grass overnight. The ability to consume the majority of the pasture allocation by pre-mowing may have been a result of grazing efficiencies which include a reduced harvest cost and larger bite volume.

- Animal behaviour was most significantly affected by pasture mass, with no observed effects from pre-mowing the pasture.

- The N intake was not significantly affected by pasture mass, this resulted in the NUE values being very similar between treatments. Pre-mowing had the tendency to decrease NUE, most likely as result of the increase in crude fibre. While still very digestible, the increase in crude fibre may have affected energy availability to rumen microbes resulting in less N retention, from the slightly higher N intakes.

5.5 Further Research

There is limited literature around the effects of mowing on pasture production, pasture quality and milk yield. More research is required to quantify seasonal changes in pasture production from mowing. The utilisation rate, and rate at which pasture can be consumed also requires more research, as this is where the most significant increases in dry matter intake will be made, by increasing allocation.

References

Allen, M. S. (2000). Effects of diet on short-term regulation of feed intake by lactating dairy cattle. *Journal of Dairy Science, 83*(7), 1598-1624.

Bircham, J. S., & Hodgson, J. (1983). The influence of sward condition on rates of herbage growth and senescence in mixed swards under continuous stocking management. *Grass and Forage Science, 38*(4), 323-331. doi: 10.1111/j.1365-2494.1983.tb01656.x

Boyce, B., & Kerr, G. (2013). Is mowing cutting management? *SIDE: Proceedings*.

Broderick. (2003). Effects of varying dietary protein and energy levels on the production of lactating dairy cows. *Journal of Dairy Science, 86*(4), 1370-1381.

Broderick. (2007). Reduced Crude Protein Rations for High Producing Cows: Production and Environmental Effects *Symposium Proceedings*.

Brougham, R. W. (1956). Effect of intensity of defoliation on regrowth of pasture. *Australian Journal of Agricultural Economics, 7*(5), 377-387. doi: 10.1071/ar9560377

Bryant, R. H., Dalley, D. E., Gibbs, J., & Edwards, G. R. (2013). Effect of grazing management on herbage protein concentration, milk production and nitrogen excretion of dairy cows in mid-lactation. *Grass and Forage Science*.

Bryant, R. H., & Edwards, G. R. (2012). *Effect of ploidy and pasture mass on milk production and nitrogen use efficiency in late summer*.

Bryant, R. H., Gregorini, P., & Edwards, G. R. (2012). Effects of N fertilisation, leaf appearance and time of day on N fractionation and chemical composition of Lolium perenne cultivars in spring. *Animal Feed Science and Technology, 173*(3-4), 210-219. doi: 10.1016/j.anifeedsci.2012.02.003

Burke, J. L., Waghorn, G. C., Brookes, I. M., Attwood, G. T., & Kolver, E. S. (2000). Formulating total mixed rations from forages - defining the digestion kinetics of contrasting species. *Proceedings of the New Zealand Society of Animal Production, 60*, 9-14.

Burns, J. C., & Sollenberger, L. E. (2002). Grazing Behavior of ruminants and daily performance from warm-season grasses. *Crop Science, 42*(3), 873-881.

Chalupa, W., & Ferguson, J. D. (1995). *Feeding Strategies to Reduce the Impact of Nitrogen on the Environment.* Paper presented at the Nutrition Conference, Dallas.

Cosgrove, C. P., & Edwards, G. R. (2007). Control of Grazing Intake. In P. V. Rattray, I. M. Brookes & A. M. Nicol (Eds.), *Pasture and supplements for grazing animals*. Hamilton, N.Z.: Hamilton, N.Z. : New Zealand Society of Animal Production.

CSIRO. (2007). *Nutrient Requirements of Domesticated Ruminants*. Melbourne: Melbourne : CSIRO Publishing.

Curran, J., Delaby, L., Kennedy, E., Murphy, J. P., Boland, T. M., & O'Donovan, M. (2010). Sward characteristics, grass dry matter intake and milk production performance are affected by pre-grazing herbage mass and pasture allowance. *Livestock Science, 127*(2-3), 144-154. doi: 10.1016/j.livsci.2009.09.004

DairyNZ. (2010). *Facts and Figures: For New Zealand Dairy Farmers*. Hamilton: DairyNZ.

DairyNZ. (2012). *New Zealand Dairy Statistics*. Hamilton: DairyNZ and Livestick Improvement Ltd.

Dalley, D. E., Roche, J. R., Grainger, C., & Moate, P. J. (1999). Dry matter intake, nutrient selection and milk production of dairy cows grazing rainfed perennial pastures at different herbage allowances in spring. *AUSTRALIAN JOURNAL OF EXPERIMENTAL AGRICULTURE, 39*(8), 923-931.

Delagarde, R., Prache, S., D'Hour, P., & Petit, M. (2001). Grass intake by grazing ruminants. [Ingestion de l'herbe par les ruminants au paturage.]. *Fourrages*(166), 189-212.

Dewhurst, R. J., & Thomas, C. (1992). Modeling of nitrogen transactions in the dairy cow and their environmental consequences. *Livestock Production Science, 31*(1-2), 1-16. doi: 10.1016/0301-6226(92)90048-9

Dillon, P. (2006). *Achieving high dry-matter intake from pasture with grazing dairy cows*.

Fulkerson, W. J., & Donaghy, D. J. (2001). Plant-soluble carbohydrate reserves and senescence - key criteria for developing an effective grazing management system for ryegrass-based pastures: a review. *Australian Journal of Agricultural Economics, 41*(2), 261-275. doi: 10.1071/ea00062

Fulkerson, W. J., & Michell, P. J. (1987). The effect of height and frequency of mowing on the yield and composition of perennial ryegrass white clover swards in the autumn to spring period. *Grass and Forage Science, 42*(2), 169-174. doi: 10.1111/j.1365-2494.1987.tb02104.x

Gourley, C. J. P., Aarons, S. R., & Powell, J. M. (2012). Nitrogen use efficiency and manure management practices in contrasting dairy production systems. *Agriculture, Ecosystems & Environment, 147*(0), 73-81. doi: http://dx.doi.org/10.1016/j.agee.2011.05.011

Griffiths, W. M., & Gordon, I. J. (2003). Sward structural resistance and biting effort in grazing ruminants. *Animal Research, 52*(2), 145-160. doi: 10.1051/animres:2003012

Griffiths, W. M., Hodgson, J., & Arnold, G. C. (2003a). The influence of sward canopy structure on foraging decisions by grazing cattle. I. Patch selection. *Grass and Forage Science, 58*(2), 112-124. doi: 10.1046/j.1365-2494.2003.00360.x

Griffiths, W. M., Hodgson, J., & Arnold, G. C. (2003b). The influence of sward canopy structure on foraging decisions by grazing cattle. II. Regulation of bite depth. *Grass and Forage Science, 58*(2), 125-137. doi: 10.1046/j.1365-2494.2003.00361.x

Haig, P. A., Mutsvangwa, T., Spratt, R., & McBride, B. W. (2002). Effects of dietary protein solubility on nitrogen losses from lactating dairy cows and comparison with predictions from the Cornell Net Carbohydrate and Protein System. *Journal of Dairy Science, 85*(5), 1208-1217. doi: 10.3168/jds.S0022-0302(02)74184-2

Harris, W., & Thomas, V. J. (1970). Competition among pasture plants. 1. Effects of frequency and height of cutting on competition between two ryegrass cultivars. *New Zealand Journal of Agricultural Research, 13*(4), 833-861.

Higgs, R. J., Chase, L. E., & Van Amburgh, M. E. (2012). Development and evaluation of equations in the Cornell Net Carbohydrate and Protein System to predict nitrogen excretion in lactating dairy cows. *Journal of Dairy Science, 95*(4), 2004-2014. doi: http://dx.doi.org/10.3168/jds.2011-4810

Hoekstra, N. J., Schulte, R. P. O., Struik, P. C., & Lantinga, E. A. (2007). Pathways to improving the N efficiency of grazing bovines. *European Journal of Agronomy, 26*(4), 363-374. doi: 10.1016/j.eja.2006.12.002

Holmes, C. W., Hoogendoorn, C. J., Ryan, M. P., & Chu, A. C. P. (1992). Some effects of herbage composition, as influenced by previous grazing management, on milk-production by cows grazing on ryegrass white clover pastures .1. Milk-production in early spring - effects of different regrowth intervals during the preceding winter period. *Grass and Forage Science, 47*(4), 309-315. doi: 10.1111/j.1365-2494.1992.tb02276.x

Hoogendoorn, C. J. (1992). Some effects of herbage composition, as influenced by previous grazing management, on milk production by cows grazing on ryegrass/white clover pastures. 2. Milk production in late spring/summer: effects of grazing intensity during the preceding spring period. *Grass and Forage Science, 47*(4), 316-325. doi: 10.1111/j.1365-2494.1992.tb02277.x

Hoogendoorn, C. J., Holmes, C. W., & Chu, A. C. P. (1992). Some effects of herbage composition, as influenced by previous grazing management, on milk-production by cows grazing on ryegrass white clover pastures .2. Milk-production in late spring summer - effects of grazing intensity during the preceding spring period. *Grass and Forage Science, 47*(4), 316-325. doi: 10.1111/j.1365-2494.1992.tb02277.x

Hortensteiner, S., & Feller, U. (2002). Nitrogen metabolism and remobilization during senescence. *Journal of Experimental Botany, 53*(370), 927-937. doi: 10.1093/jexbot/53.370.927

Hunt, W. F., & Field, T. R. O. (1979). Growth characteristics of perennial ryegrass. *Proceedings of the New Zealand Grassland Association, 40*, 104-113.

Illius, A. W., Gordon, I. J., Milne, J. D., & Wright, W. (1995). Costs and benefits of foraging on grasses varying in canopy structure and resistance to defoliation. *Functional Ecology, 9*(6), 894-903. doi: 10.2307/2389988

Irvine, L., Freeman, M., & Rawnsley, R. (2010). *The effect of grazing residual control methods on cow intake and milk production in late spring.* Paper presented at the Australasian Dairy Science Symposium: Meeting the Challenges for Pasture-Based Dairying.

Jung, H. G., & Allen, M. S. (1995). Characteristics of plant-cell walls affecting intake and digestibility of forages by ruminants. *Journal of Animal Science, 73*(9), 2774-2790.

Kemp, P. D., Condron, L. M., & Matthew, C. (1999). Pastures and Soil Fertility. In J. White & J. Hodgson (Eds.), *New Zealand pasture and crop science*
Auckland, N.Z.: Oxford : Oxford University Press.

Kennedy, E., O'Donovan, M., Murphy, J. P., Delaby, L., & O'Mara, F. P. (2007). Effect of spring grazing date and stocking rate on sward characteristics and dairy cow production during midlactation. *Journal of Dairy Science, 90*(4), 2035-2046. doi: 10.3168/jds.2006-368

Kolver, E. S., Penno, J. W., MacDonald, K. A., McGrath, J. M., & Carter, W. A. (1999). Mowing pasture to improve milk production. *Proceedings of the New Zealand Grassland Association, 61*, 139-145.

Korte, C. J., Watkin, B. R., & Harris, W. (1984). Effects of the timing and intensity of spring grazings on reproductive development, tillering, and herbage production of perennial ryegrass dominant pasture. *New Zealand Journal of Agricultural Research, 27*(2), 135-149.

Korte, C. J., Watkin, B. R., & Harris, W. (1985). Tillering in Grasslands Nui perennial ryegrass swards .1. Effect of cutting treatments on tiller appearance and longevity, relationship between tiller age and weight, and herbage production. *New Zealand Journal of Agricultural Research, 28*(4), 437-447.

L'Huillier, P. J. (1987). Effect of dairy cattle stocking rate and degree of defoilation on herbage accumulation and quality in ryegrass white clover pasture. *New Zealand Journal of Agricultural Research, 30*(2), 149-157.

LandcareResearch. (2014). SMapOnline. from http://smap.landcareresearch.co.nz/smap

Lee, J. M., Donaghy, D. J., & Roche, J. R. (2008). Short Communication: Effect of Postgrazing Residual Pasture Height on Milk Production. *Journal of Dairy Science, 91*(11), 4307-4311. doi: 10.3168/jds.2008-1188

Lee, J. M., Donaghy, D. J., Sathish, P., & Roche, J. R. (2009). Interaction between water-soluble carbohydrate reserves and defoliation severity on the regrowth of perennial ryegrass (Lolium perenne L.)-dominant swards. *Grass and Forage Science, 64*(3), 266-275. doi: 10.1111/j.1365-2494.2009.00692.x

Motazedian, I., & Sharrow, S. H. (1990). Defoliation frequency and intensity effects on pasture forage quality. *Journal of Range Management, 43*(3), 198-201. doi: 10.2307/3898671

O'Donovan, M., & Delaby, L. (2008). Sward characteristics, grass dry matter intake and milk production performance is affected by timing of spring grazing and subsequent stocking rate. *Livestock Science, 115*(2-3), 158-168. doi: 10.1016/j.livsci.2007.07.010

Pacheco, D., & Waghorn, G. C. (2008). Dietary nitrogen - definitions, digestion, excretion and consequences of excess for grazing ruminants. *Proceedings of the New Zealand Grassland Association, 70*, 107-116.

Parsons, A. J., Thornley, J. H. M., Newman, J., & Penning, P. D. (1994). A mechanistic model of some physical determinants of intake rate and diet selection in a 2-species temperate grassland sward. *Functional Ecology, 8*(2), 187-204. doi: 10.2307/2389902

Perez-Prieto, L. A., & Delagarde, R. (2013). Meta-analysis of the effect of pasture allowance on pasture intake, milk production, and grazing behavior of dairy cows grazing temperate grasslands. *Journal of Dairy Science, 96*(10), 6671-6689. doi: 10.3168/jds.2013-6964

Peyraud, J. L., Comeron, E. A., Wade, M. H., & Lemaire, G. (1996). The effect of daily herbage allowance, herbage mass and animal factors upon herbage intake by grazing dairy cows. *Annales de Zootechnie, 45*(3), 201-217. doi: 10.1051/animres:19960301

Rickard, D. S., & Radcliffe, J. E. (1976). Seasonal distribution of pasture production in New Zealand. XII. Winchmore, Canterbury Plains dryland and irrigated pastures. *New Zealand Journal of Experimental Agriculture, 4*(3), 329-335.

Rius, A., McGilliard, ML., Umberger, CA., Hanigan, MD. (2010). Interactions of energy and predicted metabolizable protein in determining nitrogen efficiency in the lactating dairy cow. *Animal Production in Australia. Proceedings of the Australian Society of Animal Production, 25*, 77-88.

Roseler, D. K., Ferguson, J. D., Sniffen, C. J., & Herrema, J. (1993). Dietary-protein degradability effects on plasma and milk urea nitrogen and milk nonprotein nitrogen in holstein cows. *Journal of Dairy Science, 76*(2), 525-534.

Tamminga, S. (1992). Nutrition Management of Dairy Cows as a Contribution to Pollution Control. *Journal of Dairy Science, 75*(1), 345-357. doi: http://dx.doi.org/10.3168/jds.S0022-0302(92)77770-4

Totty, V. K., Greenwood, S. L., Bryant, R. H., & Edwards, G. R. (2013). Nitrogen partitioning and milk production of dairy cows grazing simple and diverse pastures. *Journal of Dairy Science, 96*(1), 141-149. doi: 10.3168/jds.2012-5504

Tunon, G., Lopez-Villalobos, N., Kemp, P. D., Kennedy, E., Hennessy, D., & O'Donovan, M. (2011). Effect of pre-grazing herbage mass on grazing behaviour, grass dry matter intake and milk production of dairy cows. *Proceedings of the New Zealand Society of Animal Production, 71*, 28-32.

Van Soest, P. J. (1965). Symposium on factors influencing the voluntary intake of herbage by ruminants: voluntary intake in relation to chemical composition and digestibility. *Journal of Animal Science, 24*, 834-843.

Waghorn, G. C., Burke, J. L., & Kolver, E. S. (2007). Principles of feeding value. In P. V. Rattray, I. M. Brookes & A. M. Nicol (Eds.), *Pasture and supplements for grazing animals*. Hamilton, N.Z.: Hamilton, N.Z. : New Zealand Society of Animal Production.

Weiss, W. P. (1998). Estimating the available energy content of feeds for dairy cattle. *Journal of Dairy Science, 81*(3), 830-839.

Xia, J. X., Hodgson, J., Matthew, C., & Chu, A. C. P. (1990). Tiller population and tissue turnover in a perennial ryegrass pasture under hard and lax spring and summer grazing. *Proceedings of the New Zealand Grassland Association, 51*, 119-121.