Effect of Supplementation and Grazing Residual on Dairy Cow Production

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With the desire to increase milk production continuing the industry is developing ways to increase production without increasing costs. Two strategies to increase production are manipulating grazing residual to increase intake and pasture quality and through the addition of supplements into the system. There is on-going debate over the most effective grazing residual to maximise milk production and maintain pasture quality. In this experiment the effect of post grazing pasture residual (PGPR) on long term pasture production, pasture quality and milk production has been investigated. Also the effect of supplementation on milk production and the interaction with PGPR has been examined.

In a farmlet experiment, 32 mixed parity kiwicross cows were divided into four treatments low PGPR (grazed to 3.5 cm) without supplement (LR); high PGPR (grazed to 5cm) without supplement (HR); low PGPR with supplement (4kgDM/day)(LR+) and high PGPR with supplement (HR+). The experiment commenced in August 2012 and paddocks have been maintained under the same grazing management for two milking seasons with continual monitoring of milk production and pasture production and quality. In autumn 2014 additional measurements were taken to investigate the long term effect of PGPR on pasture characteristics.

Increasing PGPR from 3.5 cm to 5cm reduced pasture production from 11,173 to 10,639 kgDM/ha for supplemented treatments and from 10,724 to 9,829 kgDM/ha ($P<0.001$) for un-supplemented treatments for the period 30/9/2013 to 12/5/2014. Botanical and nutritive composition changed throughout the season, but there was no significant difference between treatments. Milk production was greater for the supplemented treatments at 485 and 474 kgMS/cow/year for HR+ and LR+ respectively, and 425 and 418 kgMS/cow/year for HR and LR respectively. Milk solids per hectare was also increased with the addition of supplements at 2326, 2276, 1913 and 1880 kgMS/ha/year for the HR+, LR+, HR and LR treatments respectively ($P<0.029$). Milk composition was not affected by supplement although protein yield was greater under supplement treatments at 214, 207, 179 and 174 kg milk protein/cow/year for HR+, LR+, HR and LR treatments respectively ($P<0.001$). PGPR had no effect on milk production or milk composition. There were no long term effects of PGPR on pasture quality in autumn with some small effects on diet selection (NDF, $P<0.029$).

Keywords: post grazing pasture residual, supplementation, pasture quality, milk production, marginal milk response, stocking rate.

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1 Introduction

1.1 Background

New Zealand's dairy production systems are based around a perennial ryegrass (*Lolium perenne*), white clover (*Trifolium repens*) pasture with low inputs and subsequently gaining a low cost competitive advantage over other major milk exporting countries. The demand for increased production has meant that management options such as altering post grazing pasture residual and adding supplementary feed into the system are being investigated. By increasing energy allowance through manipulating the quality and quantity of feed, there is great potential to increase milk production (Bargo, *et al*., 2002; Curran *et al*., 2010; Lee, *et al*., 2008; J. W. Penno *et al*., 2006).

Lowering post grazing pasture residual can affect pasture production through increasing tiller population and therefore increasing leaf area for light interception (Korte, *et al*., 1982; Michell, *et al*., 1987; Xia, *et al*., 1990). Whereas grazing to high residuals can increase pasture allowance and subsequently increase energy intake and therefore milk production (Curran, *et al*., 2010; Ganche *et al*., 2013). By using higher post grazing pasture residuals there is the potential for increased milk production, but there could be a long term effect on pasture quality (Roca-Fernandez, *et al*., 2012). Grazing to low pasture residuals has the potential to increase pasture quality through increasing clover content and reducing dead matter and stem material (Kelly, *et al*., 2005; Phelan, *et al*., 2013). This has subsequently meant that nutritive value of the herbage is improved due to increased crude protein, water soluble carbohydrates, dry matter digestibility and metabolisable energy (Curran, *et al*., 2010; O'Donovan, *et al*., 2004; Roca-Fernandez, *et al*., 2012). Pasture allowance plays an important role on residuals as a low pasture allowance results in lower post-grazing residuals than a higher pasture allowance. The trade-off is that low allowance and grazing to low levels reduces dry matter intake (Curran, *et al*., 2010; Macdonald, *et al*., 2008). Milk production is influenced by dry matter intake, this has meant that under low grazing residuals milk production per cow has been reduced (Delaby, *et al*., 2003; Ganche, *et al*., 2013). In the current farming climate many farmers use high stocking rates, with low herbage allowance and low post grazing residuals so losses in per cow production are compensated for with increasing milk production per hectare (Macdonald, *et al*., 2008). Further, dry matter intake and subsequently milk production has been increased through the addition of supplements (Bargo, *et al*., 2002).

As energy is the main limiting factor in milk production, increasing energy intake will increase milk production (McEvoy, *et al*., 2009). By supplementing cows with high energy supplement energy intake can be increased. The actual milk response to supplements is affected by relative energy deficit and substitution rate and both can limit milk production (Stockdale, 1999). Pasture intake can be reduced when supplements are added to the system, which can affect the pasture quality at times of pasture surplus. It can also be of benefit during pasture deficit as it has the ability to push pasture later in the rotation and increase stocking rate (Rattray, Brookes, & Nicol, 2007).

This study was designed to remove the effects of pasture allowance when grazing to different post grazing pasture residuals, by shifting cows as soon as pasture residuals were met. The purpose was to therefore investigate whether there is any benefit of grazing to a high or low residual when cows are offered dry matter above a set height. In addition, determine the effect of supplementation on productivity and whether there is an interaction between post grazing pasture residual and supplementation.

1.2 Objectives

- To determine the effects of supplementation and post grazing pasture residual on pasture production and pasture quality.
- To determine the effects of supplementation and post grazing pasture residual on milk production and body condition score.
- To determine the long term effects of supplementation and post grazing pasture residual on pasture characteristics after two years of treatment.

2 Literature review

The objective of the literature review is to evaluate the effect of grazing residual and supplementary feeding on milk production. Post-grazing pasture residual can have a significant effect on tiller population, pasture production, botanical composition, pasture quality and in-turn affects cow performance. Supplementary feeding can be used to fill the feed deficit and increase energy intake, which is the key driver of milk production. Feed allowance and feed quality is therefore critical in determining milk production, and it is manipulation of these factors through grazing residual and supplementary feeding that can influence productivity.

2.1 Pasture Residual

2.1.1 Effect of Pasture Production

Pasture production can be affected by grazing management, in particular severity of grazing, as it affects regrowth rate (Xia, *et al*., 1990). By increasing the stocking rate and grazing pressure, pasture allowance is reduced. At low pasture allowances pastures are grazed to lower post-grazing pasture residual (PGPR) which can increase tiller population, leading to have a positive effect on pasture production (Michell & Fulkerson, 1987).

Matthew, *et al*., (2000) described leaf area index (LAI) as tillers per m^2 x leaves per tiller x area per leaf. As leaves per tiller is kept reasonably constant in 3^{rd} leaf grazing systems (W. J. Fulkerson & Donaghy, 2001) and leaf area is determined by leaf length which is relatively constant due to pre-grazing heights being similar the main indicator of LAI is tiller density. Tiller density has been observed to be greater at low PGPR under hard defoliation grazing management. Xia, *et al*., (1990) reported an increase in tiller density from 4520 to 8090 tillers per m^2 and 6630 to 11180 tiller per m^2 for December and January respectively for pastures that were grazed every 21-28 days to 1000 kgDM/ha compared with those grazed to 2000 kgDM/ha. Brougham (1960), Korte, *et al*., (1982), Michell and Fulkerson (1987), Matthew, *et al*., (1995) and Grant, *et al*., (1983) all also reported increased tiller populations under hard defoliation to lower PGPR. Tiller population was reported to increase herbage mass by Xia, *et al*., (1990), Korte, *et al*., (1982), and Michell and Fulkerson (1987) although, Matthew, *et al*., (1995) reported that net herbage accumulation was reduced under severe treatments that had greater tiller density. This was observed to be due to plant plascity to reduce tiller size and maintain LAI, but under severe grazing treatments LAI was lost (Matthew, *et al*., 2000).

Phelan *et al*., (2013) compared PGPR of 4, 5 and 6 cm and assessed a 20% higher annual yield at PGPR of 4cm. Kennedy *et al*., (2012) compared PGPR of 2.7, 3.5 and 4.2 cm and reported higher annual yields at 4.2 cm (Table 2.1). Grazing to the lower than 4 cm resulted in lower growth, which could have been due to a larger lag phase generated by the harsh grazing. Lower herbage mass at the severe grazing heights results in a reduction in leaf area which reduces the interception of solar radiation which is required to meet the energy requirements for respiration and tissue growth (Grant, *et al*., 1981). Also the lower PGPR meant that it took longer for the pre-grazing target mass to be met for the next rotation (Ganche, *et al*., 2013).

Table 2-1: Effect of Post-grazing sward height (PGSH) on pre and post grazing pasture characteristics

Parameters	**PGSH**		
	2.7cm	**3.5cm**	**4.2cm**
Pre-grazing herbage mass >2.7cm (kg DM/ha)	976a	935a	1076b
Pre-grazing sward height (cm)	5.8a	5.8a	6.4b
Post-grazing herbage mass>2.7cm (kgDM/ha)	58a	112ab	195b
Post-grazing sward height (cm)	2.7a	3.5b	4.2c
Sward Utilisation (%)	94c	82b	74a
Total Herbage Produced (kgDM/ha	14074a	14115a	15510b

(Letters Denote Significant difference) (Kennedy, *et al*., 2012).

Macdonald *et al*., (2008) looked at the effect of stocking rate (SR) and PGPR in the Waikato with Holstein-Friesian cows at stocking rates of 2.2, 2.7, 3.1, 3.7 and 4.3 cows per hectare. As the stocking rate increased the post-grazing pasture residual (PGPR) decreased significantly from 2265kgDM/ha to 1766kgDM/ha (Table 2.2). As the PGPR decreased there was an increase in annual pasture production of 2346kgDM/ha. As well as that by having a lower PGPR the grazing interval was greater meaning more time for herbage accumulation (Table 2.2). Due to the ryegrasses sigmoidal pattern of growth where it starts off slowly and then increases exponentially until senescence of the first leaf occurs at the full emergence of the third leaf (Phelan, *et al*., 2013).

Table 2-2: Effect of stocking rate on Pasture Characteristics

Item	Stocking Rate					
	2.2	2.7	3.1	3.7	4.3	P-value
Pasture Grown (kgDM/ha/yr)	18048	18050	19484	18538	20394	0.11
Pregrazing mass (kgDM/ha)	3300	3253	3355	3457	3530	<0.01
Postgrazing mass (kgDM/ha)	2265	2022	1985	1836	1766	<0.001
Grazing Interval (d)						
Winter	58.1	66.3	70.2	68.9	76.9	<0.05
Spring	31.3	30.5	29.8	33.0	31.6	<0.01
Summer	22.9	25.4	25.2	29.7	29.6	<0.01
Autumn	25.9	27.9	30.4	35.1	36.1	<0.05
ADF (%)	24.4	23.6	23.4	22.9	22.7	<0.01
NDF (%)	44.4	43.3	43.0	42.4	41.5	<0.01
OMD (%)	76.3	77.7	78.2	78.8	79.0	<0.05
ME (MJME/kgDM)	11.0	11.2	11.3	11.4	11.4	<0.05

(Macdonald, *et al*., 2008).

An experiment was carried out in France by Delaby *et al*., (2003), which looked at the effect of different pasture allowances and supplementation on the performance of pasture and grazing dairy cows. The study was carried out over 6 years with 60 cows focusing on spring pasture production. The results found the severe grazing treatment grew more grass than the lax grazing treatment. The severe grazing treatments had higher spring growth rates at 78.0kgDM/ha/day compared to 65.9kgDM/ha/day with the lax grazing treatment. The total growth for the spring rotation (89 day grazing interval) was therefore higher for the severe grazing treatment at 2974kgDM/ha compared to 2468kgDM/ha (Table 2.3). At 5.7 and 6.8 cm these grazing treatments were both not as severe as some of the other trials (Ganche, *et al*., 2013; Kennedy, *et al*., 2012; Phelan, *et al*., 2013), but it still shows that grazing to a lower PGPR has a positive effect on pasture production.

Table 2-3: Effect of grazing treatment on Pasture production

Grazing Treatment	Severe	Lax
Post-grazing height (cm)	5.7	6.8
Herbage Production (kgDM/ha/rotation)	2974	2468
Grass Growth (kgDM/ha/day)	78.0	65.9

(Delaby, *et al*., 2003).

It has been observed across the literature that decreasing PGPR increases pasture production. It has been reported that daily growth rates are higher under lower PGPR as well as total herbage yields. The reason for this has been found to be due to longer grazing intervals giving more time for pasture accumulation. As well as this the more pasture that is removed results in more being grown due to opening of the canopy and removal of dead matter and other growth obstructing materials.

2.1.2 Pasture Quality

Pasture quality along with pasture allowance affects metabolisable energy (MJME) intake which is the key requirement for milk production. By improving pasture quality ME intake can be increased and therefore production can be increased. Pasture quality can be affected by botanical composition of the pasture, with higher legume content and reduced dead and stem material having an effect on the measured quality characteristics. Pasture quality can be measured by different variables such as MJME, crude protein, acid detergent fibre (ADF), neutral detergent fibre (NDF), water soluble carbohydrates (WSC) and organic matter digestibility (OMD). These quality factors can be altered by grazing management and are affected by post-grazing residual.

Botanical composition is important for milk production as it affects the quality of the pasture as well as having an influence on pasture intake due to altering grazing preference and digestibility (Rogers, *et al*., 1982). The proportion of clover in the sward can have an effect on energy intake as DMI has been observed to increase with a greater proportion of clover in the sward (Harris, *et al*., 1997). Clovers contain less structural carbohydrate, leading to more rapid rates of break-down of organic matter, nitrogen and cell walls than ryegrass and subsequently have a greater OMD (Beever, *et al*., 1986). Clover has a higher energy content and therefore greater protein synthesis can occur increasing milk protein (Harris, *et al*., 1997; Rogers, *et al*., 1982). By increasing clover content in the pasture and reducing dead material milk production can be increased, as shown by Phelan, *et al*., (2013) and Kelly, *et al*., (2005) clover content can be affected by PGPR.

A farmlet experiment carried out in Tasmania by Michell *et al*., (1987) involved dairy cows grazing at two different grazing intensities. The high grazing intensity resulted in a lower PGPR than the low grazing intensity. The composition of the pasture was different under the different treatments. The high grazing intensity pasture had a lower dead material content (60.6% less), higher leaf to stem ratio (1.4 vs. 4.2) and higher clover content (72.7% more). The lower dead material and higher leaf content make the pasture more digestible and improve pasture quality characteristics (Hoogendoorn, *et al*., 1992).

Clover content has an effect on pasture quality due to it being shown to increase nutritive value and herbage intake rates (Dewhurst, *et al*., 2009; Harris, *et al*., 1998). Phelan, *et al*., (2013) reported a 22% increase in clover content when PGPR was reduced from 6cm to 4cm. This was similar to the findings of Kelly, *et al*., (2005) who observed a 33% increase in clover content after three years of grazing at below 4cm compared with above 5cm. Thompson (1993) and Heraut-Bron, *et al*., (2001) have reported that the reason for the increased clover content at lower defoliation is due to reduced shading of clover growing points by ryegrass.

Roca-Fernandez *et al*., (2012) conducted a trial in Spain on the effect of pasture allowance on sward quality. The lower pasture allowance resulted in lower PGPR which then had an effect on pasture quality (Table 2.4). Table 2.4 shows the effect of PGPR on pasture quality during early lactation. The dry matter content was higher for the high PGPR indicating that there is a higher fibre portion of the sward, which can reduce digestibility of the sward. This is also shown by the high PGPR having a higher ADF and NDF content than the low PGPR. The crude protein content is 10% higher in the low PGPR and the OMD is also 2% higher. This therefore shows that by having a lower PGPR the pasture quality can be increased.

Table 2-4: Effect of Post Grazing Height on Sward Quality Characteristics during Early Lactation

	Grazing Treatment	
	Low	**High**
Post grazing sward height (cm)	5.2a	6.2b
Dry Matter (%)	16.78a	18.48b
Crude Protein (g/kgDM)	153.8a	139.7b
ADF (g/kgDM)	290.7a	298.8b
NDF (g/kgDM)	518a	528.7b
WSC (g/kgDM)	167.8b	155.8a
OMD (g/kgDM)	781.3a	767.1b

(Letters denote significance) (Roca-Fernandez, *et al*., 2012)

A study based in Ireland involved Holstein-Friesian dairy cows grazing pasture at different pasture allowances and herbage masses by Curran *et al*., (2010). It was found that by having different pasture allowances the PGPR was altered. The low pasture allowance treatments had a 20% lower PGPR than the high pasture allowance treatments. The pre-grazing herbage mass also affected PGPR at high pasture allowance and this had an effect on pasture quality. The crude protein content (8%) and OMD (1%) was higher when the pasture had a lower PGPR (Table 2.5). The ADF content was 6% higher in the treatments that had a higher PGPR indicating that there was a higher fibre content in the pastures with a higher PGPR (Table 2.5). This could be due to a higher stem proportion and dead material in the high PGPR pastures (O'Donovan, *et al*., 2004).

Table 2-5: Effect of Pre-grazing mass and Pasture Allowance on Sward Quality

Pre-Herbage Mass (kgDM/ha)	**1600**		**2400**		**P-Value**
Pasture Allowance (kgDM/cow/day)	**15**	**20**	**15**	**20**	**PGH**
Post-Grazing Height (cm)	4.3	4.8	4.3	5.2	<0.001
Dry Matter (%)	16.1	16.3	16.7	16.2	<0.05
DM Composition (g/kg)					
OMD	826.7	829.4	818.3	824.3	<0.05
Crude Protein	209.8	213.3	184.9	199.0	<0.05
ADF	272.7	286.5	262.0	278.5	0.427
NDF	409.7	408.5	424.0	419.4	<0.05

(Curran, *et al*., 2010)

Macdonald *et al*., (2008) showed that an increase in stocking rate decreased the PGPR which had a major effect on the pasture quality characteristics (Table 2.2). The decrease in PGPR decreased the ADF from (24.4 to 22.7 %DM) and NDF (44.4 to 41.5 %DM) concentration in the sward which means the fibre content has decreased, resulting in an increase in pasture quality. This decrease in fibre has also increased the OMD from 76.3% to 79.0%. Along with the increase in digestibility, the energy (MJME) increased from 11.0 to 11.4 MJME/kgDM. This increase in pasture quality has been mainly due to the harsher grazing which has resulted in more of the dead matter and stem being removed (Macdonald, *et al*., 2008). This decreases fibre content and increases digestibility and quality.

A general trend has been found with regard to pasture quality and PGPR. It has been found that the lower the PGPR the lower the dead material and higher leaf proportion of the plant. It has also been found that clover content increases with a decrease in PGPR (Kelly, *et al*., 2005; Phelan, *et al*., 2013). These factors influence quality characteristics which have been found to increase with a decreasing PGPR. The OMD and MJME increase with decreasing PGPR allowing the cow increase their energy intake (Macdonald, *et al*., 2008). High ME is also related to the decrease in ADF and NDF with decreasing PGPR due to the lower proportion of stem and dead material.

2.1.3 Milk Production

Dairy cow production, in particular milk production is can be greatly affected by grazing management. As previously discussed grazing pressure and pasture allowance can have an effect on the production and quality of a pasture. These production and quality issues through energy intake, then influence milk production and therefore profitability of the dairy farm. This is the case for both per cow milk production and per hectare milk production.

Macdonald *et al*., (2008) found in their study on the effect of stocking rate the major impact that grazing pressure and PGPR had on milk production. It was found that there was a decrease in milk production per cow with the lower PGPR but there was an increase in the milk production per hectare. Table 2.6 shows that there was a drop in milk production of 1584kg/cow/year with increase in stocking rate from 2.2 to 4.3 cows per ha. There was also a drop in fat, protein and lactose yields with the increasing stocking rate, decreasing PGPR (Table 2.6). The annual milk production per hectare increased by 3757kg, with the decrease in PGPR. This is due to more cows producing more milk, utilising more of the forage and the diet being of a higher quality. The milk composition did not change significantly at less than 4 cows/ha, but once stocking rate was increased to 4.3 cows per hectare protein and fat content decreased.

Table 2-6: Effect of Stocking Rate on Milk Production per cow and per hectare

	Stocking Rate					
Item	2.2	2.7	3.1	3.7	4.3	P-Value
Postgrazing mass (kgDM/ha)	2265	2022	1985	1836	1766	<0.001
Annual Production per cow (kg)						
Milk	5032	4351	4128	3616	3448	<0.01
Fat	231	206	192	169	150	<0.01
Protein	176	154	146	126	115	<0.01
Lactose	244	211	202	177	168	<0.01
Annual Production per hectare (kg)						
Milk	11071	11747	12796	13380	14828	<0.01
Fat	507	557	595	625	647	<0.01
Protein	388	415	452	467	494	<0.01
Lactose	537	570	626	653	723	<0.001
Milk Composition (%)						
Fat	4.59	4.75	4.67	4.69	4.37	0.12
Protein	3.51	3.54	3.53	3.49	3.33	<0.05
Lactose	4.85	4.86	4.91	4.89	4.88	0.34

(Macdonald, *et al*., 2008)

Ganche *et al*., (2012) reported a significant effect of grazing height on milk production. The study showed an increase in PGPR from 2.7cm to 3.5cm to 4.2cm resulted in an increase in milk production per cow per day of 22.5, 23.6 and 25.1kgmilk/cow/day respectively. There was also an increase in the milk fat and protein content with an increase in PGPR (Table 2.7). This had an impact on the milk solids yield which increased from 1.75 to 1.91 to 2.00kg/day for the respective grazing treatments. The main reason for the decrease in milk yield from the decrease in PGPR was the feed restrictions the cows were under at low residuals. This meant that there daily dry matter intake (DMI) was significantly reduced resulting in a drop in energy for milk production. The grazing residuals used in this trial were all low. It shows the ideal PGPR to be above 3.5cm as when the cows are grazed to low levels their intake is severely restricted affecting their production.

Table 2-7: Effect of grazing severity on Milk production

Post-grazing sward height (cm)	2.7	3.5	4.2
Milk Yield (kg/cow)	22.5a	23.6b	25.1c
Milk fat content (g/kg)	43.9a	46.8b	45.9b
Milk protein content (g/kg)	33.1a	34.1b	34.0b
Milk Lactose content (g/kg)	46.8	46.9	47
Milk solids yield (kg/day)	1.75a	1.91b	2.00c

(Letters denote significant difference) (Ganche, *et al*., 2012)

Delaby *et al*., (2003) also looked at the effect of grazing intensity on milk production, by comparing 5.7cm to 6.8cm PGPR. They found that milk yield per cow was lower under the severe grazing treatment (24.5kg/day) than the lax grazing treatment (25.4kg/day)(Table 2.8). It was also found that the grazing treatment affected protein content with the lax treatment having 31.8g/kg compared to the severe grazing treatment of 31.4g/kg (Table 2.8). The decrease in milk yield from the severe grazing treatment could be due to the limited pasture allowance and increased grazing pressure that they were under. Even though the pasture quality was greater for the severe treatment it did not make up for the limited pasture supply.

Table 2-8: Effect of grazing intensity on milk production in spring

Grazing Treatment	Severe	Lax
Post-grazing height (cm)	5.7a	6.8b
Milk Yield (kg/day)	24.5a	25.4b
Milk fat content (g/kg)	38.9	38.9
Milk Protein Content (g/kg)	31.4a	31.8b
Fat Yield (g/day)	949a	984b
Protein Yield (g/day)	767a	805b

(Letters denote significant difference <0.001) (Delaby, *et al*., 2003)

Curran *et al*., (2010) conducted a trial on the effect of pre-grazing herbage mass and pasture allowance on dairy cow production over a 30 week period. It was found that the cows allocated a low pasture allowance had a lower PGPR, which was found to then have an effect on milk production. The high pasture allowance cows were found to have a 5% higher milk yield than the low pasture allowance cows (Table 2.9). There was no difference in the composition of the milk apart from protein which was 4% higher in the high pasture allowance (Table 2.9). There was a 5% difference in the milk solids yield due to the increase in milk yield (Table 2.9). The main reason for this is that the cow has more feed available to consume therefore DMI is increased and milk production benefits.

Table 2-9: Effect of pasture allowance on milk production

Pre-Herbage Mass (kgDM/ha)	**1600**		**2400**		**P-Value**
Pasture Allowance (kgDM/cow/day)	**15**	**20**	**15**	**20**	**PGH**
Post-Grazing Height (cm)	4.3	4.8	4.3	5.2	<0.001
Milk Yield (kg/day)	22.8	24.5	22.5	23.0	<0.05
Milk fat content (g/kg)	38.8	38.0	39.8	38.4	0.35
Milk protein content (g/kg)	32.8	33.8	32.2	33.6	0.239
Milk lactose content (g/kg)	46.6	46.7	46.5	46.8	0.986
Milk Solids Yield (kg/cow)	1.6	1.7	1.6	1.6	<0.05

(Curran, *et al*., 2010)

From the studies that have been conducted it is shown that decreasing PGPR results in a drop in per cow milk production. The main reason for this being the cows are pushed to graze harder, which therefore limits their DMI (Ganche, *et al*., 2013). Farmers compensate for the per cow production by increasing stocking rates, management can then be used to fill the feed deficit through the use of supplementary feeds..

2.2 Supplement

Energy intake is the determining factor in milk production, so by increasing energy intake milk production can be increased. Supplementary feeds in the form of concentrates, such as cereal grains and high energy mixes; as well as conserved pasture in the form of silage and hay, are used to increase energy intake. By feeding these supplements feed deficits are able to be filled and further increase in energy intake can be achieved. This can result in increased milk production per cow and per hectare if the energy intake of the supplement is greater than the substitution of pasture.

2.2.1 Response

The response to supplements is the measure of production output from the supplemented feed input. In dairy systems this is generally measured as gMS/kgDM or gMS/MJME. Energetic theory suggests that 76 MJME will synthesise 1kgMS. This works out to 13g MS produced for every 1 MJME and for a supplement containing 10 to 11 MJME/kgDM, 130-140g MS per 1 kgDM (Holmes & Roche, 2007). Actual measured results however have been found to be much lower at around 4.1 g MS per 1 MJME of supplement eaten (Rattray, *et al*., 2007). This response is called the short term or immediate response to supplements and is the measured increase in production through the feeding of supplements. The overall response to supplements incorporates the short term response with the long term response which is the overall increase in milk production created from feeding the supplement.

2.2.2 Short Term Response

The short term response to supplement is affected by relative energy deficit (RED). When there is a high RED the response to supplements is greater as the energy deficit is overcome and the cow can produce closer to its potential. When there is a high RED the substitution rate (SubR) is lower. Substitution rate is the decrease in pasture dry matter intake (DMI) per unit supplement eaten. This can be affected by variables such as feed allowance, pasture quality.

Pasture allowance has been found to have an effect on the response to supplements with dairy cattle. In a farmlet trial conducted by Bargo *et al*., (2002) in the United States, twenty four cows were assigned to four treatments of low and high pasture allowance and with or without supplement. The response to the feeding of supplement varied at the different feed allowances. Table 2.10 shows that at high pasture allowance the response to the concentrate was 0.96kg of milk per kg of concentrate compared to 1.36 kg of milk per kg of concentrate at low pasture allowance. Significant effects were also found regarding fat and protein concentrations in the milk resulting in a change in milk solid production. The main reason for this is that substitution rate was higher at 0.55 kg pasture per kg concentrate at high allowance compared to 0.26 kg pasture per kg concentrate at low allowance. This was due to the RED being greater for the cows at the low allowance than the high allowance.

Table 2-10: Effect of Pasture Allowance on response to Supplementation

	Low Pasture Allowance		High Pasture Allowance	
	Unsupplemented	Supplemented	Unsupplemented	Supplemented
DMI kg/day				
Supplement	0.8	8.6	0.7	8.7
Pasture	17.5	15.5	20.5	16.1
Total	18.3	24.1	21.2	24.8
Milk Production				
Milk kg/day	19.1	29.7	22.2	29.9
3.5% FCM kg/day	20.3	28.4	23.3	28.9
Fat kg/day	0.74	0.96	0.84	0.98
Protein kg/day	0.55	0.89	0.64	0.9
Fat (%)	3.82	3.29	3.79	3.32
Protein (%)	2.98	3.08	2.93	3.11

(Bargo, *et al.*, 2002)

Grainger & Mathews (1989) in a study carried out in Victoria, also found a significant difference in the response to supplements at different feed allowances. They found that the response to concentrate was 0.97 litres of milk per kg of concentrate at the low allowance compared to 0.28 litres of milk per kg of concentrate at the high allowance (Table 2.11). The main reason for the difference between the intake trials was due to total DMI. With the low pasture allowance the total DMI is increased substantially and the pasture DMI does not change significantly. Whereas at the high pasture allowance, when the cows consume the concentrate their substitution rate is higher and therefore their total DMI does not increase as much.

Table 2-11: The effect of Pasture Allowance on the response to supplementary feeding

Pasture Allowance (kg DM/cow/day)	33.1		17.1		7.6	
Concentrate Intake (kg DM/cow/day)	0	3.2	0	3.2	0	3.2
Pasture Intake (kg DM/cow/day)	15.9	13.7	11.8	11	6	6.3
Milk Yield (L/cow/day)	23.1	24	20.9	23.1	15.4	18.5
Fat conc (g/L)	43.5	41.8	42.7	41	47.5	41.1
Fat Yield (g/cow/day)	1002	1005	890	947	727	760
Protein Conc (g/L)	30.9	31.3	30	30.6	29.4	28.4
Protein Yield (g/cow/day	714	750	628	707	452	526

(Grainger & Mathews, 1989)

The season can have an effect on the response to pastures due to changes in pasture quality throughout the year. In a trial in Victoria carried out by Stockdale (1999) it was found that pasture quality varied greatly between the seasons. It went from 10.1-11.3 MJME/kgDM in spring to 8.3-9.0 MJME/kgDM in late summer-autumn (Table 2.12). The responses to the supplement were highest in the summer and autumn when the pasture quality was low and had a poor energy content. This resulted in responses to the supplements of ≥1.0kg milk per kgDM concentrate compared to when the pasture was higher with a response of ≤0.6kg milk per kgDM of concentrate (Table 2.12). The reason for this being that on supplemented diets energy intake was much higher when pasture quality was low as substitution rate does not have as much of an effect. When pasture quality is high, substitution of the high quality pasture for the concentrate results in a lower response (Stockdale, 1999).

Table 2-12: Effect of Season on Response to Supplement

		Unsupplemented		Supplemented				
Expt Start Date	MJME/kgDM	Daily Pasture DM intake (kg/cow)	Daily FCM (kg/Cow)	Daily DM intake per cow (kg/cow) Pasture	Supplement	Daily FCM (kg/cow)	Substitution Rate (kg DM/ kg DM)	Milk Response (kgFCM/kgDM)
Oct	10.3	16.4	25.8	14.4	4.6	27.8	0.4	0.4
Nov	9.5	16.2	24.0	14.0	4.9	26.7	0.5	0.6
Jan	8.7	15.0	18.6	13.6	4.9	24.4	0.3	1.2
Feb	8.2	15.0	16.4	14.1	3.0	19.9	0.3	1.2
Nov	9.8	14.2	25.0	12.2	4.7	27.3	0.4	0.5
Jan	8.9	14.4	17.9	12.2	4.8	22.6	0.5	1.0
Mar	8.7	14.1	15.9	12.6	4.9	20.5	0.3	0.9

(Stockdale, 1999)

Cows have shown to have similar responses to supplements at different stages of lactation when they have similar relative feed deficits. Stockdale, *et al*., (1987) carried out a trial in Victoria with 47 cows at various stages in lactation. It was found that responses to supplements fell from 1.6 to 0.7 kg milk per kg of supplement as lactation progressed and as the level of feeding increased. The main reason for this was as lactation progressed the partitioning of energy into body condition and liveweight increased, reducing the RED, which limited the milk production response (Stockdale, *et al*., 1987).

2.2.3 Long Term Response

The carryover effects of supplementary feeding are also taken into account when working out the response to supplements. The long term responses are mainly due to the substitution rate and how pasture is conserved for later harvest. As well as this the effect of cows partitioning more energy in body condition can also have an effect on the response as these cows will be able to milk for longer periods extending the lactation and therefore increasing their milk solids production (Figure 2.1).

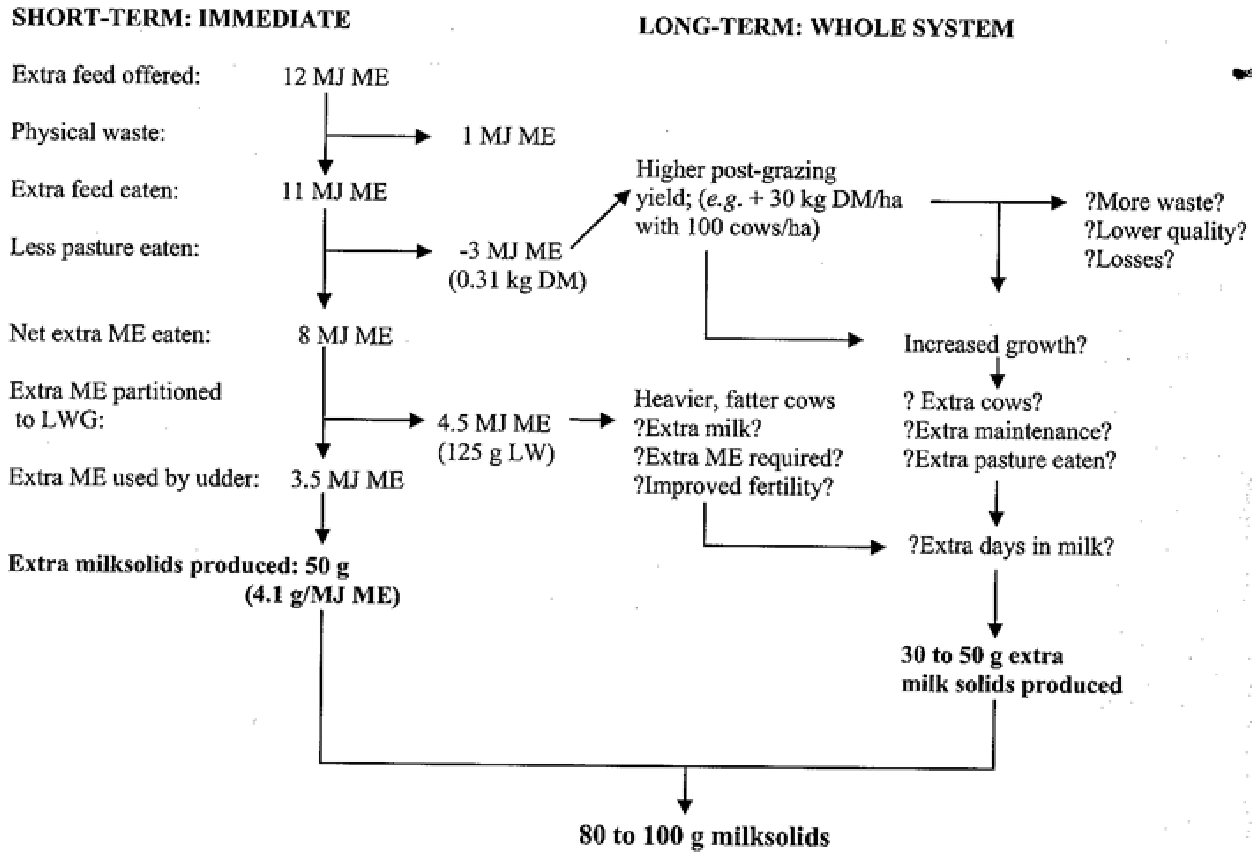

Figure 2-1: Total Long Term Responses to 1kg extra DM fed (12MJME/kgDM). The fate of energy in the 'average' response to 1kg extra DM fed (12MJME/kgDM) using the average values for short term responses from Penno (2002), plus probable events and average vales for short term responses from Penno (2002), plus probable events and average vales for whole system responses. (Figure 4 from Chapter 13 (Rattray, *et al.*, 2007).)

Figure 2.1 shows the long term effect of supplementary feeding dairy cows and how it can increase BCS and also provide more grass for later in the season. These factors are then taken into account for later in the season as having an impact on milk production.

The ability to push the pasture mass further in to the rotation is a critical part of supplementary feeding during feed deficit. With the addition of supplements the rotation can be extended and the grazing interval can be lengthened resulting in greater pasture mass for the next rotation. This can be critical especially in late lactation when pasture growth has slowed. It means that lactation can be extended which results in an increase in total milk production. It can also have an effect for the following season as pasture cover at drying off is important in regard to the target pasture residual at calving the following season. By having a greater pasture mass due to the substitution of pasture for concentrate, it allows for the opportunity to increase stocking rate. An increase in stocking rate has been reported to increase pasture production by up to 12% (Macdonald, *et al*., 2008). This would then lead to a greater milk solid production per hectare.

The other long term response that happens due to the short term responses is due to body condition. The cows that partition some of the extra energy from milk production into body condition will have a higher BCS during late lactation. This means that their dry-off date will be later than if they had a lower BCS resulting in more days in milk. More days in milk means higher total milk production for that season and has benefits for the following season.

Table 2-13: Effect of BCS on reproduction

	HP	HD	NZ
BCS at Calving	2.8	2.88	3.06
Anoestrous Cows (%)	10.3	9	6.4
24 day submission rate (%)	78.2	85.9	88.5
Conception to first service (%)	40	62	57

(BCS 0-5 scale) (Horan, *et al*., 2005)

Cows that have partitioned more energy into body condition will have a lower feed requirement over the winter months and calve in better condition. This results in a higher early lactation milk production than cows with a lower BCS (Table 2.13). It also means that the post-partum anoestrous period can be shortened. With this cows can be mated earlier and therefore calve earlier the following season. The higher BCS also results in lower anoestrous and higher conception (Table 2.13).

2.3 Pasture Allowance

2.3.1 Dry Matter Intake

Milk Production is greatly affected by dry matter intake (DMI), it is therefore important that in dairy systems we are maximising it. Total DMI is lower for cows grazing in pasture based systems than it is in total mixed ration (TMR) or partial mixed ration (PMR) systems. Therefore DMI can be increased by adding supplement to the system which leads on to an increase in milk production. It has also been reported that DMI is greatly affected by pasture allowance (PA), so therefore by increasing the PA the DMI can be increased and with that a milk production increase has been observed (McEvoy, *et al*., 2009).

Dalley *et al*., (1999) found that DMI increased from 11.2 to 18.5kgDM/cow/day with an increase in PA from 20-70kgDM/cow/day which was generated by adjusting the post-grazing height from 4.9-7.8cm. This gave an increase in pasture intake of 0.14kgDM/kgDM offered which resulted in a decrease in of pasture utilisation of 54-26%. This agreed with the findings of Wales *et al*., (1999) and Peyraud *et al*., (1996) who found increases of 53% and 28% when PA was increased from 19 to 68kg/cow/day and 18.9 to 26.4kg/cow/day respectively. It is therefore shown that by increasing PA there is the potential to increase DMI. This agrees with the findings of Pulido *et al*., (2010) who found that pasture DMI and total DMI increased 9.6 to 11.1 and 13.9 to 15.4 kgDM/cow/day respectively with an increase in PA from 25.5 to 38.5kgDM/cow/day

By adding in supplementary feed, DMI is able to be increased at low pasture allowances. As discussed earlier there is an effect on pasture intake with the addition of supplements due to substitution rate, but generally total DMI is increased. In a study carried out by Bargo *et al*., (2002) where cows were grazed at two pasture allowances and different levels of supplements there was a change in pasture and total DMI with the addition of supplements. At low PA the un-supplemented cows consumed 17.5kg pasture with a total DMI of 18.3 kgDM/cow/day. The supplemented cows consumed 15.5kgDM pasture and 8.6kgDM supplement giving them a total DMI of 24.1kgDM/cow/day. At the high PA the un-supplemented cows consumed 20.5kg pasture with a total DMI of 21.2 kgDM/cow/day. The supplemented cows consumed 16.1kgDM pasture and 8.7kgDM supplement giving them a total DMI of 24.8kgDM/cow/day (Table 6). This means that by adding supplement total DMI can be increased although the effectiveness of the addition of the supplement is greater at the low PA. Delaby *et al*., (2003) also reported that total DMI could be affected by PA and supplementary feeding. It was observed that cows that had a pasture allowance of 17.7 kgDM/cow/day consumed 15.7 kgDM/cow/day and those that were offered 26.2 kgDM/cow/day consumed 18.6kgDM/day. With the addition of supplement Delaby *et al*., (2003) found that DMI could be increased by 17% at low PA and 16% at high PA when supplement was added.

Overall, it was observed that by increasing pasture allowance and offering supplement there is the potential to increase DMI of dairy cows. With this increase in DMI there is the potential to increase DMI which leads to increased milk production.

2.3.2 Diet Selection

The herbage that is offered in the pasture system is often different to what the animal consumes due to the diet selection that takes place when grazing. The diet selection has been reported to be affected by grazing intensity and PA (Wales, Doyle, & Dellow, 1998).

Dalley *et al*., (1999) reported differences in the selected diet to the herbage offered. They observed that the animals selected herbage that had a higher *in vitro* DM digestibility (IVDMD) (1.12 ± 0.006) and higher crude protein (CP) (1.32 ± 0.058) and lower NDF (0.80 ± 0.019) than the pasture offered (Numbers in brackets represent selection differential with S.E). However, Dalley *et al*., (1999) found no effect of PA on diet selection. This agrees with the findings of Wales *et al*., (1999) who found average selection differentials were 1.09, 1.33 and 0.79 for IVDMD, CP and NDF respectively, but found no effect of PA. Wales *et al* .,(1998) findings agreed that herbage allowance had no effect on IVDMD, although there was significant differences for CP and NDF. It was found that as herbage allowance increased the selection differential for CP increased from 1.21 to 1.41). They also reported a decrease in the selection differential for NDF from 0.80 to 0.73 when herbage allowance increased from 15 to 40 kgDM/cow/day. These findings were similar to those of Stockdale, *et al*., (2001) who found that as herbage mass increased so did the selection differential for IVDMD and CP with NDF decreasing. They found this to be associated with the leaf to stem ratio which is affected by pasture mass resulting in increasing dead matter decreasing pasture quality as herbage mass increases.

2.4 Conclusions

Post grazing pasture residual can have a significant effect on pasture production and pasture quality and in-turn affect cow performance. The main factors influencing this are grazing interval, opening of the canopy and lag phase.

Response to supplementary feeding is related to the RED and SubR. Factors that influence RED and SubR include PA and pasture quality and therefore affect milk production. Long term response to supplements takes into account the added BCS, pasture pushed later into the rotation and the potential to increase stocking rate.

Dry matter intake is affected by altering PA and offering supplement. DMI can be increased through increasing the DM offered to the cows, although this can lead to lower utilisation.

Diet selection has also been reported to be affected by post grazing pasture residual. The IVDMD and CP can be increased by increasing herbage mass and at the same time decreases NDF selection differential.

3 Materials and methods

3.1 Experimental site and design

The experiment was at the Lincoln University Research Dairy Farm (LURDF, 43°38'S, 172°27'E, 13 m.a.s.l) in Canterbury, New Zealand. The long term rainfall is 660 mm/yr and the soil type is Templeton sandy silt loam. The experimental design consisted of a fully factorial 2 X 2 complete randomised block design. The four treatment groups were low post grazing pasture residual (PGPR) (grazed to 3.5cm) without supplement (LR); low PGPR with supplement (LR+); high PGPR (grazed to 5cm) without supplement (HR); high PGPR with supplement (HR+); each group was allocated to a farmlet.

The study was part of an ongoing farmlet trial which commenced spring 2012 (15^{th} August 2012). Data was collected for the entire 2012/13 and 2013/14 seasons with autumn measurements being taken April-May 2014. The pasture was 18 months old at trial commencement, consisting of *Lolium perenne* (cv.Trojan NEA2, heading date +16 days) and *Trifolium repens* (cv.Weka). The experimental area consisted of 72 x 0.096ha paddocks laid out in 8 blocks of 8 paddocks plus an additional 2 blocks of 3 paddocks. The 8 blocks were separated using permanent fencing while the 0.096 ha paddocks were separated using temporary polywire fencing materials (See Figure 3.1). Troughs were present in each paddock so water was available to stock at all times. Each block was randomly assigned to one of the four farmlet systems. The unsupplemented groups (HR and LR) had 19 paddocks and a stocking rate (SR) of 4.4 cows per ha while the supplemented groups (HR+ and LR+) had 17 paddocks and a SR of 5.0 cows per ha.

The purpose of this investigation was to look at the annual and within season (autumn) effects of farm system on pasture and animal production characteristics. Pasture and animal production data which were routinely collected on an ongoing basis were used for the long term annual productivity of pastures and animals for the 2013/14 lactation season. An additional investigation carried out in autumn 2014 when the two year farmlet study ended, to determine the impacts of farm system on pasture attributes.

3.2 Animals and Management

3.2.1 In August 2012

32 mixed parity kiwicross cows from the LURDF were assigned to one of the four treatments (n=8/group) immediately after calving. Cows were blocked into 8 groups of 4 cows based on age, production, genetic merit, days in milk and liveweight with 8 cows assigned to each farmlet. The first seven groups included multiparous cows while the eighth group was primiparous cows; one cow per group was assigned to each treatment.

The cows were milked twice daily, in the morning (07:00hr) and in the afternoon (15:00h). The cows from the supplemented groups (HR+ and LR+) received 4 kgDM of supplement per cow per day. This was fed by automatic feeders with half the allocation (2 kg) being fed at each milking (see Table 3.1 for nutritive composition). All groups were supplemented with silage at different times of the lactation to ensure pre and post grazing targets were able to be met.

Table 3-1: Nutritional Composition of Concentrate

Component	Amount
Acid detergent fibre (g/kgDM)	69
Neutral detergent fibre (g/kgDM)	179
Crude protein (g/kgDM)	175
Fat (g/kgDM)	21
Starch (g/kgDM)	539
Water Soluble Carbohydrate (g/kgDM)	56
Dry matter digestibility (g/kgDM)	899
Metabolisable energy (MJ/kgDM)	13.9

Paddocks were grazed in order of highest pre-grazing mass, which was measured through weekly pasture walks with a calibrated rising plate meter (Jenquip Ltd, Fielding, New Zealand) creating a pasture wedge allowing for paddocks to be ranked on pre-grazing mass. All pastures were fertilized with 320kgN/ha as urea per year. Gibberellic acid (Progibb, Nufarm, Auckland, New Zealand) was applied at a rate of 8g active ingredient per ha to all paddocks in spring and autumn.

Cows were moved to the next ranked paddock once target post grazing residuals were met. The time spent grazing in each paddock was recorded. Post grazing targets were based on height measured using a rising plate meter. When pasture surpluses were revealed from the pasture walks, paddocks were taken out of the grazing rotation and were grazed by a separate herd of cows to the target post-grazing residuals. If any mowing was required either before or after cows grazing it was done to 3.5cm for LR and LR+ and 5cm for HR and HR+.

Plate 3-1: Rising Plate Meter (Jenquip Ltd, 2014)

3.3 Annual Production

3.3.1 Pastures

A calibrated rising plate meter was used to monitor residuals. Pasture height was measured pre and post grazing by 30 readings per paddock. Weekly farm walks were carried out and a pasture wedge created to determine feed available and if any paddocks should be removed from rotation or supplement be added.

Weekly snip cuts were taken prior to grazing by sampling the pasture to grazing height. These samples were analysed for botanical and chemical composition. The herbage was freeze dried; ground through a 1mm sieve and the chemical composition estimated using near infrared spectrophotometry (NIRS) (FOSS NIRSystems 5000, Maryland, USA). Each new batch of concentrate was also sampled, ground and scanned by NIR using a separate calibration for cereal feeds.

3.3.2 Animals

Milk yield (l) was recorded daily for each cow using an automatic milk recording system. Milk samples were taken from consecutive evening and morning milkings once a week. Milk fat, protein and lactose concentration were found using an infrared analyser (Milkoscan™, Foss Electric, Denmark). Days in milk was calculated from daily milk samples enabling annual milk yields to be determined.

Body condition scoring was carried out once a month and then fortnightly from 1st April 2014. This was carried out by a trained technician and was based on the 0-10 scale. Cows were dried off according to BCS during late lactation.

3.4 Autumn Production

3.4.1 Pasture Measurements

Late lactation during the last rotation, 4 paddocks from each group were selected based on consistently meeting their post-grazing residuals. These paddocks were sampled via quadrat cuts to determine pasture mass pre and post grazing. Four 0.2m^2 quadrats per paddock were taken randomly throughout each paddock, both immediately before and after grazing. Before cutting, a plate meter reading was taken so a calibration between RPM and kgDM/ha could be established. These were then cut using hand held battery powered shears to ground level to determine grazing preferences and the quality of the diet. Each sample was sub sampled for botanical composition, tiller density and dry matter yield. The fresh weight for the sub sample for botanical composition was weighed and then seperated into ryegrass, clover, weeds, reproductive material and dead matter. From the ryegrass sub-sub sample 20 tillers were individually counted. These were then dissected into stem and leaf. All components of the sample were then placed in individual bags and placed in the oven at 65^oC for 48 hours. All components were then weighed and dry weight measurements of ryegrass, clover, weeds, reproductive material and dead matter were able to be calculated. Along with this an individual tiller weight was found as well as a leaf to stem ratio for the ryegrass plants. Another sub sample of the main sample was taken and the fresh weight was weighed. These were then dried at 65^oC for 48 hours and weighed to find the dry weight. From this a dry matter content was calculated. The remaining sample was then washed to remove excess dirt and non-plant material and was dried at 65^oC for 48 hours. These samples were then weighed and dry matter yield was ascertained for the quadrat with the addition of botanical composition sample and dry matter content sample. Sub samples were taken for chemical composition from each pre and post grazing quadrat sample. These samples were ground through a 1mm sieve and the chemical composition estimated using NIRS.

Plate 3-2: Pasture Shears and 0.2m^2 Quadrat.

3.4.2 Selection Differential

Selection differential was calculated using data gathered from autumn measurements.

To calculate selection differential an equation from Stockdale, *et al*., (2001) was first used.

Nutrient eaten (%DM) =

$$\frac{(\text{herbage mass pre} \times \text{nutrient concentration pre}) - (\text{herbage mass post} \times \text{nutrient concentration post})}{\text{mass pre} - \text{post}}$$

A selection differential was then obtained by solving the equation:

$$\frac{\%\ \text{concentration of a nutrient eaten}}{\%\ \text{concentration of a nutrient on offer}}$$

From this a selection differential for clover, dead, nitrogen, crude protein, water soluble carbohydrates, neutral detergent fibre, acid detergent fibre, organic matter content and metabolisable energy was created.

3.5 Statistical Analysis

Statistical analysis will be carried out using Genstat using Complete Randomised Design structure for analysis of variance (ANOVA). The grazing residual and supplement will be fixed effects and paddock as block and quadrat as random effects.

Individual cows were used as experimental units in milk production and BCS analysis. Grazing residual, concentrate treatments and their interactions were fixed effects and cow was included as a random effect.

Repeated measures ANOVA were used for the variables growth rate, pasture characteristics, milk production and BCS, with grazing residual and supplement the fixed affects and paddock random effect for pasture analysis, with individual cows included as random effects in milk production and BCS analysis.

4 Results

4.1 Climate

The monthly rainfall and the mean air temperature are shown in Figure 4.1. It shows that there was a drier than average July and August, with late spring rain. It was a dry summer that was ended with greater than average rainfall in February, March and April. Soil moisture was able to be controlled by irrigation so moisture deficits did not greatly exceed critical levels. Mean air temperature followed a similar pattern to previous years with no major fluctuations.

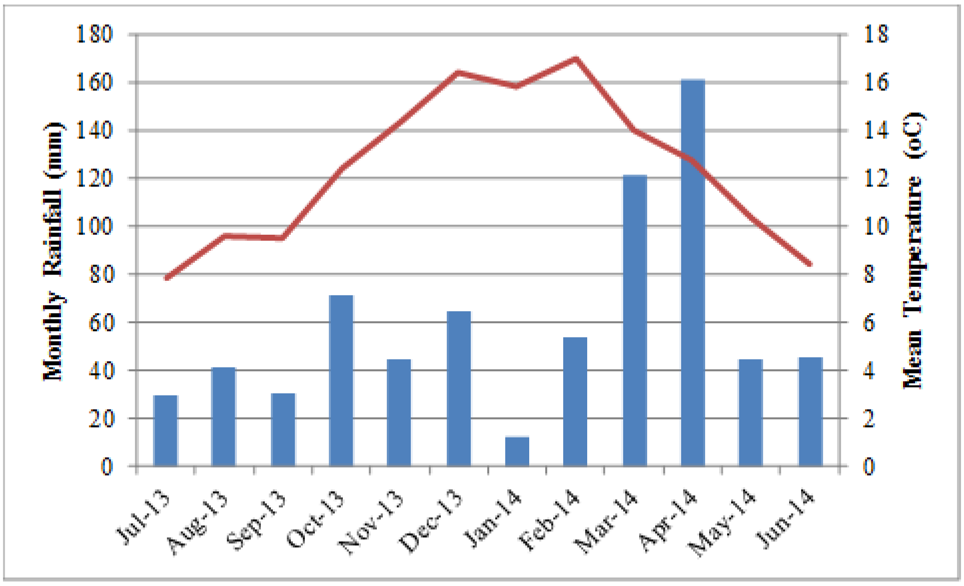

Figure 4-1: Monthly rainfall and mean temperature for the 2013/14 season**.** Figure is a calculated average from July 1999 to March 2013, from Lincoln Broadfields weather station (-43.63^{0}N, and 172.47^{0}E) (NIWA, 2014).

4.2 Annual Production Results

4.2.1 Pastures

4.2.1.1 Pasture Production

Pre-grazing compressed pasture height varied throughout the year, with highest pre-grazing heights in April, with significant differences shown between treatments in all months except February and March (Figure 4.1). The mean pre-grazing RPM over the season for HR, HR+, LR and LR+ was 19.04 ± 4.12 clicks, 19.07 ± 3.79 clicks, 18.97 ± 1.85 clicks and 19.27 ± 3.06 clicks respectively. Post-grazing RPM for HR, HR+, LR and LR+ treatments was 9.33 ± 0.10 clicks, 9.35 ± 0.10 clicks, 7.51 ± 0.11 clicks and 7.64 ± 0.17 clicks respectively. This gives post-grazing heights of 4.7 ± 0.10 cm, 4.7 ± 0.10 cm, 3.7 ± 0.17cm and 3.8 ± 0.17 cm for the HR, HR+, LR and LR+ treatments respectively. The post-grazing height was significantly affected by PGPR (Figure 4.2) over the whole season, with supplement having an effect on post-grazing height during November, January, February, March and May.

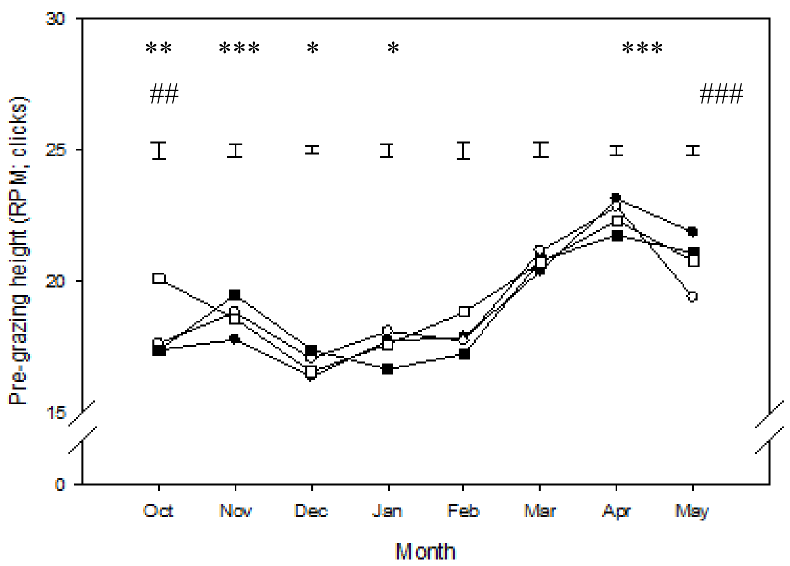

Figure 4-2: Pre-grazing pasture height (RPM) of pasture offered to dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. # P<0.05 ##P<0.01 ###P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

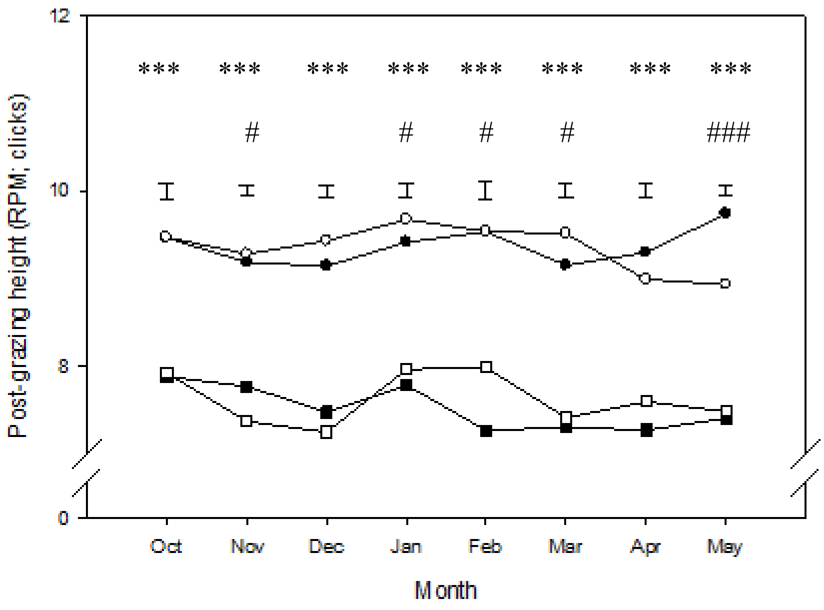

Figure 4-3: Post-grazing pasture height (RPM) of pasture offered to dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. # P<0.05 ##P<0.01 ###P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

Seasonal pasture production is shown in Table 4.1 for the period 30th September 2013 to 12th May 2014. Spring pasture production was not affected by grazing residual. Supplement treatment had a significant effect on spring pasture production with, without supplement pastures having a greater production than low pastures grazed by supplemented cows. Summer pasture production was significantly affected by grazing residual with low residual pastures having a greater pasture production than high residual. In summer there was a significant interaction with low residual pastures having a greater production under no supplement and high residual pastures had greater production under supplement. Low residual autumn pasture production was greater than high residual autumn pasture production. This resulted in a significant effect of grazing residual and supplement treatment on annual pasture production.

Table 4-1: Seasonal and Annual Pasture Production (kgDM ha^{-1}) from dairy pasture grazed at high (HR) or low (LR) post-grazing pasture height with (+) or without supplementary concentrate feeding for the 2013/14 season.

						P-Value		
Parameters[1]	HR	HR+	LR	LR+	SEM	Residual	Supplement	Interaction
Spring	2857a[2]	1958c	2657a	2193b	150.4	0.594	0.006	0.340
Summer	3531c	4587b	5162a	4450b	139.9	0.004	0.788	<0.001
Autumn	3441c	4094b	4232b	4531a	167.7	0.035	0.076	0.486
Annual	9829c	10639b	10724b	11173a	122.2	<0.001	<0.001	0.284

[1] Spring= 30/9/2013 - 30/11/2013; Summer=1/12/13 - 28/2/2014; Autumn=1/3/2014 – 12/5/2014; Annual=30/9/2013 – 12/5/2014.

[2] Letters next to numbers denote significance; Least Significant Difference (P<0.05)

Growth rate increased through spring, dropped off during summer and increased again early autumn as shown in Figure 4.3. Growth rate was significantly (P<0.001) greater for low residual pastures than high residual pastures. Pastures grazed by animals receiving supplement also had significantly (P<0.001) greater growth rates than those without supplement. An interaction was found between supplement and residual (P<0.004) in the summer, with the supplement treatments having a higher growth rate at high residual. Time had a significant (P<0.001) influence on growth rate and there were significant interactions between time and residual (P<0.001), time and supplement (P<0.007) and time, residual and supplement (P<0.002).

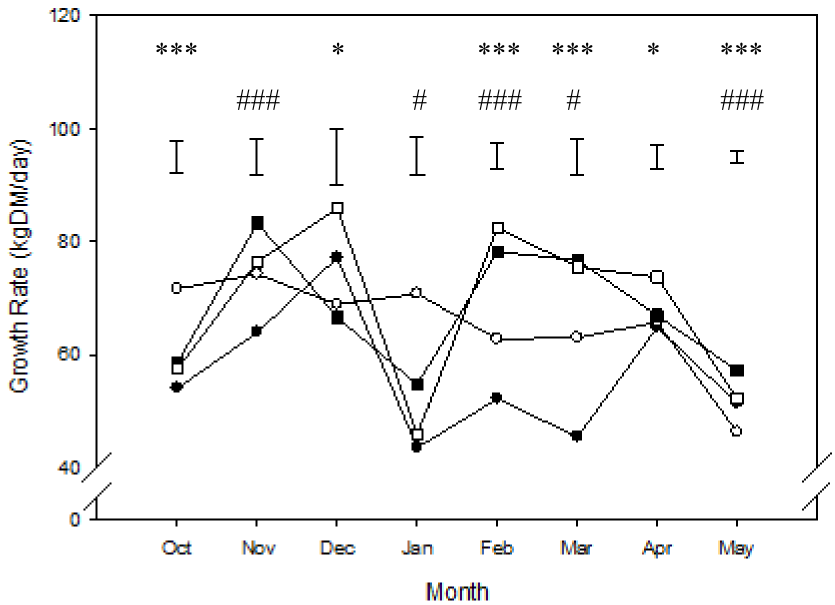

Figure 4-4: Growth rate (kgDM/day) of pasture offered to dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. # P<0.05 ##P<0.01 ###P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

4.2.1.2 Pasture Characteristics

Botanical and nutritive composition varied throughout the year and differences were found between the treatments. Repeated measures analysis showed no significant effect of grazing residual or supplement treatment over time on clover content. Low grazing residual in December and April significantly increased clover content (Figure 4.5). No significant effect of grazing residual and supplement was found on NDF content over the year. High grazing residual pastures had a greater NDF content in February only (P<0.024). A repeated measures analysis found that there was a significant effect of time on NDF content with all treatments increasing from September through to December, a decrease January and then increasing through to April (Figure 4.6). CP content was not affected by grazing residual or supplement treatment. Season had a significant effect on CP content with all treatments decreasing from September to October and increases for the remainder of the year (Figure 4.7). There was no consistent effect of treatments on ME which decreased from September to November then increased (Figure 4.8). In December supplemented pastures had a higher ME content (P<0.035). WSC content of the pasture changed significantly over the season, with all treatments increasing initially and then decreasing from November through May (Figure 4.9). Grazing residual had a significant effect on WSC content in February (P<0.031), but not in any other month. Supplement had no effect on WSC content.

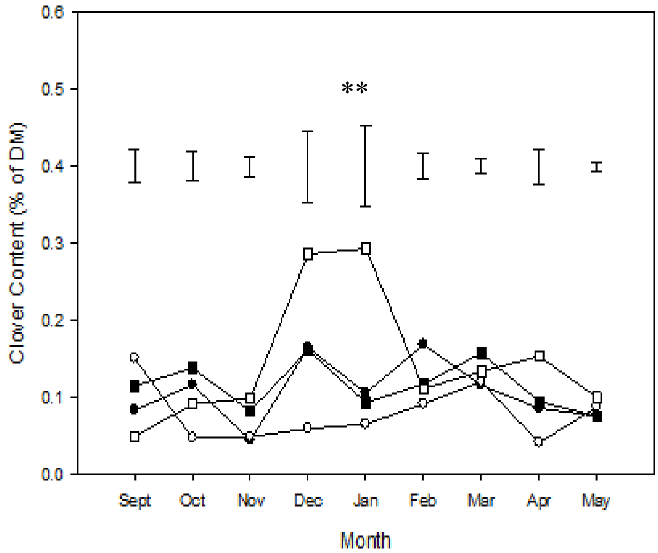

Figure 4-5: Clover content of pasture offered to dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. # P<0.05 ##P<0.01 ###P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

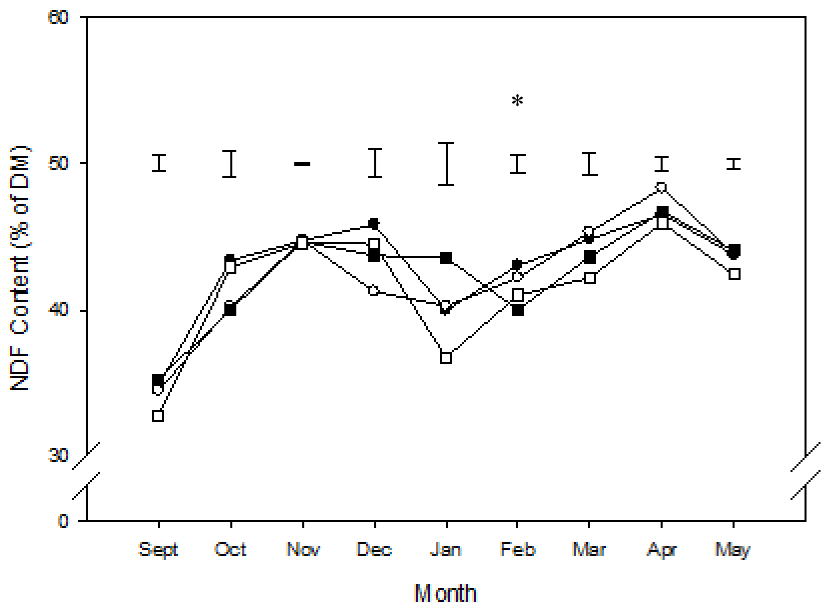

Figure 4-6: NDF content of pasture offered to dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. # P<0.05 ##P<0.01 ###P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

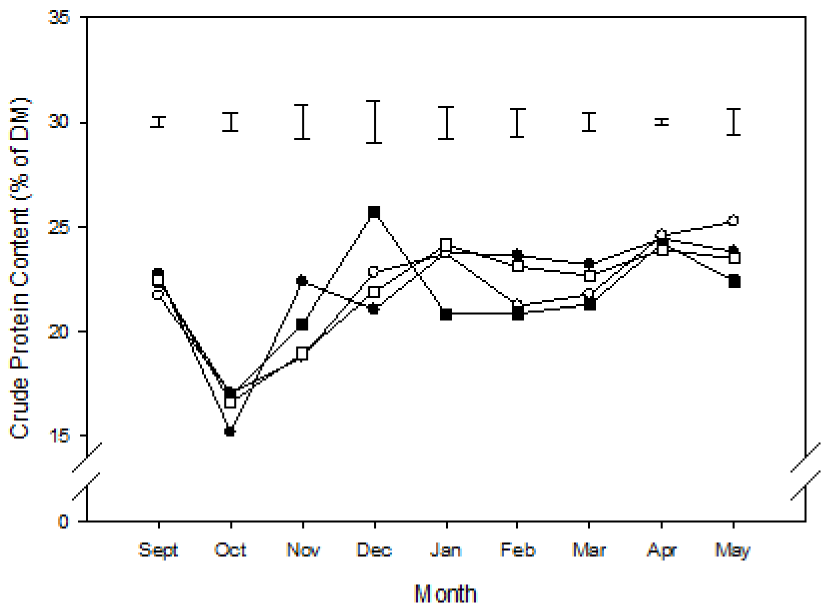

Figure 4-7: Crude Protein content of pasture offered to dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (Error bars are SEM for interaction).

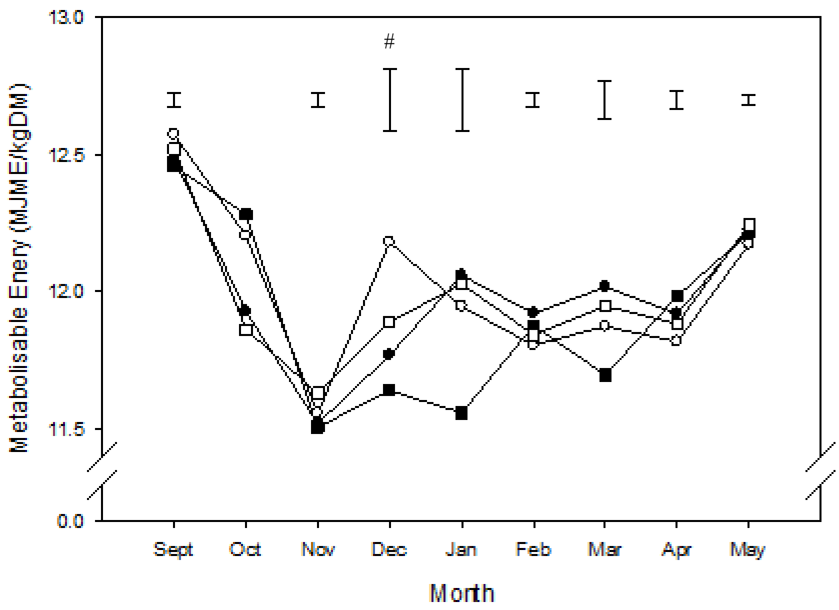

Figure 4-8: Metabolisable Energy content of pasture offered to dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. # P<0.05 ##P<0.01 ###P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

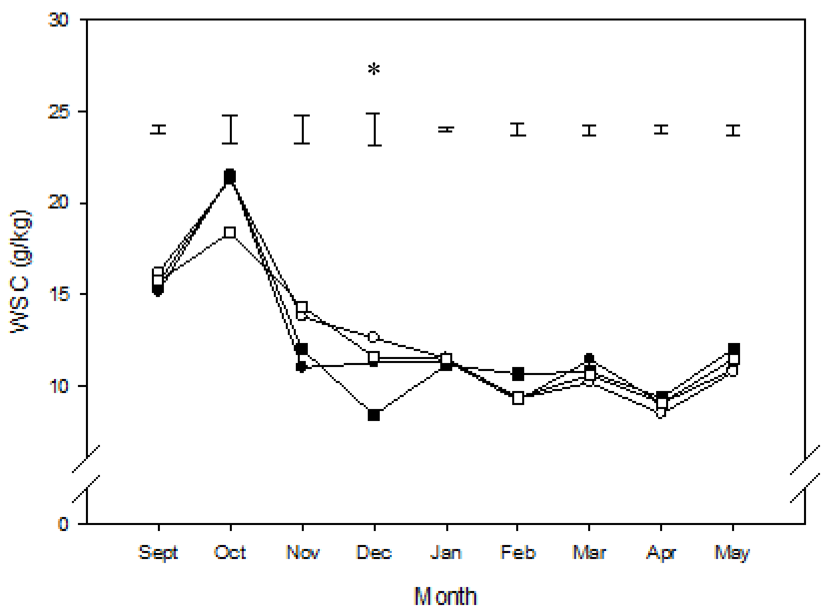

Figure 4-9: Water soluble carbohydrate content of pasture offered to dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. # P<0.05 ##P<0.01 ###P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

4.2.2 Animal Production

4.2.2.1 Milk Production

The effects of grazing height and concentrate supplementation on milk yield and milk composition are shown in Table 4.2. Grazing height had no effect on any milk yield or milk composition factors. Milk yield and milk solids production per cow was greater in cows fed supplemented with concentrate, compared with those which were fed pasture only. Milk solid production per hectare was significantly higher in concentrate fed cows than those only fed pasture. Protein yield and lactose yield were also found to be greater from cows fed concentrate compared with those fed pasture (Table 4.2).

Table 4-2: Milk yield and milk composition (kg/cow/yr) from dairy cows grazed at high (HR) or low (LR) post-grazing pasture height with (+) or without supplementary concentrate feeding for the 2013/14 season.

						P-Value		
Parameters	HR	HR+	LR	LR+	SEM	Residual	Supplement	Interaction
Milk Yield (kg/cow/yr)	4760ab	5474a	4578b	5199ab	431.1	0.456	0.028	0.875
Milk Solids (kgMS/cow/yr)	425bc	485a	418c	474ab	25.20	0.724	0.029	0.952
Milk Solids (kgMS/ha)	1913	2326	1880	2276	166.4	0.724	0.002	0.943
Milk Protein (%)	3.87	4.00	3.88	4.09	0.110	0.615	0.132	0.727
Milk Fat (%)	5.32	4.96	5.35	5.21	0.216	0.526	0.261	0.602
Lactose (%)	5.07	5.08	5.02	5.01	0.035	0.113	0.922	0.838
Protein Yield (kg/cow/yr)	179b	214a	174b	207a	9.41	0.519	<0.001	0.933
Fat Yield (kg/cow/yr)	246	270	244	267	16.37	0.864	0.165	0.965
Lactose Yield (kg/cow/yr)	242ab	279a	230b	262ab	14.48	0.321	0.025	0.852

[2] Letters next to numbers denote significance; Least Significant Difference (P<0.05)

Milk solid production per cow per day was greater for the concentrate supplemented cows for the entire lactation (Figure 4.10). All treatments followed a similar pattern over for the bulk of the season reaching peak lactation at similar stages. Grazing treatment had no significant effect on daily milk solid production and milk yield per cow throughout the season. Milk yield per cow per day followed a similar pattern for all grazing and supplement treatments (Figure 4.11). Concentrate supplemented cows maintained consistently higher daily milk yields across the lactation compared with the pasture only fed cows. Milk yield per cow was above 15kg milk/cow/day for the whole lactation for HR+ and was above 15kg milk/cow/day up to week 30, week 32 and week 34 for LR, HR and LR+ respectively. Peak milk yield per cow for LR was 24.6 kg/day/cow in week 6, and for HR, HR+ and LR+ was 22.6, 25.8 and 24.8 kg/day/cow respectively, in week 7. Milk composition followed a consistent pattern across lactation for all treatments, although there was no effect of residual or supplement on milk lactose and milk fat, with the supplement treatments having a slightly higher milk protein content consistently (Figure 4.12).

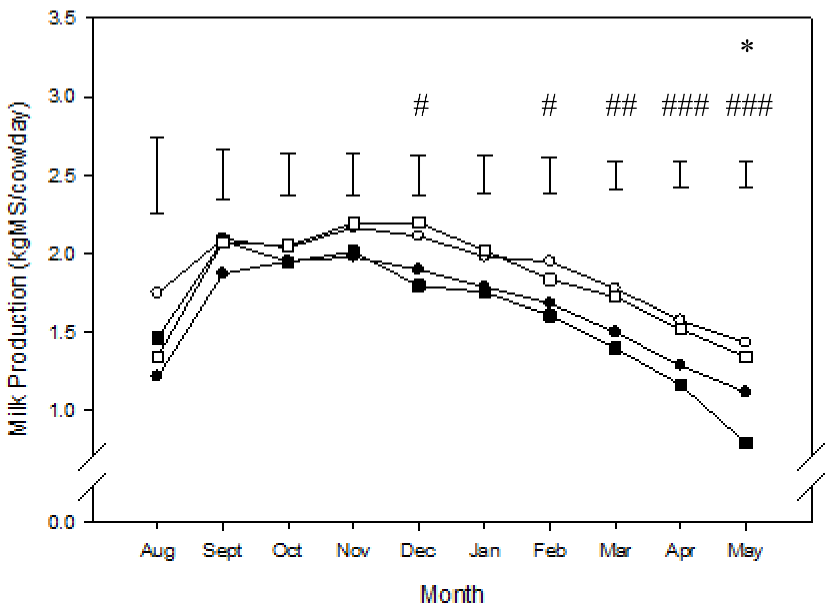

Figure 4-10: Milk solid production of dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. # P<0.05 ##P<0.01 ###P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

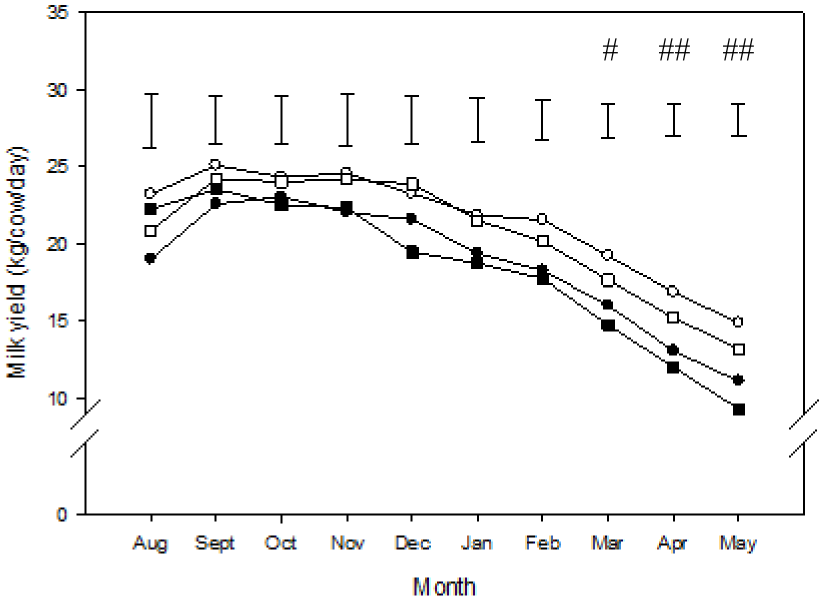

Figure 4-11: Milk production of dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. $^{\#}$ P<0.05 $^{\#\#}$P<0.01 $^{\#\#\#}$P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

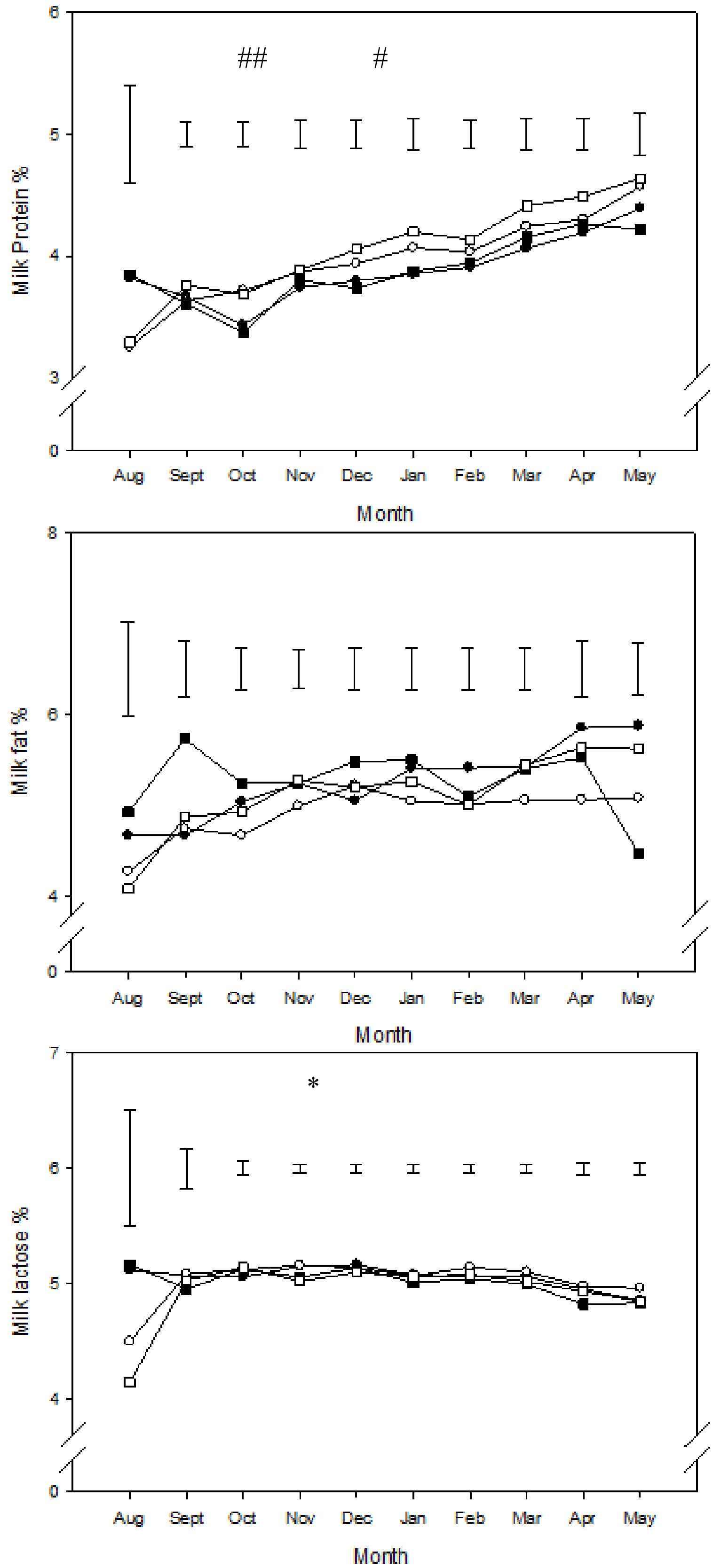

Figure 4-12: Milk protein %, milk fat % and milk lactose % of dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. # P<0.05 ##P<0.01 ###P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

4.2.2.2 Body Condition Score

The change in body condition score (BCS) as affected by grazing height and supplement is shown in Figure 4.13. BCS increased throughout lactation with a decrease in April resulting in cows being dried off. Cows fed supplement had a significantly higher BCS at all dates except for mid-April when BCS had declined under all treatments. Grazing height was not found to have a significant effect on BCS at any stage of lactation. Average BCS across lactation was 3.94, 4.33, 3.91 and 4.22 for HR, HR+, LR and LR+ respectively. All treatments had a slight increase in BCS from December through to May of 0.18, 0.19, 0.06 and 0.09 for HR, HR+, LR and LR+ respectively.

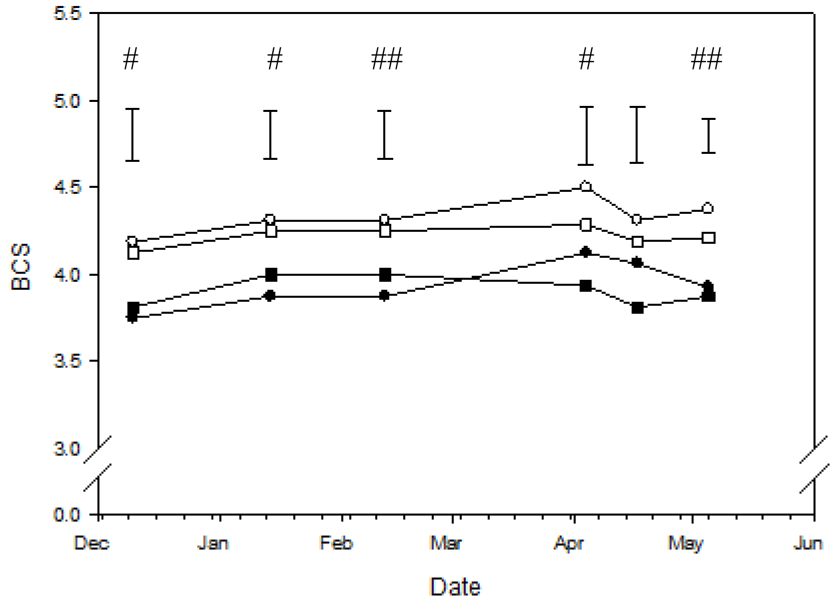

Figure 4-13: Autumn Production Body condition score (BCS) of dairy cows grazed at high (HR; ●) or low (LR; ▪) without concentrate and at high (HR+; ○), or low (LR+; □) with concentrate during 2013-2014 season. (* P<0.05 **P<0.01 ***P<0.001 represent significance of effect of residual. # P<0.05 ##P<0.01 ###P<0.001 represent significance of effect of supplement. Error bars are the SEM for interaction).

4.2.3 Pasture Characteristics

Table 4.3 shows the effect of grazing height and supplement feeding on pasture characteristics to ground level, after grazing for two years. There was no significant effect of grazing height on green leaf mass, botanical composition, tiller mass, tiller density and leaf to stem ratio. Pre-grazing mass was found to be lower at low residual without supplement but no significant effect was found as interaction was $P>0.05$.There was a tendency ($P=0.101$) for white clover content to be higher for low residual pastures compared to high residual pastures, although this was not statistically significant. The proportion of dead was greater at high residuals although this was not found to be significant ($P=0.142$). Supplement treatment had no significant effect on any pasture characteristics and there was no effect of interaction (Table 4.3).

Table 4-3: Pasture characteristics of monitor paddocks after 2 years grazing to high (HR) or low (LR) residuals with (+) or without supplementation

						P-Value		
	HR	HR+	LR	LR+	SEM	Residual	Supplement	Interaction
Mass (kgDM ha^{-1})	3176	3017	2411	3071	199.8	0.109	0.241	0.071
Green Leaf (kgDM ha^{-1})	1785	1692	1510	1882	162.4	0.799	0.407	0.177
Ryegrass (%)	71.0	72.9	73.6	71.1	3.1	0.901	0.912	0.490
White Clover (%)	9.0	6.3	10.6	11.8	1.9	0.101	0.707	0.346
Weed (%)	2.6	1.3	1.7	1.2	0.6	0.455	0.168	0.494
Dead (%)	17.3	19.5	14.1	16.0	2.1	0.142	0.348	0.934
Tiller mass (g)	0.0429	0.0387	0.0373	0.0405	0.0020	0.414	0.824	0.130
Tiller Density ($/m^2$)	5418	5806	4978	5614	330.4	0.364	0.156	0.716
Leaf to Stem Ratio	2.31	2.32	2.50	2.41	0.239	0.424	0.820	0.798

The effect of grazing residual and supplement on chemical composition of pasture cut to ground level is shown in Table 4.4. Dry matter content, organic matter content and crude protein were found to not be affected by grazing residual or supplement. NDF and ADF were both slightly higher in high residual pastures although this was not statistically significant. WSC and ME were slightly higher in low residual pastures although this was found to not be statistically significant. No effect of supplement was found and there was no significant interactions.

Table 4-4: Chemical Composition of pastures pre-grazing, cut to ground level monitor paddocks after 2 years grazing to high (HR) or low (LR) residuals with (+) or without supplementation

						P-Value		
Parameters[1]	HR	HR+	LR	LR+	SEM	Residual	Supplement	Interaction
Dry Matter %	16.0	14.0	17.0	16.0	0.013	0.236	0.456	0.982
Organic Matter %	88.49	88.47	88.89	89.64	0.498	0.160	0.488	0.594
Crude Protein (%)	20.35	20.45	20.37	19.51	0.545	0.430	0.511	0.786
WSC (%)	8.33	8.88	9.67	10.79	0.817	0.087	0.345	0.485
NDF (%)	44.47	45.07	43.76	44.14	0.658	0.252	0.478	0.596
ADF (%)	26.04	26.09	25.08	25.51	0.349	0.062	0.517	0.175
ME (MJME/kgDM)	10.26	10.40	10.47	11.06	0.283	0.169	0.237	0.690

[1] WSC= water soluble carbohydrates; NDF=neutral detergent fibre; ADF=acid detergent fibre; ME=metabolisable energy.

4.2.4 Diet Selection

Table 4.5 shows the effect of grazing residual and supplement on selection differential for pasture components and nutrients. Clover was selected for under all treatments although was more strongly selected in the HR treatment group. Dead material was selected against in all treatments with a significant interaction between residual and supplement being found due to higher levels in HR and LR+ compared with HR+ and LR. Nitrogen was selected for under all treatments with greater selection under the HR treatment found, although no significant effect of residual or supplement was found. Crude protein was selected for under all treatments with a lower selection found under LR+ treatment. WSC was selected for in all treatments except

HR where it was selected against, this resulted in a significant (P=0.038) interaction between residual and supplement. NDF was selected against in all treatments, with a greater selection against in the high residual treatments than the low residual treatments (P=0.003). ADF was also selected against by all treatments with a tendency to be selected against greater by high residual treatments (P=0.070). There was no selection for or against organic matter content and this was consistent across treatments. ME was selected for across all treatments and there was no effect of residual or supplement on ME selection differential.

Table 4-5: Effect of grazing treatment on selection differential[2] for pasture components and nutrients.

						P-Value		
Parameters[1]	HR	HR+	LR	LR+	SEM	Residual	Supplement	Interaction
Clover	1.305	1.098	1.168	1.077	0.282	0.705	0.920	0.905
Dead	0.515	0.246	0.127	0.634	0.138	0.970	0.457	0.056
Nitrogen	1.502	1.358	1.283	1.262	0.152	0.310	0.409	0.619
Crude Protein	1.444	1.411	1.341	1.195	0.150	0.231	0.513	0.758
WSC	0.913	1.151	1.078	1.028	0.072	0.803	0.164	0.157
NDF	0.812ab[3]	0.756a	0.900ab	0.929b	0.054	0.029	0.728	0.494
ADF	0.749	0.747	0.806	0.901	0.0957	0.238	0.610	0.736
Organic Matter	0.998	0.981	0.998	1.039	0.192	0.124	0.638	0.125
ME (MJME/kgDM)	1.154	1.131	1.115	1.147	0.092	0.938	0.998	0.745

[1] WSC= water soluble carbohydrates; NDF=neutral detergent fibre; ADF=acid detergent fibre; ME=metabolisable energy.

[2] A selection differential of 1 is no selection, <1 is selection against and >1 selection for.

[3] Letters denote significance; Least Significant Difference (P<0.05)

[4] Means not adjusted for missing values

5 Discussion

It is accepted that pasture allowance and total energy intake have an effect on milk production. This can be manipulated through altering the PGPR and adding supplement into the system. The purpose of this investigation was to examine the long term effects of PGPR and the feeding of supplement on annual pasture production, pasture quality and milk production.

5.1 Annual Production

5.1.1 Pastures

5.1.1.1 Pasture Production

Pre-grazing compressed pasture height remained relatively constant across the treatments, with increases in autumn due to the desire to increase pasture covers going into winter. This was achieved by restricting pasture allowance with the feeding of pasture silage to all treatments to maintain DMI. Post-grazing height was managed effectively over the season to keep the treatments significantly different so that the effects of PGPR could be investigated.

Total pasture production (October 2013 to May 2014) was found to be significantly greater under low residual pastures. This was similar to the findings of Phelan, *et al*., (2013) who found an increase in pasture production from 10,300 to 12,800 kgDM/ha when PGPR was decreased from 6 to 4 cm. The reason for increased herbage production at lower PGPR could be due to increased tillering, photosynthetic efficiency, increased light penetration of the sward, and less respiration and senescence below the defoliation height (Binnie, *et al*., 1972; Lee, *et al*., 2008).

Growth rate under low PGPR was greater than the high PGPR which attributes to the greater pasture production. The same can be said for the supplement treatments having greater growth rates than the non-supplement treatments. The higher growth rates under low PGPR is similar to the findings of Michell, *et al*., (1987) who reported an accumulation of green leaf and sheath of 17.0 kgDM/day under grazing to low PGPR compared with 5.6 kgDM/day under high PGPR. The reason for the greater growth rates could be due to a greater accumulation of leaf and sheath with a reduction in stem material as pastures are grazed to lower

PGPR and have greater tiller populations (Korte, *et al*., 1982; Xia, *et al*., 1990). Growth rates were affected by time and changed over the course of the season. Growth rates were restricted by moisture in January due to the summer dry and declined in late autumn due to decreasing soil temperature and daylight hours.

Total pasture production was also greater for the treatments grazed by cows that had been fed supplement. This could have been attributed to the high stocking rate supplement treatments having fewer paddocks in their rotation and therefore the cows spent more time in each paddock as average rotation length was similar over all treatments for the season. Pasture production was found to be affected by supplement but not residual in the spring period. This could be due to supplemented pastures having a slightly shorter rotation length during spring at 19 and 20 days for the HR+ and LR+ treatments respectively compared with 20 and 27 days for the HR and LR treatments respectively. A short rotation length can limit reproductive development and increase tillering, improving vegetative growth (Brock, *et al*., 1993; Dale, *et al*., 2008).

Summer pasture production was greater for the low residual treatment without supplement and the high residual with supplement. This could be attributed to the HR+ and LR treatments having shorter grazing rotations at 22 days compared with HR and LR+ which had rotation length of 29 and 26 respectively. Autumn pasture production was found to be greater under low PGPR treatments. This is contrary to the findings of Kennedy, *et al*., (2012) who reported a yield of 3045kgDM/ha compared with 1894kgDM/ha for a single grazing rotation during autumn at a grazing residual of 6.6 and 5cm respectively

5.1.1.2 Pasture Composition

Generally clover production responds positively to low grazing residuals (Phelan, *et al*., 2013) due to increased light at the base of the sward (Thompson, 1993). In the current study clover content was variable and rarely significantly different between treatments. However, in December and April, clover was highest in the low residual treatment. This has been reported to be due to the reduced shading of clover growing points by ryegrass at low PGPR (Heraut-Bron, *et al*., 2001).

High post grazing residuals resulted in higher fibre (NDF) content of herbage at the end of summer compared with the low grazing residuals. The higher NDF content in the high PGPR treatments in February could be due the accumulation of dead and stem material due to the defoliation not being as harsh. Roca-

Fernandez, *et al*., (2012), Curran, *et al*., (2010) and Macdonald, *et al*., (2008) also found that NDF content increased when PGPR increased. Seasonal fluctuations in NDF content, showed an increase in fibre through spring and summer, this could be due the ryegrass plant going reproductive creating more fibrous reproductive tillers, as well as accumulation of dead stem material throughout the season (Fulkerson, *et al*., 1998).

Fulkerson, *et al*., (1998) reported similar changes in CP content over the season with a decrease in CP in late spring during rapid herbage growth (Schils, *et al*., 1999). Metabolisable energy was found to decrease from September to November and then increase again and stay relatively constant across the rest of the season. The decreased ME in November occurred earlier than expected, as the ryegrass cultivar 'Trojan' is a late heading date cultivar, so the sward was expected to go reproductive and lose quality later in the season. However, the pasture may have gone reproductive earlier due to the drier than average spring, resulting in a decrease in pasture quality. The supplemented pastures had a higher ME in December than the non-supplemented pastures; this was not expected as the previously supplemented cows have been more selective resulting in increased dead material (Delaby, *et al*., 2003). Water soluble carbohydrate content fluctuated over the season with the highest levels occurring in October and then decreasing to a steady state for the remainder of the season. This is consistent with findings of Fulkerson, *et al*., (1998) and Smith, *et al*., (1998) who found that WSC concentration increased at certain stages of ryegrass maturity and seasonal climate effects. It has been found that WSC content increases at flower initiation and during periods of high herbage accumulation (McGrath, 1988). Early spring in New Zealand is also the best time of year for WSC accumulation due to increasing sunshine hours and colder nights which results in reduced respiration rates and therefore less carbohydrate use (Thom, *et al*., 1989). A greater WSC content was found in high PGPR pastures during December, this could be due to the higher PGPR pastures not being grazed as low therefore having a greater LAI for light interception and subsequently greater photosynthesis and WSC accumulation.

Generally there were no consistent effects of treatment on botanical and chemical composition of herbage at high or low grazing residuals. While growth rates showed large seasonal fluctuations between treatments, the pre-grazing pasture mass was maintained at a relatively consistent height which may have played a role in maintaining composition of the pasture across treatments.

5.1.2 Animal Production

5.1.2.1 Milk Yield

Milk yield and milk solids production per cow was greater for the cows fed supplement due to the increased energy intake from the high energy supplement. Milk response was 60 g/kgMS at high PGPR and 64 g/kgMS at low PGPR, this is low compared to other studies. This works out to be 0.714 kg milk/kgDM and 0.629 kg milk/kgDM which is lower than reported results. Bargo, *et al*., (2002) reported a response to supplements of 0.96 kg milk/kgDM and 1.36 kg milk/kgDM at high and low pasture allowances respectively. This is consistent with the findings, albeit higher of Robaina, *et al*., (1998) who observed a milk response of 0.54 and 0.98 kg milk/kgDM at high and low pasture allowances respectively.

The milk response above shows the production benefit of feeding the supplement and the effect of increasing energy intake on milk production. Milk production per hectare was also greater for the supplement treatments than the non-supplement treatments. The increase in stocking rate was necessary to avoid pasture wastage due to the substitution of pasture for supplement that occurred. Milk protein also increased with the addition of supplements into the system. As more energy is available for protein synthesis from the high starch feed microbial protein synthesis is increased as shown in studies by Bargo, *et al*., (2002) and Reis, *et al*., (2000). When concentrates high in starch are consumed changes in the end product of digestion favour propionate (Van Soest, 1994). When propionate is absorbed from the rumen it increases the concentration of glucose and subsequently insulin, with the latter being associated with the uptake of protein by the mammary gland (Rius, *et al*., 2010).

Milk production is affected by energy intake which can be manipulated through altering PGPR and by feeding supplementary feeds and is determined by the response to supplements. The effect of pasture allowance on milk response to supplements was due to substitution rate and RED. At low pasture allowance substitution rate was lower as the potential DMI was at a greater deficit than at high pasture allowance. The RED therefore was greater at low pasture allowance allowing for a greater response to supplement (Grainger & Mathews, 1989).

Post grazing pasture residual had no significant effect on milk production although tendencies appeared for high PGPR to have higher production than low PGPR. Similarly, other studies have shown an effect of PGPR on milk production with increased milk yield of 6% when PGPR was increased from 3.5 cm to 4.5 cm (Ganche, *et al*., 2013). Delaby, *et al*., (2003) also observed a 4% increase in milk production when PGPR increased from 5.7 cm to 6.8 cm due to a rise in pasture allowance and subsequently an increase in DMI. The effect of PGPR on milk production is affected by pasture intake and pasture quality and in this study there was not a great enough difference in pasture intake and little difference in pasture quality to give a significant effect.

Milk production across the season followed a conventional lactation curve with supplemented groups having greater production for the whole season. In May there was an effect of PGPR on milk production per day, with the high PGPR cows outperforming the low PGPR cows. The reason for this could be associated with the drying off of some of the lower BCS cows, with the lower performing cows gone the average milk production. Four of the LR cows were dried off 10 days early with 1 being dried off three days early, 1 of the LR+ cows was dried off 10 days early, 1 of the HR cows was dried off 5 days early and 1 three days early with all of the HR+ cows going through till the end of lactation. This means that the numbers were altered so the averages were not as consistent as the rest of the season.

5.1.2.2 Body Condition Score

Body condition score changed for all treatments throughout the season, with increases from December through to April and then decrease in the last month. BCS were greater for the supplement treatments throughout the season greater increase being in the high PGPR treatments although this was not significant. Pulido and Leaver (2001) found no significant effect of concentrate or sward height on BCS, although in a trial only carried out for 6 weeks. The partitioning of energy to BCS for the supplement treatments, could explain the milk response being lower than some previous experiments (Holmes & Roche, 2007). By having a greater BCS it could lead to greater early lactation milk production the following season as the cow mobilises body reserves (Holmes & Roche, 2007). The higher BCS could have an effect on overall profitability, however as it has been reported than increased BCS shortens the post-partum anoestrous period (Horan, *et al*., 2005).

Milk production was greater for the supplement treatments than the un-supplemented treatments. Protein production was greater under the supplement treatments due to the higher energy availability for protein synthesis. There were tendencies for milk production to be greater under high grazing residuals as pasture intakes may have been affected by PGPR. Supplemented cows had a greater BCS which may have an effect on future performance.

5.2 Autumn Production

The autumn pasture sampling was carried out to determine the long term effects of PGPR and supplementation on botanical composition, proportion of green leaf, tiller density, nutritive characteristics and diet selection. The results show that although there was a significant difference in pasture production under the different PGPR there was no significant effect on milk production. By looking at the pasture quality attributes the reason for this can be explained.

5.2.1 Pasture Characteristics

Botanical composition was not found to be significantly affected by PGPR or supplement treatment. There was however a tendency for white clover content to be higher under low PGPR. If more sampling was carried out there may have been a significant result which would agree with the findings of Phelan, *et al*., (2013) and Kelly, *et al*., (2005) who reported a 22% and 33% increase in clover content respectively under lower PGPR (6 to 4cm and 5 to 4cm respectively). The reason for the expected increase in clover content under low PGPR is due to reduced shading of clover growing points by ryegrass (Heraut-Bron, *et al*., 2001). Green leaf production was not affected by PGPR, it was expected that under low PGPR green leaf production would be increased due to more time in the high growth rate zone of the sigmoidal growth curve (Binnie & Harrington, 1972). Michell, *et al*., (1987) reported that green herbage production was greater under low PGPR in the spring, but in the summer and autumn there was no effect of PGPR on green herbage production. This could explain the results of this trial as by autumn there are other limiting factors involved in production resulting in PGPR having no effect (Hoogendoorn, *et al*., 1992). Leaf to stem ratio was not affected by PGPR which is different to expected, as it was predicted that due to lower PGPR having a less stem material and therefore a greater stem to leaf ratio as shown by O'Donovan, *et al*., (2008) and Hurley, *et al*., (2006).

Tiller mass and tiller density were not affected by PGPR contrary to the findings of Brougham, *et al*., (1960), Korte, *et al*., (1982), Michell and Fulkerson (1987), Matthew, *et al*., (1995), Grant, *et al*., (1983) and Xia, *et al*., (1990) who all reported increase in tiller population under low PGPR. By doing the cuts in autumn the tiller population could have diminished in both treatments, whereas if the harvest was in spring differences may have been found as soil moisture and temperature restrictions over summer could have had an effect (Michell & Fulkerson, 1987). Therefore the pasture production benefit described in section 5.1.1.1 cannot be attributed to tiller population as first suggested.

There was no significant effect of PGPR or supplement treatment on nutritive characteristics of the pasture. Other studies have shown an influence of PGPR on nutritive characteristics of the pasture with the PGPR being higher than in this trial (Curran, *et al*., 2010; Roca-Fernandez, *et al*., 2012). Macdonald, *et al*., (2008) and Lee, *et al*., (2007) both also reported changes in ADF, OMD and MJME, but their trials involved a greater difference in PGPR than was used in this study. Lee, *et al*., (2008) and Pulido, *et al*., (2001) had similar findings to this trial with no significant effect of PGPR on the nutritive characteristics on the pasture.

5.2.2 Diet Selection

Grazing residual and supplementation had no effect on diet selection of clover, dead, N, CP, WSC, ADF, OM or ME, with PGPR affecting the diet selection of NDF. The findings of Wales, *et al*., (1998) as they reported a significant effect of PGPR on CP and NDF only, with Wales, *et al*., (1999) finding no significant effect of PGPR on diet selection. NDF was selected against in all treatments with greater selection displayed under high PGPR treatments. This could be due to the high PGPR cows not having to graze as low into the sward where there is a higher proportion of fibrous stem and dead material, agreeing with the findings of Stockdale, *et al*., (2001). Across all treatments clover, N, CP and ME were selected for which is consistent with the literature (Dalley, *et al*., 1999; Stockdale, *et al*., 2001; Wales, *et al*., 1998; Wales, *et al*., 1999). Dead material, ADF and NDF were selected against which again agrees with the literature. WSC and OM were not selected for or against with little evidence found on their selection in the literature.

6 Conclusion

Grazing to a low PGPR has increased pasture production but has had no great effect on pasture quality. Subsequently, there has been no effect of PGPR on milk production or milk composition over the 2013/14 season. It was expected that cows grazing to high PGPR would have a greater DMI as they were not pushed as hard which would result in them having a greater milk production. However, in this study cows were shifted as soon as the target PGPR had been met and therefore there was no set pasture allowance.

By feeding supplement, milk production per cow and per hectare was increased, although milk response to the supplement was lower than previously reported elsewhere. Therefore the economic viability of feeding the supplement is lower as the margin has been reduced. There is however the added benefit of increased BCS from the supplemented treatments, which could have a positive effect on reproductive performance by reducing the anoestrous interval and increasing milk production the following season.

The long term effect of grazing to high and low PGPR has been little on pasture composition and quality. It then fuels the debate whether there is benefit in pushing cows to graze to a low PGPR, to have little effect on pasture quality and in-turn limit milk production.

6.1 Further Research Opportunities

- To investigate the effect of grazing to different PGPR on spring and summer pasture composition and how it affects the reproductive development of the pasture and in-turn pasture quality.
- To quantify the reproductive benefit and following seasons milk production of the higher BCS that was achieved by feeding cows supplement.
- To establish the differences in energy intakes of the treatments and the effect that it has on milk production.

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