Grazing management strategies of diverse pastures on irrigated dairy farm systems

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Strategies to increase herbage dry matter (DM) production and quality while reducing environmental impacts are sought for dairy farming systems. Two strategies to improve DM production and quality are grazing management and the choice of forage species mixture. While grazing management rules are well developed, particularly timing and intensity, for perennial ryegrass-white clover pastures, the rules are less clear for diverse pasture mixtures that include perennial ryegrass, Italian ryegrass, alternative legume species (red clover and lucerne) and herbs (chicory and plantain). This thesis examined the effect of grazing management strategies in spring and autumn on herbage DM production, botanical composition, herbage quality, and milk production of lactating dairy cows grazing diverse pastures. Four field experiments were conducted in Canterbury, New Zealand on irrigated diverse pastures grazed by dairy cows. Data were used in the FARMAX farm systems model to simulate the effects of grazing management on herbage DM production and farm profitability.

The first experiment measured over two years herbage DM production, quality and botanical composition of two diverse pasture mixture types managed either by conventional grazing by dairy cows or by lenient grazing in either spring or autumn. Diverse pasture mixture consisted of perennial ryegrass, white clover, red clover, chicory and plantain (diverse) or the same pasture mixture plus Italian ryegrass (diverse + Italian). The two pasture types were grazed in three specific regimes: (1) conventional hard grazing, where cows grazed to a compressed pasture height of 3.5 cm year-round, (2) autumn lenient grazing, where cows grazed to a compressed pasture height of 5 cm during autumn before a switch to 3.5 cm for the remainder of the year and (3) spring lenient grazing, where cows grazed to a compressed pasture height of 5 cm during spring before a switch to 3.5 cm for the remainder of the year. Annual herbage DM production was greater in diverse mixtures (13.4 ± 0.25 t

DM/ha, *P*<0.01) than diverse pasture + Italian ryegrass (12.8 ± 0.25 t DM/ha). Averaged over two years, pastures managed by autumn lenient grazing had the lowest annual herbage DM production (12.6 ± 0.3 t DM/ha) compared to those managed by spring lenient grazing (13.8 ± 0.3 t DM/ha) or conventional grazing (13.9 ± 0.3 t DM/ha, *P*=0.03). Although autumn lenient grazing resulted in the lowest herbage DM production, this grazing management had a greater proportion of red clover (16.5 ± 0.9%, *P*≤0.01) and plantain (21.8 ± 1.4%, *P*≤0.05) in the first year compared to the proportion of red clover and plantain in spring lenient grazing (13.2 ± 0.9% and 20.7 ± 1.4%) or conventional grazing (12.3 ± 0.9% and 16.8 ± 1.4%). Grazing management did not affect crude protein concentration, ranging from 165 to 169 g/kg DM. Total ME produced per hectare averaged 147 GJ/ha/year and was unaffected by grazing management.

The second experiment examined the effect of five defoliation intensities (defoliation heights) during the late autumn on winter and early spring herbage dry matter production, regrowth, botanical composition and nutritive value of a diverse pasture mixture containing perennial ryegrass, Italian ryegrass, white clover, lucerne, chicory and plantain. In late autumn, pastures were defoliated to five post-grazing heights (20, 30, 40, 50, 60 mm), and herbage DM production and nitrogen concentration were measured over a 112 d regrowth period. Accumulated herbage DM production was similar across all defoliation heights when measured to ground level, ranging from 1612 to 2476 kg DM/ha, averaging 2079 ± 807 kg DM/ha. After 112 days, increasing defoliation height tended to result in greater herbage DM mass above a simulated spring grazing height of 35 mm. Contrasts between low and lenient defoliation treatments confirmed greater herbage DM accumulation from lenient autumn defoliation (2408 vs 1860 ± 262 kg DM/ha). At the initial defoliation treatment (day 0), botanical composition did not differ among defoliation heights, except for perennial ryegrass (*P*<0.001). At the end of the regrowth period (day 112), all treatments remained relatively stable in botanical composition except for a trend for an increased proportion of Italian ryegrass (*P*=0.09) in the severe (≤40 mm) defoliation treatments. Nitrogen concentration was greatest in severe defoliation (20 mm) compared to lax defoliation (60 mm) (2.88 versus 2.41%DM, respectively). However, when herbage N concentration was multiplied by the final herbage DM mass to estimate herbage N uptake, the average herbage N uptake was 40.8 kg N/ha and was similar across all treatments (*P*=0.99). Nutritive value (CP, ME, WSC, DOMD) was not affected by defoliation height at the final harvest, where the ME ranged from 12.0 to 12.3 MJ ME/kg DM and CP averaged 16.4% DM. It is concluded that diverse pasture mixtures can maintain its high quality through winter and defoliation height had no significant effect on herbage DM production, botanical composition or N uptake. Leaving a greater defoliation height in autumn increased the harvestable DM mass for early spring.

The third experiment examined the effect of spring grazing management with pre-graze mowing on milk production of dairy cows grazing pastures containing perennial ryegrass, white clover, chicory, plantain and lucerne. Diverse pastures were managed over two grazing rotations in spring under conventional (grazed to 3.5 cm) or lax management (grazed to 5 cm, allowing early ryegrass seedhead development before conventional grazing at anthesis 'late control'). On the third grazing rotation, a milk production study was conducted. Thirty-six, mid-lactation spring calving Friesian × Jersey dairy cows were allocated to nine groups of four cows and randomly allocated to three replicates of the following three treatments: (1) conventional grazing (Norm), (2) lax grazing of standing herbage (Lax) and (3) lax grazing with pre-graze mowing of herbage (Mow). Cows were offered a daily herbage allocation of 30 kg DM/cow above ground level, with milk production measured over 8 days. Pastures managed under lax management had higher pre-grazing herbage mass (4149 kg DM/ha) than did pastures managed under conventional management (3105 kg DM/ha), but all treatments had similar metabolisable energy (~12.26 MJ ME/kg DM). Daily milksolid (MS) production tended to be lower (P=0.07) for cows grazing pastures managed under Lax and Mow (2.34 and 2.24 MS/cow/day respectively) than with Norm (2.43 MS/cow/day). Although there was no difference in daily MS production between mowing and greater pre-graze herbage mass, switching from a high to low post-grazing height managed by either grazing or mowing in late spring is likely to have a negative impact on milk production.

The fourth experiment compared the immediate and carry over effects of the defoliation treatments in the third experiment on milk production of dairy cows. Irrigated, diverse pastures were managed under conventional (grazed to 3.5 cm) or lax (grazed to 5 cm allowing ryegrass seedhead development) grazing intensity, with or without mowing (to 3.5 cm), in spring. On the subsequent grazing rotation in summer, an experiment was conducted to investigate the carry-over effects of previous management on herbage regrowth and milk production. Nine groups of three Friesian x Jersey dairy cows each were randomly allocated to three replicates of three treatments: conventional grazing (Norm); previously lax managed pastures (Lax); previously lax managed pastures that were pre-graze mown (Mow). Herbage in Mow treatments had a higher ME (P<0.05) than Lax and Norm (11.7, 11.3 and 11.4 MJ ME/kg DM, respectively). There was no difference in DMI (18 ± 0.30 kg DM/cow/d) or MS production (1.85 ± 0.02 kg MS/cow/d) among treatments. Results of this study indicated that milk production was not altered by grazing management.

The final study used the commercial modelling tool, Farmax Dairy Pro to assess the effect of diverse pasture mixtures and grazing management on profitability of irrigated Canterbury dairy farms. Herbage quality data and herbage DM production were used from the first experiment. The data were fitted to a base model farm (average of North Canterbury region) using Farmax Dairy Pro to

produce six different farm scenarios. Farm scenarios were ranked and compared by profit expressed as earnings before tax. Farm scenarios 1-3 were diverse pasture managed by conventional grazing, autumn lenient grazing and spring lenient grazing management, respectively and farm scenarios 4-6 were diverse pasture plus Italian ryegrass managed by conventional grazing, autumn lenient grazing and spring lenient grazing management, respectively. Pastures managed by autumn lenient grazing had the lowest herbage DM production, more supplement purchased, and hence lowest profit compared with conventional or spring lenient grazing management. The diverse pasture managed by spring lenient grazing resulted in greater profit ($2,658/ha) than the other scenarios (average $2,261/ha). The greater profit was driven by greater annual herbage DM production per hectare (15.0 vs. 13.3 t DM/ha/year) in diverse pasture management by a lenient grazing in spring and, hence, less purchased feed required to meet animal demand (NZ$0/ha) compared to other scenarios (NZ$404/ha). In addition, the lenient grazing of diverse pasture in spring was the only scenario that resulted in a surplus feed supply ($3145/year). An excess of 15 t DM of pasture silage was sold in May and less purchased feed required, decreasing the operating costs/MS. Surplus feed supply was calculated based on cost to cut silage and priced to sell at $40/ha (Farmax default value for the Canterbury region). When diverse pasture is considered, spring lenient grazing is a potential management option for an irrigated Canterbury dairy farm system to increase DM production and thereby profitability.

This thesis highlights seasonal grazing management strategies of alternative diverse pasture mixtures that includes legumes (red clover and lucerne), herbs (chicory and plantain) and Italian ryegrass in a perennial ryegrass white clover mixture onto an irrigated dairy farm system with rotational grazing. The study also determined whether or not the potential production benefits would occur on farm would be profitable. The results from these projects provide relatively simple grazing management practices of diverse pasture mixtures for dairy farmers to implement into their farm systems to increase herbage DM production, maintain pasture quality with no detrimental effects on milk production. This study confirmed high DM production and quality of diverse pastures. It was demonstrated that spring grazing management (e.g., lenient grazing in spring until perennial ryegrass reached seedhead development, followed by a hard-conventional grazing) could be used to improve DM production with little effect on herbage quality. Milk production was unaffected by the lenient grazing in spring and not improved by mowing. Combined with the environmental benefits of diverse pastures (i.e., reduced urinary N excretion) demonstrated in other studies, this study confirms the role of diverse pastures in promoting environmentally sustainable dairy systems.

Keywords: diverse pasture, mixed swards, dry matter production, botanical composition, nutritive values, grazing management, lax grazing, pre-graze mow, Farmax

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List of Abbreviations

Abbreviation	description	Units
ADF	Acid detergent fibre	g/kg DM
AL	Autumn lenient grazing	
ANOVA	Analysis of variance	
CG	Conventional, hard grazing	
CHI	Chicory (*Cichorium intybus)*	
CP	Crude protein	g/kg DM
DM	Dry matter	kg DM/ha
DOMD	Digestible organic matter in dry matter	%
DP	Diverse pasture	
DP+Ita	Diverse pasture with Italian ryegrass	
g	Gram	g
GJ	Gigajoule	
ha	Hectare	ha
ITA	Italian ryegrass (*Lolium multiflorum*)	
kg	Kilogram	kg
LUC	Lucerne (*Medicago sativa)*	
LSD	Least significant difference	
LURDF	Lincoln University Research Dairy Farm	
m^2	Metre square	m^2
ME	Metabolisable energy	MJ ME/kg DM
MJ	Megajoules	
mm	Millimetre	mm
N	Nitrogen	
n	Number	n
NDF	Neutral detergent fibre	g/kg DM
NIRS	Near-infrared spectroscopy	
NO_3^-	Nitrate	
NZ	New Zealand	
OM	Organic matter	
PLA	Plantain (*Plantago lanceolata)*	
PRG	Perennial ryegrass (*Lolium perenne)*	
RC	Red clover (*Trifolium pretense)*	
SL	Spring lenient grazing	
UN	Urinary nitrogen	
USA	United States of America	
WC	White clover (*Trifolium repens)*	
WSC	Water soluble carbohydrates	g/kg DM

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Chapter 1

Introduction

1.1 Introduction

As the human population continues to grow, agriculturalists need to find ways to produce more food with readily available resources while minimizing the environmental footprint of farming. The dairy industry is a significant contributor to New Zealand's (NZ) economy, contributing NZ$7.8 billion (3.5%) to New Zealand's total gross domestic products (GDP) (Ballingall and Pambudi 2017). However, additional feeds and forage crops are needed to meet the demands of the ever-increasing productivity goals. This generally means more water and nutrients such as nitrogen (N), which would increase the risk of nitrate (NO_3^-) leaching. Proposed regulations in NZ are increasing the pressure on intensive pastoral dairy farming to adopt systems that reduce their environmental footprint, namely less nitrate leaching to soil water (Payn *et al.* 2013), while at the same time maintaining economic viability.

Mitigation techniques to reduce nitrate leaching from grazed livestock production systems have been proposed which improve whole farm N efficiency (Monaghan *et al.* 2005; deKlein *et al.* 2016), such as infrastructure-stand-off pads (deKlein and Ledgard 2001), nitrification inhibitors (Di and Cameron 2002b; Monaghan *et al.* 2009) and use of alternative forages (Moir *et al.* 2013; Fritch *et al.* 2014). With regards to forages, there are some forage characteristics that have been identified which led to reduced N excretion in urine, increased N uptake from urine patches and held N in the soil compared to the standard perennial ryegrass white clover pastures (Moir *et al.* 2013; Malcolm *et al.* 2014; Woods *et al.* 2016; Maxwell *et al.* 2018). Recent research has identified that compared to the standard perennial ryegrass white clover pastures, the inclusion of alternative legumes, herbs and grass in a multi-species sward – hereafter referred to as diverse pasture - may reduce urinary N excretion, in lactating dairy cows without negatively affecting milk production (Woodward *et al.* 2013; Edwards *et al.* 2015; Bryant *et al.* 2017) and hence, potentially mitigate the environmental N footprint (Beukes *et al.* 2014).

However, concerns remain on DM production and nutritive value of diverse pastures, and whether these diverse pastures improve N efficiency or are practical in a farm system. Several studies have compared the agronomic performance of diverse pastures with conventional perennial ryegrass white clover mixtures in a New Zealand farm system. Under a common management regime, the diverse pastures had a similar distribution of DM and feed quality throughout the grazing season (Tharmaraj *et al.* 2008; Nobilly *et al.* 2013; Woodward *et al.* 2013). However, while pasture management principles (e.g., grazing and N fertilizer) are well developed for perennial ryegrass-white clover mixtures (Holmes *et al.* 1992; Hoogendoorn *et al.* 1992; Macdonald and Penno 1998; Lee *et al.* 2008; Lee *et al.* 2011), defoliation requirements to increase DM and quality of diverse pasture are less well defined (Lee *et al.* 2012; Pembleton *et al.* 2015) and need further research. In particular, identifying effects on DM production, quality and botanical composition are important, as these link directly to productivity and environmental performance.

Grazing management has a significant influence on DM production and pasture quality with temperate pasture systems requiring a balance between managing the pasture and managing the livestock to maximize sustainable profit (Dillon *et al.* 2005; Macdonald *et al.* 2010). Grazing management may affect two important variables within this balance: (i) the amount of herbage grown and harvested and (ii) quality of herbage harvested. For example, early studies of perennial ryegrass white clover pastures (Brougham 1970; Butler and Chu 1988) demonstrated the importance of ‘hard’ grazing to low post-grazing height (<4cm) to maintain quality and production. The now accepted post-grazing herbage mass of 1400-1600 kg DM/ha (3.5 cm compressed pasture height) maintains pasture quality and allows light into the base of the sward to promote growth of clover stolons and tillering of grasses, which in turn promotes green leaf growth (Korte 1982; Butler and Chu 1988; Holmes *et al.* 2002). Herbage quality offered to grazing dairy animals has a major effect on milk production and animal performance over the length of the milking season. Thus the current recommendation to dairy farmers to maximise the utilisation of pasture and maintain high quality, is to graze pastures to 3.5 cm (Holmes *et al.* 2002).

Despite the strong suggestion that hard, frequent grazing will maximise DM production and quality, alternative approaches have been researched. For example, Matthew *et al.* (1989) proposed the method of ‘late control’ grazing for perennial ryegrass to increase DM production. In this approach, the reproductive tiller develops to anthesis in spring. By allowing the reproductive parent tiller of grass to develop to anthesis (*i.e.*, early flower stage) before removal by grazing or mowing ("late control"; Matthew 1991) daughter tiller survival is improved (Matthew *et al.* 1989) resulting in greater herbage mass in subsequent grazing in spring and summer (Da Silva *et al.* 1994). However, while DM production may increase, the effect on pasture quality and milk production is unclear. For example, DM intake may potentially decrease as animals’ graze herbage of high herbage mass and it is possible that alternative grazing regimes (e.g. pre-graze mowing) (Bryant 1982; Holmes and Hoogendoorn 1983; Kolver *et al.* 1999) are required to maintain milk production. Given the inclusion of herbs in diverse pastures and their questionable persistence, questions regarding grazing management remain for diverse pastures which are not dominated by perennial ryegrass and contain species which have different defoliation requirements.

A further critical grazing period is late autumn, prior to a period of low herbage growth. This is important as it will determine the quality and quantity of feed available at the start of lactation in spring. Furthermore, an increased DM production over the cool season period, may enhance N uptake from the soil, potentially mitigating environmental impacts by decreasing N available for leaching. Autumn grazing prior to winter has the potential to increase feed available in early spring, because plants are likely to be altering carbon storage patterns to protect growing points from cold conditions and ensure sufficient energy for growth in spring (Krasensky and Jonak 2012). Hence, conflict exists over the benefits of lenient grazing of pastures in autumn. On one hand, laxly defoliated plants retain greater residual leaf area than severely defoliated plants, potentially providing plants with a greater capacity for photosynthesis, and therefore regrowth (Booysen and Nelson 1975; Grant *et al.* 1981). On the other hand, the leaves remaining post- defoliation are generally older and have a reduction in photosynthetic activity compared to younger tissue, therefore unlikely to contribute substantially to regrowth (Gay and Thomas 1995). Repeated lax defoliation has been shown to decrease the quality of the pasture in subsequent rotations because of increased stem production and accumulation of dead material (Lee *et al.* 2007) and reduce pasture production/ha (Lee *et al.* 2008). Further investigation is required for alternative pasture types to examine the effect on DM production, botanical composition and N uptake to enable recommendations on grazing management.

Farmers require a range of options to support grazing management decisions which also take into account the use of mechanical defoliation tools if required e.g. mowing, and how these tools integrate with grazing management decisions which ultimately impacts on the environment. For example, if hard grazing is recommended in autumn, the lower herbage mass may reduce post grazing growth over winter due to low leaf area available. If growth is low, winter uptake of N from soil will also be low (Moir *et al.* 2013) leading to higher loss of N as NO_3^- in drainage water. In addition, at a farm system level, a farmer's economic objective is usually to maximise their net return. Computer models are increasingly being used to simulate farming systems to understand the interaction of different components. Data are used to complement experimental studies and evaluated to understand the implications of various management options in different environmental conditions (Snow *et al.* 2014). Bioeconomic modelling may help support farmers in guiding decisions on farm. There is a lack of information of suitable grazing practices for diverse pasture systems. The development of these livestock grazing management strategies will need to achieve environmental sustainability and maintain or improve the long-term production capacity of pastoral grazing systems.

1.2 Research objectives

This thesis presents a series of experiments which examine the effects of defoliation (grazing and mowing) strategies in spring and autumn on DM production, growth, nutritive value, botanical composition of grass-herb-legume pastures and subsequent milk production from dairy cows. The specific objectives were:

i) To investigate the effects of grazing management strategies in spring and autumn on seasonal and annual DM production, botanical composition and quality of grass-herb-legume pastures under irrigation

ii) To determine the effect of late autumn season grazing management on nutrient uptake and early spring DM production

iii) To compare contrasting spring defoliation regimes with pre-graze mowing on milk production and milk composition of mid lactation dairy cows grazing grass-herb-legume pastures.

iv) To investigate the carry-over effect of alternative spring defoliation regimes on pasture quality, apparent intake and milk production for cows fed grass-herb-legume pastures in early spring.

v) To use a commercial modelling tool: Farmax Dairy Pro, to assess the effect of grass-herb-legume pasture mixtures and grazing management on profitability of Canterbury dairy farms.

1.3 Hypothesis

Null hypothesis 1: Grazing leniently in spring and autumn will not affect DM production or forage quality of grass-herb-legume pastures containing chicory and plantain, lucerne, red clover, white clover and perennial ryegrass and the same mixture also including Italian ryegrass.

Null hypothesis 2: Milk production of dairy cows will not be reduced by lenient grazing in spring.

Null hypothesis 3: When modelled at farm level, dairy farm profitability will not be affected by grazing leniently in spring and autumn of grass-herb-legume pastures.

1.4 Thesis structure

This thesis is presented in eight chapters. Chapter 1 is an introduction while Chapter 2 is a literature review concerning the effects of grazing management and pasture mixture on DM production, nutritive value and milk production. Chapters 3 to 7 correspond to five individual experiments. Chapter 3 reports on a study conducted over two years measuring DM production, botanical composition and nutritive value of two irrigated pasture mixtures under rotational grazing by dairy cows. Chapter 4 presents the effect of late autumn season grazing management on nutrient uptake and early spring growth. Chapter 5 reports the animal production response to defoliation strategies in late spring while Chapter 6 examines the carry over effects of defoliation regimes from Chapter 5 with respect to herbage quality and animal production in the summer. Chapter 7 uses the results of previous chapters to compare the physical and economic feasibility of incorporating a farm with diverse pastures under specific grazing regimes. Finally, in Chapter 8, the results are drawn together and compared with those previously reported in the literature to provide general grazing management strategies when alternative legumes and herbs are included in a diverse pasture mixture in irrigated New Zealand dairy farm systems. Overall conclusions, implications and further research suggestions are summarised at the end of the thesis.

Chapter 2

Literature Review

2.1 Introduction

This review examines the effects of grazing management strategies on herbage DM production, botanical composition, nutritive value, and milk production of dairy cows grazing a diverse pasture mixture that includes alternative legumes, lucerne (*Medicago sativa* L.) and red clover (*Trifolium pretense* L.) and herbs, chicory (*Cichorium intybus* L.) and plantain (*Plantago lanceolata* L.) and an annual, Italian ryegrass (*Lolium multiflorum* L.), in a sward mix with conventional perennial ryegrass (*Lolium perenne* L.) white clover (*Trifolium repens* L.) mix.

2.2 New Zealand dairy farm systems

Pasture grazing provides a low feed cost to farm systems, and pasture species and cultivars have been well developed for the New Zealand environment. A mixture of perennial ryegrass and white clover is commonly sown. This mixture performs well in most situations, has a high nutritive value (*i.e.,* metabolic energy concentration >11.5 MJ ME/kg of DM and crude protein (CP) up to 30% (Waghorn *et al.* 2007), and tolerates a wide range of grazing management when generously fertilised (Charlton and Stewart 1999). Although white clover supplies these pastures with nitrogen (N) through fixation, in order to increase the N supply to the plant and ultimately increase DM production, N fertiliser is normally applied. However, poor persistence of a conventional perennial ryegrass white clover mixture has become a major issue for dairy, beef and sheep farmers throughout the country (Parsons *et al.* 2011). Insect pressure, changeable climate conditions and poor grazing management has highlighted the need for farmers to spread their risk across more than one pasture type. Moreover, environmental and social pressure to manage nutrient losses (e.g. NO_3^-) (Beukes *et al.* 2014; Malcolm *et al.* 2014; Woods *et al.* 2016; Box *et al.* 2017; Maxwell *et al.* 2018) are prompting investigation into alternative pasture species which can meet desired outcomes and spread risk (Sanderson *et al.* 2004; Woodward *et al.* 2012; Nobilly *et al.* 2013; Beukes *et al.* 2014; Grace *et al.* 2016).

In the context of diverse pastures, there has been an increased interest in the use of alternative grasses, legumes and herbs to perennial ryegrass white clover mixture. These include grasses such as Italian ryegrass, legumes such as lucerne and red clover, or forage herbs such as chicory and plantain in mixed swards to increase DM production (Sanderson *et al.* 2005; Tharmaraj *et al.* 2008; Nobilly *et al.* 2013; Woodward *et al.* 2013), buffer environmental extremes such as drought (Sanderson *et al.* 2004), improve feeding value (Zemenchik *et al.* 2002; Huyghe *et al.* 2008; Sanderson 2010), mitigate nutrient loss (eg. NO_3^-, N_2O emissions) (Beukes *et al.* 2014; Malcolm *et al.* 2014; Woods *et al.* 2016; Box *et al.* 2017; Maxwell *et al.* 2018). It is important that these mixed swards are properly managed so milk and milksolids production or herbage intake in dairy cows are evident (Soder *et al.* 2006; Engelbrecht *et al.* 2014). Mixed swards have proven to be a viable option for achieving sustainable intensification of temperate pasture based agricultural production and decrease the environmental burden of forage production (Pembleton *et al.* 2015).

2.3 Seasonal and annual DM production

Dairy systems in New Zealand rely primarily on pasture as a feed source with strong relationships between feed harvested and a profitable farm system. However, the challenges from the management point of view is that many factors can affect herbage growth, including rainfall, temperature, season, soil fertility, legume content, sward management and sward composition, pest and diseases. Herbage growth in New Zealand is seasonal, whereby growth peaks in the spring and declines to a minimal during the winter and hotter summer temperatures (Figure 2.1). There is a high demand for feed in early spring to coincide with the start of calving. Figure 2.1 depicts a typical pasture supply curve fitted against animal demand for a spring-calving dairy farm.

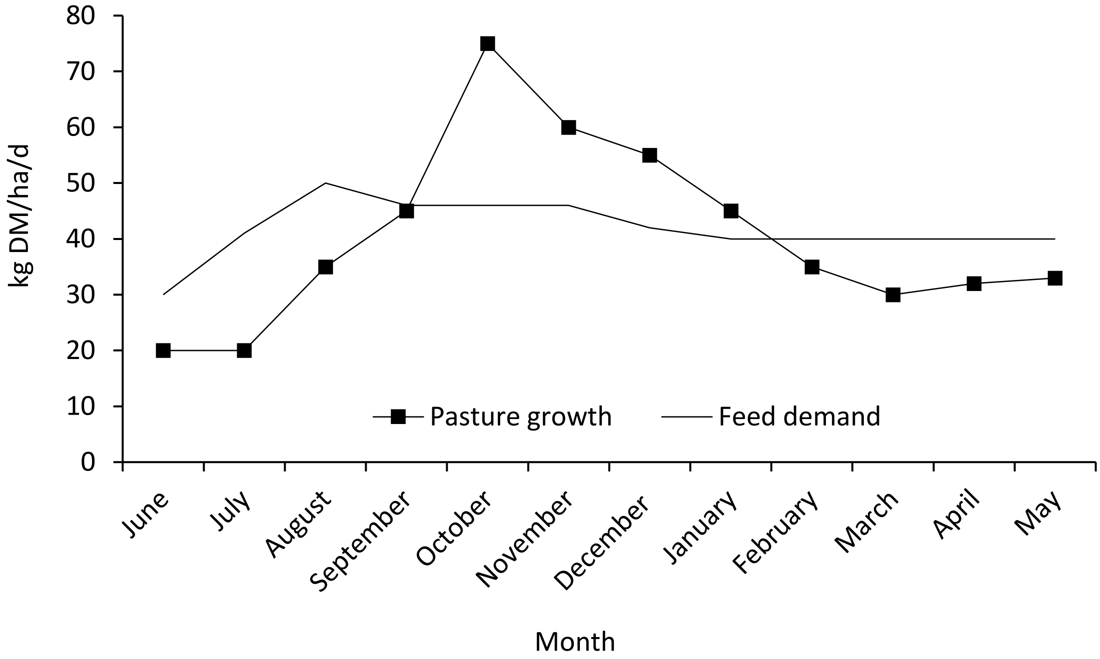


Figure 2.1 Monthly pasture supply versus animal feed demand for dairy farms in New Zealand. Adapted from (Holmes *et al.* 2002).

Pasture growth in New Zealand is seasonal and variable among environments (Figure 2.2). In the South Island of New Zealand, spring and autumn had relatively steep pasture growth profiles, whereas the North Island had a more even growth distribution throughout the year with growth peaking in the summer. The even DM distribution in the North Island was evident by the greater winter and lower spring flush of growth compared to catchments in the South Island (Figure 2.2; Monaghan *et al.* 2004). Pasture growth and production can influence the profitability of farm systems, which is driven by revenue from milk production as well as operating costs. Increased milk production can be achieved through extended lactation, but this is often not achieved due to decreasing pasture growth in autumn as temperatures cool. Similarly, cost of milk production in spring can be great if low pasture growth requires purchase of expensive supplements to meet animal demand for high quality feeds.

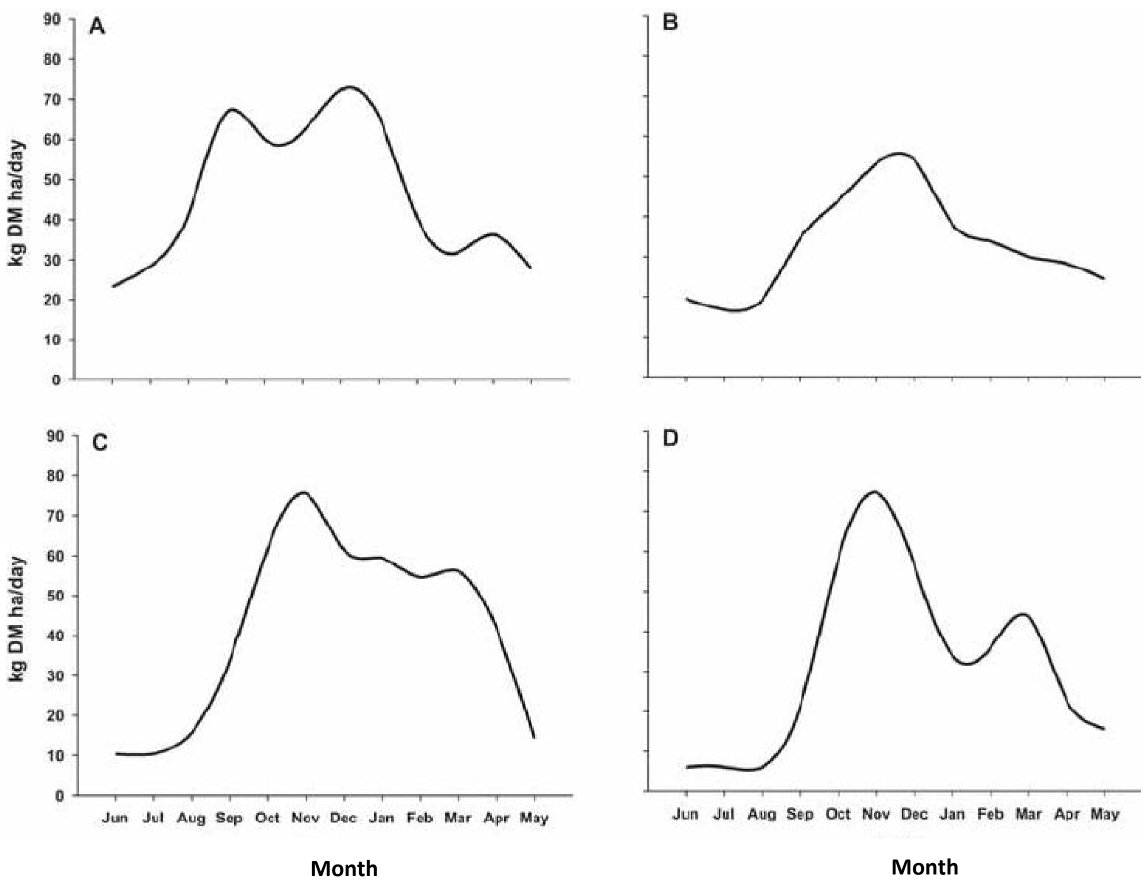


Figure 2.2 Monthly pasture growth rates recorded in the (A) Toenepi, North Island (B) Waiokura, North Island (C) Waikakahi, South Island and (D) Bog Burn, South Island catchments of New Zealand. Data presented are mean values for 2 years of pasture monitoring. Sourced from (Monaghan *et al.* 2004).

Pasture species may have a significant effect on annual and seasonal herbage DM yield and farmers will want the best cultivars for the economic return of their farm system. Economic values (EV) have been placed on seasonal dry matter yield. An economic value is the estimated change in operating farm system profit per unit of change in a defined plant trait (McEvoy *et al.* 2011). Chapman *et al.* (2012) reviewed and estimated EV for farm systems in New Zealand using Farmax Dairy Pro and results are presented in Table 2.1 for the Canterbury region. When animal feed demand is at its highest relative to herbage growth in early spring and winter, EV are higher. Extra feed produced in late spring had a lower economic value as animal feed demand is lower.

Table 2.1 Economic values ($/kg additional dry matter) for seasonal dry matter yield in dairy systems in the upper South Island of New Zealand

Season	EV
Winter	0.45
Early spring	0.42
Late spring	0.29
Summer	0.17
Autumn	0.29

*adapted from Chapman et al. 2012

Herbage DM production and pasture quality of perennial ryegrass-based pastures is often limited in the summer and autumn months by poor growth and feed quality, leading to feed deficits and ultimately reduced animal performance (Burke *et al.* 2002b; Li and Kemp 2005; Sanderson 2010; Nobilly *et al.* 2013). Pasture herbs and legumes may increase pasture production and feed quality over the summer, when perennial ryegrass-based pasture often constrains livestock production (Ruz-Jerez *et al.* 1991; Daly *et al.* 1996; Harris *et al.* 1997; Li and Kemp 2005; Sanderson 2010; Nobilly *et al.* 2013). For example, Daly *et al.* (1996) showed greater growth in late spring and summer from a multi species pasture, that includes chicory, plantain, lucerne and red clover, and produced at least 20% more annual herbage DM than the perennial ryegrass white clover mixture over a three year period and across two experimental sites (Table 2.2). A study in Ireland found the legume in a diverse mixture increased annual herbage DM production, particularly in autumn to greater than 3000 kg DM/ha compared to grasses and herbs (Grace *et al.* 2016). Others have found the inclusion of forage herbs (e.g. chicory and plantain) in a grass clover mix can change the seasonal feed supply and extend the growing season with greater herbage DM production, particularly in the summer and autumn (Sanderson *et al.* 2004; Pembleton *et al.* 2015). Plantain begins growing earlier in spring than chicory, red clover, and white clover (Kemp *et al.* 2010). Moorhead and Piggot (2009) found a diverse sward, which included perennial ryegrass, white clover, plantain and red clover yield significantly more by 1.8 and 0.9 t DM/ha during the summer and autumn season, respectively compared to conventional binary mixtures.

Plant diversity can buffer plant communities from environmental extremes (Sanderson *et al.* 2004) by having some species that are tolerant of different environmental fluctuations and therefore stabilize productivity (Yachi and Loreau 1999; Ives *et al.* 2000). Some evidence suggest greater plant diversity in grassland plant communities has been linked to increased plant herbage DM production (Tilman *et al.* 1996; Tracy and Sanderson 2004). Sanderson *et al.* (2005) found a 54% increase in herbage yield in complex mixtures with the inclusion of chicory, compared to a simple grass-white clover mixture (Sanderson *et al.* 2005) (Table 2.2). In recent years, researchers have found the benefits in the productivity of diverse pastures in dairy systems such as increased DM production in the summer (Ruz-Jerez *et al.* 1991; Daly *et al.* 1996; Tharmaraj *et al.* 2008; Nobilly *et al.* 2013; Woodward *et al.* 2013) compared to a simple ryegrass white clover mixture. For example, Nobilly *et al.* (2013) found on average a 1.62 t DM/ha increase for its annual DM production in diverse pastures and a 1 t DM/ha increase in the summer compared to simple ryegrass white clover pastures (Table 2.2). In the North Island of New Zealand, Ruz-Jerez *et al.* (1991) found a 25-30% increase in late spring and summer DM production for a herbal pasture mixture (inclusion of grasses, legumes and chicory) compared with perennial ryegrass-white clover mixture (Table 2.2). The increased DM production was associated with the presence of drought tolerant and heat tolerant species such as chicory, plantain and legumes with deep tap roots to extract water from a deeper soil profile (Charlton and Stewart 1999; Nobilly *et al.* 2013). In early spring, animal feed demand is at its highest relative to new pasture growth and winter pasture management has a significant impact on the early spring feed supply and pasture growth. While increased summer growth has been demonstrated with diverse pastures containing chicory and plantain, the effects of an increased DM production are more valuable in late autumn or winter because less feed is available, so strategies are needed to increase herbage DM production in these time periods.

Table 2.2 Seasonal dry matter production and annual dry matter production (kg DM/ha) of simple and diverse pasture mixtures

	Spring	Summer	Autumn	Winter	Annual
Sanderson et al. (2005)					
Simple					7000
3 species (grass, legume, herb)					8500
6 species (3 grasses, 2 legumes, 1 herb)					9100
9 species (4 grasses, 4 legumes, 1 herb)					8500
Sanderson (2010)					
Simple	1725	1360	750		
3 species (grass, legume, herb)	2185	1525	1470		
6 species (3 grasses, 2 legumes, 1 herb)	2235	1710	1770		
9 species (4 grasses, 4 legumes, 1 herb)	2055	1780	1420		
Nobilly et al. (2013)					
Simple	5145	5955	2410	1640	15150
Diverse	5590	6890	2550	1740	16770
Cranston (2014)					
Simple					36 -109 kg/ha/day or 4141-12780 kg DM/ha*
Diverse (Herb/legume mix)					62 -73 kg DM/ha/day or 6470-13800 kg DM/ha*
Woodward et al. (2013)					
Simple					14700
Diverse					15300
Daly et al. (1996)					
Simple					~5200 (3 year average)
Diverse					~5800 (3 year average)
Ruz-Jerez et al. (1991)					
Simple	3607	3349	3033	1501	11686
Diverse	5202	5107	3367	1705	15231

*growth rates for 24 weeks

However, it is important to note that more species did not translate to more DM production (9 species, consisting of orchardgrass (*Dactylis glomerate* L.), tall fescue (*Schedonorus phoenix*), perennial ryegrass, red clover, chicory and birdsfoot trefoil (*Lotus corniculatus* L.), white clover, alfalfa and bluegrass versus 3 species, consisting of orchardgrass, white clover, and chicory and 6 species, consisting of orchardgrass, tall fescue, perennial ryegrass, red clover, chicory and birdsfoot trefoil), rather the functional groups increased DM production (Sanderson *et al.* 2005; Sanderson 2010). In addition, Black *et al.* (2017) modelled 19 seed mixture combinations of perennial ryegrass, red clover, white clover and plantain under irrigation in the Canterbury region, varying from 1 to 4 species and relative abundance, and found the greatest annual DM production in the combination was with 25% perennial ryegrass, 47% red clover and 28% plantain. Thus, there is increasing demand for cool season and deep-rooted species (*e.g.,* Italian ryegrass, lucerne, plantain and chicory) that continue to grow well at cooler temperatures or high summer temperatures. Pasture species vary in seasonal growth patterns and this is governed by their genetics associated with temperature requirements.

One potential option to increase DM production during a cool season is to include species that complement perennial ryegrass pasture when the perennials are growing slowly to provide a higher quality forage. Italian ryegrass is often used by NZ dairy farmers to overcome feed shortages in early lactation where Thom and Prestidge (1996) showed Italian ryegrass has winter/early spring growth potential compared to perennial ryegrass (24-35 kg DM/ha/day; Table 2.3). Thom and Prestidge (1996) noted that drilling Italian ryegrass into a perennial ryegrass white clover mixture increased DM production by an extra 40% (3.0 t DM/ha compared to 2.2 t DM/ha) from winter to early spring (mid-July to September) in Northern New Zealand. However less is known about the inclusion of Italian ryegrass for well irrigated pastures under dairy management in the Southern parts of New Zealand. The inclusion of alternative legumes and herbs in a diverse mix swards showed an increasing trend of seasonal (e.g., summer) and annual DM production than simple binary mixtures. For example, the inclusion of alternative legumes, grasses and a herb (3, 6 or 9 species) in a mixture increased DM production compared to a simple grass-white clover mixture (Sanderson *et al.* 2005; Sanderson 2010).

Table 2.3 demonstrates DM production of pasture species in winter and summer. Plants with a low base temperature such as Italian ryegrass have greater cool season growth whereas, plants such as chicory and lucerne, have a high base temperature for summer growth (Table 2.3). Other plant attributes, such as a tap root in the chicory species, contribute to growth patterns. The combination of legumes and herbs provides pasture with a longer growing season than any one species itself. Plantain begins its growth earlier in spring and continues later into autumn than other species (Kemp *et al.* 2010), while chicory and red clover remain more productive in the summer (Charlton and Stewart 1999; Kemp *et al.* 2002; Li and Kemp 2005).

Table 2.3 Seasonal growth rates (kg DM/ha/d) of pasture species

	Winter	Spring	Summer	Autumn
Perennial ryegrass				
Lancashire (1978)	6	13	9	3
White clover				
Lancashire (1978)	<1	4	5	4
Italian ryegrass				
Thom and Prestidge (1996)	24	35	58	21
Hickey and Baxter (1989)	19			16
Ryan-Salter and Black (2012)	13	41	35	9
Plantain				
Powell *et al.* (2007)	30	48	75	46
Chicory				
Brown *et al.* (2005)	<5	10 to 70	50 to 90	10 to 30
Powell *et al.* (2007)	18	32	64	48
Lucerne				
Brown *et al.* (2005)	<5	30 to 70	70 to 105	30 to 65
Thom (1978)	50	97	81	71
Red clover				
Brown *et al.* (2005)	<5	10 to 70	30 to 90	10 to 30
Powell *et al.* (2007)		43	39	14

2.4 Nutritive value

While it is important to achieve the greatest possible DM production, it is also desirable to have high quality pasture. A high-quality pasture should be highly digestible (DOMD > 70%) (Ulyatt 1970), have sufficient fiber content (e.g. 40-50% NDF) for rumen function and contain a high concentration of protein (e.g. 18-25% CP) (Bargo *et al.* 2003). The nutritive value of perennial ryegrass is generally reduced due to reproductive stem development in the summer of 9.9 MJ ME/kg DM, 52% NDF, 22.1% CP (Fulkerson *et al.* 2007) with ME levels as low as 7.6 MJ ME/kg DM (Burke *et al.* 2002b). Legumes such as lucerne and red clover have a wider range in metabolisable energy (9.2-13.4 MJ/kg DM), crude protein (22-30%) and lower in fibre (34-41% NDF, 25-38% ADF) compared to grass based pastures (Valentine and Kemp 2007). Increasing clover content in a sward leads to higher nutritive value than grass, owing to lower levels of structural carbohydrate and higher digestible protein in clover (Ulyatt *et al.* 1976). Brown *et al.* (2005) noted that lucerne, red clover and chicory had similar ME content ranging from 10.9-11.6 MJ/kg DM. Chicory and plantain have variable CP concentrations of 10.5-20.0% DM, depending on the season and cultivar (Sanderson *et al.* 2003). The ME are greater in chicory swards (9.2-13.4 MJ/kg DM) compared with ME of perennial ryegrass (7.6 to 12.3 MJ/kg DM) (Barry 1998; Burke *et al.* 2002b; Fulkerson *et al.* 2007).

Generally, crude protein content between 14 to 18% DM, depending on stage of lactation, is required in the diets of dairy cows to support milk production (NRC 2001). Though individual species may have their limitations, the inclusion of legume (red clover and lucerne) and forage herbs (chicory and plantain) within a pasture mixture improved nutritive characteristics with greater CP concentrations and lower NDF concentrations (Zemenchik *et al.* 2002; Deak *et al.* 2007; Chapman *et al.* 2008; Tharmaraj *et al.* 2008; Nobilly *et al.* 2013; Totty *et al.* 2013; Woodward *et al.* 2013). Among several studies (Nobilly *et al.* 2013; Engelbrecht *et al.* 2014; Edwards *et al.* 2015; Bryant *et al.* 2017), the average CP content of a diverse pasture mixture was 17.9% DM, similar to CP concentrations in conventional perennial ryegrass white clover pastures (17.6% DM) (Table 2.4). However, the CP content of these diverse swards vary greatly between vegetative and reproductive growth and thus, CP content is likely to vary between seasons (Table 2.4).

In dry summer conditions, the combination of decreased pasture production and low pasture quality from an increased fibre content may be limiting for dairy cow milk production. The supply of metabolisable energy is generally the first limiting factor for milk production for dairy cows on a pasture-based system (Kolver and Muller 1998). Burke *et al.* (2002b) showed metabolisable energy values of perennial ryegrass are as low as 7.6 MJ ME/kg DM in the summer compared to 11 MJ ME/kg DM in spring, whereas the ME values of a diverse sward that included herbs and legumes ranged from 10.4-12.6 MJ ME/kg DM (Table 2.4). Nobilly *et al.* (2013) found little difference in ME of perennial ryegrass white clover mixtures (12.2 MJ ME/kg DM) and diverse pastures (12.0 MJ ME/kg DM), though the total ME produced per hectare was greater in diverse than simple pastures (202 vs 185 GJ/ha) due to greater DM production of diverse pasture. The high nutritive value of a diverse pasture mixture that includes herbs and legumes during the summer complements conventional perennial ryegrass white clover mixtures that often has poor nutritive values during this time of the year (Burke *et al.* 2002a). For example, Burke *et al.* (2002a) found greater ME (11.1 MJ ME/kg DM) and lower NDF (35.3% DM) when Sulla (*Hedysarum coronarium* L.) was added to a perennial ryegrass white clover mixture compared to NDF concentrations of 48.0% DM and 10.1 MJ ME/kg DM in the summer of conventional perennial ryegrass white clover mixtures. Thus, effective grazing management is important to maintain the sward quality of a grass-legume-herbs mixture.

Table 2.4 **Average chemical composition (crude protein (CP), neutral detergent fibre (NDF), acid detergent fiber (ADF), water soluble carbohydrates (WSC) and metabolisable energy content (ME) in simple grass and legume mixtures (simple) compared to diverse mixtures which includes combinations of grass, legumes and forage herbs across a number of studies.**

Study	CP (g/kg DM)	NDF (g/kg DM)	ADF (g/kg DM)	WSC (g/kg DM)	ME (MJ ME/kg DM)
Deak *et al.* (2007)					
2 species	241	361	251		
3 species	216	400	262		
6 species	224	400	261		
9 species	232	363	250		
Nobilly *et al.* (2013)					
Simple	217	368		206	12.0
Diverse	214	301		186	12.2
Edwards *et al.* (2015)					
Simple	186	381	245	202	11.8
Diverse	182	394	245	217	12.0
Bryant *et al.* (2017)					
Simple					
Spring 2010	115	438		247	11.9
Summer 2011	109	469		239	11.8
Autumn 2011	218	381		185	12.7
Diverse					
Spring 2010	127	388		201	11.8
Summer 2011	136	381		174	11.2
Autumn 2011	225	308		184	12.6
Soder *et al.* (2006)					
Simple	225	387	242		
3 species (grass, legume, herb)	223	317	224		
6 species (3 grasses, 2 legumes, 1 herb)	227	324	217		
9 species (4 grasses, 4 legumes, 1 herb)	242	264	203		
Cranston *et al.* (2015b)					
Herb and legume mixture					
Spring	243	194	133		12.1
Summer	211	286	193		11.4
Autumn	200	285	201		11.4
Engelbrecht *et al.* (2014)					
Simple	210				10.5
Diverse	190				10.4

2.5 Pasture persistence

An important issue with pasture persistence is the botanical composition of diverse pasture mixture through time and in particular, whether the herbs, such as chicory and plantain and legumes, such as red clover persist in the mixture. It is crucial to maintain the botanical composition as any botanical shifts can affect forage quality (Belesky *et al.* 1999). Also, given the key role of species such as plantain in reducing the environmental impact of dairy farming (Box *et al.* 2017), it is important to maintain botanical composition. However, managing species diversity in a pasture has proven to be challenging since diverse pastures can revert to simple grass dominant pastures over a period of three to four years (Sanderson *et al.* 2007). Pasture persistence is a complex phenomenon that is dependent on a number of factors; environment, management, plant genetics, and can be defined as the stability of DM production of the sown population over time (Parsons *et al.* 2011). Long term persistence is desirable since the replacement of an old pasture with a new pasture is a capital cost that must generate a positive return on investment-the attainment of which will be strongly influenced by the number of years for which the new pasture continues to perform at high level, as the cost of pasture renewal is approximately $600/ha, but can increase depending on the method and crops used (Bryant *et al.* 2010).

Grazing animals have considerable influence on plant communities and diversity in grazing lands and the loss of diversity is often associated with diet selection and overgrazing of preferred species. In a pasture mixture, animals show a partial preference for legumes and herbs and forbs over grass (Rutter 2006; Edwards *et al.* 2008; Pain *et al.* 2010). The selective grazing of herbs and legumes species are less competitive with grasses. In turn, this could result in the dominance of a grass species with a reduction of herbs and legume components in a forage mixture (Sanderson *et al.* 2005; Jing *et al.* 2017), although some of this effect may be mitigated by intensive rotational grazing. Grass pasture persistence is dependent on the ability of plants to maintain a high and stable tiller density, and the ability of individual tillers to maintain live leaves (Hirata and Pakiding 2001). An increased perennial ryegrass tiller population is positively correlated with persistence and long term pasture yield (Edwards and Chapman 2011). There are two periods of active tillering in perennial ryegrass swards, the first in spring before culm elongation and the second after interruption of reproductive development (Korte 1986) which is generally between November to January in the South Island of New Zealand.

As with grasses, the persistence of herbs is also driven by plant density and initiation of growing point on each plant. Persistence of herbs such as chicory typically ranges from two to five years depending on the weather, management and species (Li and Kemp 2005). For example, Li and Kemp (2005) showed chicory population decreased from 56 to 20 plants/m^2 over 4 years. Powell *et al.*

(2007) examined pure swards of plantain, chicory and red clover establishment and growth over time to best determine suitable grazing management practices to maintain pasture persistence. Chicory requires a longer thermal time before defoliation than plantain. Powell *et al.* (2007) suggested 19 weeks after sowing or at 840°C/d of thermal time to allow seven fully developed leaves and a plant height of 25 cm for the first defoliation will aid chicory persistence. On the other hand for plantain, a delay of the first defoliation at 12 weeks after sowing or approximately 690°C/d of thermal time, with a minimum of six fully developed leaves and at a sward height of 30 cm may improve plantain persistence (Powell *et al.* 2007). Glassey *et al.* (2013) found plantain population decreased from 155 to 86 plants/m^2 six months after establishment. In addition, Cranston *et al.* (2015b) compared a herb and clover mix under sheep grazing with 4 and 8 cm post-grazing defoliation height using 3-4 week grazing interval with no winter grazing. They found the more lenient management of 8 cm defoliation height better supported the maintenance of the four species in the herb and clover mix over 2 years, but a decrease in DM production (8.9 t DM/ha/year) compared to 11.6 t DM/ha/year from a severe defoliation height of 4 cm (Cranston *et al.* 2015b). Within monoculture swards, grazing severely in chicory or plantain during late autumn has negative effects on growth and plant persistence (Li *et al.* 1997).

Unlike grasses, persistence and regrowth from the crown of lucerne is supported by root reserves and thermal time (Moot *et al.* 2003). A reduction in lucerne persistence can be expected if the crown is removed by the animal, depleting root reserves and comprising growth (Moot *et al.* 2003). Ford and Barrett (2011) tested the growth and persistence of red clover cultivars in a mixed sward under rotational grazing by cattle and found an improved potential for persistence under medium and long rotational grazing in spring, summer and autumn. Grazing commenced when pasture was estimated at 2600-3000 kg DM/ha and a post-grazing to 1400 to 1600 kg DM/ha, though red clover plants were not allowed to set seed (Ford and Barrett 2011). The carbohydrate storage of tap roots influences the persistence of red clover plants, so key principles are not to graze into the crown and to use a rotation that maintains the tap root size and initial growth of the next generation of shoots (Kemp *et al.* 2010). Grazing management strategies after establishment of plant species are further discussed in the next section.

2.6 Grazing management and pasture regrowth

Grazing management strategies, such as frequency and intensity, to optimize DM production, persistence and nutritive value of conventional binary perennial ryegrass white clover mixture are well developed (Holmes *et al.* 1992; Hoogendoorn *et al.* 1992; Macdonald and Penno 1998; Lee *et al.* 2008; Lee *et al.* 2011). Best grazing management practices have been established for individual species of chicory, plantain, lucerne and red clover or in mixtures without grasses (Sanderson *et al.*

2003; Brown *et al.* 2005; Li and Kemp 2005; Lee *et al.* 2012; Cranston *et al.* 2015a) while there is limited information on the management of diverse pastures containing herbs, legumes and grasses. It is important to note that individual species may have a range of optimum grazing management that could result in difficulties optimising grazing management for all sown species in a diverse mixed sward. Optimum grazing management for one species may have a negative effect on another species' yield, quality or persistence, though key aspects of seasonal grazing management (timing, frequency, and severity) to consider may be a strategy to limit any negative effects.

2.6.1 Frequency of grazing

Leaf stage is a useful plant related indicator of the optimal time to defoliate and the optimal time for grazing perennial ryegrass is between the 2 and 3 leaf stages of regrowth (Fulkerson and Donaghy 2001). If pastures are grazed before the second new leaf has fully emerged (low leaf area available), reductions in pasture growth are likely. In contrast, grazing pastures after the 3½ leaf stage will waste a portion of the grown herbage through senescence, provide a lower quality, more fibrous feed (a greater proportion of stem and dead matter), and can result in reduced tillering (decreased light penetration) (Grant *et al.* 1981; Fulkerson and Slack 1994; Fulkerson and Donaghy 2001). Perennial ryegrass defoliation should occur around the three-leaf stage to maintain pasture quality and maximise DM production, whereas for herbs and alternative legumes, thermal time, leaf appearance or plant height may be more important to maximise production (Powell *et al.* 2007; Lee *et al.* 2015). A range of tactical spring management strategies have been proposed in perennial ryegrass-based pastures. In south western Victoria, Australia, the effects of various spring regimes based on a combination of grazing rotations set by ryegrass leaf development stage, grazing intensity measured by pasture post- grazing height on pasture accumulation rates, DM and pasture nutritive characteristics were measured (McKenzie *et al.* 2006a, 2006b). This group examined the effects of different spring defoliation strategies and traditional management (pastures grazed at the 3-leaf stage) throughout the rest of the year on tiller densities and botanical composition in ryegrass-white clover pastures grazed by dairy cows. Greater perennial ryegrass tiller densities were seen when cows grazed at high frequency and high intensity (at the 2-leaf ryegrass development stage to 3 cm, ~1500 kg DM/ha) compared to low (grazing at 3-leaf stage) and medium (grazing at 4-leaf stage) grazing frequency treatments. The frequent and intense spring grazing also maintain high pasture DM production and improved metabolisable energy, crude protein and neutral detergent fibre contents (McKenzie *et al.* 2006a, 2006b). While grazing frequency of perennial ryegrass has been heavily reviewed, there is limited information on grazing frequency of herbs and legumes in a diverse mixed sward.

Herbs such as plantain and chicory and red clover are summer active and accumulate most of their DM over the summer period, becoming virtually dormant in winter (Labreveux *et al.* 2006; Valentine and Kemp 2007; Moorhead and Piggot 2009). Labreveux *et al.* (2004) found grazing chicory and plantain every 3 weeks versus 5 weeks reduced DM production in the summer by more than two-fold (1.7 versus 4.5 t DM/ha, respectively), though they also recommended a resting period of no more than three weeks to prevent the accumulation of reproductive stems (Labreveux *et al.* 2004) and an improved herbage nutritive value (Sanderson *et al.* 2003). Similarly, Li *et al.* (1997) found a 4 week grazing frequency of chicory resulted in the greatest yields but also the highest stem content compared to a 1 week frequency. Chicory produced a greater DM production under a 5 to 6 week defoliation than under more frequent defoliation (Belesky *et al.* 1999; Kemp *et al.* 2002; Sanderson *et al.* 2003). Though, the first defoliation of chicory should occur at 19 weeks after sowing or at 840°C/d of thermal time to allow seven fully developed leaves and a plant height of 25 cm (Powell *et al.* 2007). For maximum chicory DM production, defoliation at 350-550 mm extended leaf height is recommended (Lee *et al.* 2015), whereas, the first defoliation of plantain can occur earlier than chicory (Table 2.5). The first grazing of plantain should occur 12 weeks after sowing or approximately 690°C/d of thermal time with a minimum of six fully developed leaves and at a sward height of 30 cm (Powell *et al.* 2007) or 450 mm extended leaf height (Lee *et al.* 2015) to maximise plantain production (Table 2.5). In contrast to herbs, red clover and lucerne perform best under 4-6 week rotational grazing to maximise production and maintain pasture persistence (Kemp *et al.* 2002). Repeated defoliation in the autumn depletes carbohydrate reserves and diminish the ability of red clover and lucerne to recover (Hay and Ryan 1983; Teixeira *et al.* 2007). Thus, grazing frequency may need to be altered depending on the species vulnerability during a season in a diverse mixed sward.

Table 2.5 Seasonal and annual dry matter yields (t DM/ha) from spring-sown swards defoliated at extended leaf height of 150, 250, 350 or 550 mm (chicory) and 150, 250, 350 or 450 mm (plantain). Taken from (Lee *et al.* 2015).

	Chicory				Plantain			
Extended leaf height (mm)	150	250	350	550	150	250	350	450
	Year 1 (December 2010-May 2011)							
Summer	6.9	7.2	8.1	7.7	9.6	9.6	10.3	11.4
Autumn	1.2	2.3	2.9	2.9	1.9	3.0	4.1	4.7
Total (Year 1)	8.1	9.5	11.0	10.6	11.5	12.7	14.4	16.1
	Year 2 (June 2011-May 2012)							
Winter	-	-	-	-	0.6	1.5	2.3	2.8
Spring	4.1	4.0	4.8	6.2	3.3	3.5	4.5	4.5
Summer	4.7	4.8	5.2	5.0	4.5	4.3	4.5	5.0
Autumn	1.8	1.8	1.5	1.2	1.4	1.3	1.2	1.4
Total (Year 2)	10.7	10.6	11.4	12.4	9.8	10.7	12.5	13.7
Total (Year 1 + Year 2)	18.8	20.1	22.4	23.0	21.3	23.4	26.9	29.8

2.6.2 Intensity and timing of grazing

Animals can influence pasture production following grazing defoliation, treading, and return of dung and urine (Sears and Goodall 1942). Treading by grazing cattle in the winter can influence pasture growth rates in early spring from 39 kg DM/ha/day to 21 kg DM/ha/day (Pande *et al.* 2000). Herbage quality offered to grazing dairy cows has a major effect on milk production and animal performance over the length of the milking season. The intensive management of grazing in spring improved pasture utilisation in spring and summer, and milk production in summer (Michell and Fulkerson 1987). Though spring is the one-time of the year when the feed supply exceeds demand, the intensive grazing management in spring may be crucial to the subsequent performance and production of the pasture at other times of the year when actual feed supply is critical (Brock and Hay 1996). Studies have emphasized the importance of hard grazing to maintain quality and production (Brougham 1970; Butler and Chu 1988). The traditional post- grazing height of 3-4 cm was proposed to maintain pasture quality and allow light into the base of the sward to promote growth of clover stolons and tillering of grasses, which in turn promotes green leaf growth (Butler and Chu 1988). This recommendation maximises the use of high quality pasture per hectare. Regrowth of perennial ryegrass is linked to sufficient leaf area to intercept available light energy to continue photosynthetic uptake (Parsons *et al.* 1983) and the number of live leaves per tiller of a mature plant

(Hunt and Field 1978). To maximise DM production, the optimal time to defoliate perennial ryegrass corresponds between the two and three leaf stage (Fulkerson and Donaghy 2001).

However, Matthew *et al.* (1991) indicated that severe grazing (<4cm) in early spring suppressed rather than enhanced perennial ryegrass tillering. This is because the supply of assimilates from the parent tiller to the smaller dependent daughter tillers is reduced or ceases with severe defoliation (Matthew *et al.* 1991), risking the daughter tillers survival. Reports of paddock scale studies with sheep and dairy cattle, have suggested more lax grazing (post-grazing pasture mass of 1800 kg DM/ha) and allowing pasture to accumulate to a higher herbage mass (>5000 kg DM/ha) improved herbage mass by around 24.5% in spring (October-November) and 32.0% in the summer (December-March) compared to a hard conventional grazing to a post-grazing pasture mass of 1500 kg DM/ha (Da Silva *et al.* 1994; Hernández Garay *et al.* 1997; Matthew *et al.* 2000). Researchers have suggested a longer grazing rotation in early spring to allow early flower head formation, followed by hard grazing (pasture mass of 1500 kg DM/ha) to utilize the young seed heads before maturity reduces their palatability as a method to improve herbage mass in perennial ryegrass pastures during the summer and autumn season (Matthew *et al.* 1989; Hernández-Garay *et al.* 1993; Da Silva *et al.* 1994; Edwards and Chapman 2011). By allowing the reproductive parent tiller of grass to develop to anthesis (i.e., early flower stage) before removal by grazing or mowing, aided daughter tiller survival (Matthew *et al.* 1989). This was possibly through better nutrition owing to the strongly growing parent tiller and/or reabsorption of nutrients from the decapitated flowering stem base. However, the 'window of opportunity' for enhanced levels of herbage is quite narrow. If the parent tiller defoliation is left too late, competition for nutrients by the developing seed head can have a negative effect on daughter tiller survival. Furthermore, a decrease in herbage quality due to high herbage mass may occur. Also, livestock may have difficulty grazing to a low herbage mass and DM intake may be reduced. This may require alternative strategies, such as pre-graze mowing. Several key questions remain for tactical defoliation strategies that include alternative herbs and legumes. First, whether grazing management strategies derived for perennial ryegrass-white clover pastures can be applied to diverse pastures that contain herbs and alternative legumes. Second, allowing plants to be grazed more laxly just before reproductive development in spring may reduce pasture quality. The reproductive stem of perennial ryegrass has a lower quality than the green leaf portion (Chaves *et al.* 2006). Further, DM intake from livestock may be reduced as animals are required to graze through fibrous material and into a lower horizon. Moreover, if herbage is left behind, herbage in subsequent grazing rotation may be of lower quality. Pre-graze mowing of herbage is one strategy used to ease with which the cows can consume the pasture that is readily available but how effective this may be in diverse pastures is unclear.

Mechanical defoliation, mowing pre- or post-grazing, is an alternative means of achieving consistent post- grazing heights as it non-selectively removes stem and accumulated senescent material. Mowing enables high quality green leaf in the subsequent regrowth (Kolver *et al.* 1999) which animals would otherwise reject. Often the result of mowing is similar to that of severe defoliation, resulting in large loss of leaf area which takes longer to re-establish compared with less severe defoliation (Brougham 1956). The outcome of pre-graze mowing is reduced regrowth of pastures compared to grazing standing herbage (Bryant *et al.* 2016). One of the perceived benefits of mowing is improved utilisation, or DM intake, of pasture, if all mown material is consumed. Consequently, the practice of pre-graze mowing of pastures has become a common management tactic in New Zealand dairy farm systems. The general belief is that mowing leads to additional benefits in subsequent grazing rotations because the carry-over effects of achieving desired post- grazing heights by mowing is that high pasture quality is retained. However, research results using perennial ryegrass-dominant swards have failed to demonstrate either improved intake or improved long term quality. One study showed that pre-graze mowing increased dry matter intake (2.2 kg DM/cow/day) and a 5.5% increase in milksolids production (Bryant 1982) from mid spring to summer, while others showed that mowing before grazing reduced DMI and milk response (Kolver *et al.* 1999; Irvine *et al.* 2010; Bryant *et al.* 2016). The explanation for variation in intake results, arise from reduced selection opportunity for a higher quality diet when offered mown material (Kolver *et al.* 1999; Irvine *et al.* 2010), while others reported reduced allocation due to slow herbage regrowth following mowing (Bryant *et al.* 2016). Response to defoliation of diverse pastures containing deep-rooted species has not been closely examined and may present some opportunities to overcome issues surrounding regrowth after mowing.

An important aspect of grazing management is the grazing intensity or severity as these impacts subsequent herbage mass. In southern parts of NZ, herbage growth rates are low in the winter <10 kg DM/ha/d (Monaghan *et al.* 2004) and pastures are not ready for grazing again for approximately 90 days or mid-September. Animal feed demand at early spring is generally greater than the herbage available. So, the last round of grazing in autumn will impact the early spring feed supply. The beneficial effect of residual leaf (post-grazing height or mass) following defoliation has been debated in perennial ryegrass white clover pastures. Severe grazing to low herbage height (<30 mm) before the onset of winter was proposed to increase DM herbage mass (Brougham 1960) and the long regrowth periods in winter may increase herbage growth through an increase in light interception (Brougham 1957; Robson 1973). Research suggests that leaves remaining post- defoliation are generally older and have a reduction in photosynthetic activity compared to younger tissue, therefore unlikely to contribute substantially to regrowth (Gay and Thomas 1995). However, contrasting research suggest that a greater residual leaf mass may increase pasture growth rate and consequently, DM herbage mass (Booysen and Nelson 1975; Grant *et al.* 1981). Plants defoliated to low post-grazing height, with insufficient leaf area, are unable to replenish energy demands for growth and respiration solely through photosynthesis during the immediate post- defoliation period (Booysen and Nelson 1975; Grant *et al.* 1981; Li *et al.* 1997). Similarly, Lee *et al.* (2008) identified that severe grazing (<30 mm) between spring and autumn reduced herbage regrowth due to lower plant energy reserves, while a more lax defoliation (>60 mm) increased stem production and accumulation of dead material (Lee *et al.* 2007) and reduce pasture production/ha (Lee *et al.* 2008). The post-grazing height or mass to which swards are defoliated, can potentially affect regrowth. Lee *et al.* (2007) considered low post- defoliation herbage mass during winter and concluded that grazing severely (1260 ± 101 kg DM/ha) and laxly (1868 ± 139 kg DM/ha) provided similar regrowth potential, though there was a small transient concentration reduction of water soluble carbohydrates (WSC) in the low post- defoliation pasture at 1260 kg DM/ha. This may be significant if frequent defoliation to low herbage mass (650-800 kg DM/ha) takes place during winter, and may help explain the slow start to spring recovery measured by Harris and Brown (1970).

It has been suggested for pure swards of chicory to minimize grazing below 5 cm (Li *et al.* 1997) and avoiding grazing chicory and plantain during late autumn and winter (Li *et al.* 1997; Ayala *et al.* 2011). In addition, a lenient grazing on red clover will improve species persistence (Brock *et al.* 2003). Although quality is compromised in lax grazed ryegrass dominant pastures (Holmes *et al.* 1992; Hoogendoorn *et al.* 1992; Da Silva *et al.* 1994), there are likely to be smaller compromises in quality in diverse pasture with a high proportion of herbs and legumes due to greater feeding values (Zemenchik *et al.* 2002; Huyghe *et al.* 2008; Sanderson 2010). Greater post-graze herbage mass in autumn may lead to greater growth, however, insufficient information is available on grazing management practices for dairy cows grazing diverse pastures (that contain herbs and legumes) and whether it affects herbage quality at first grazing in spring.

2.7 Nitrogen losses

Nitrate leaching is an important environmental factor in livestock production system and approaches using forages to mitigate nitrate leaching are proposed. The urinary nitrogen (N) concentration and total urine excretion from livestock can lead to high soil N loading under urine patches (Di and Cameron 2002a) and consequently nitrate (NO_3^-) leaching (Moir *et al.* 2013). The N deposition in the urine pasture exceeds the pasture N requirements due to minimal pasture growth and low temperatures in the autumn and winter (Haynes and Williams 1993). Research on NO_3^- mitigation of sixteen grasses in soil column trials under glasshouse conditions has shown a general trend of lower N leaching in annual ryegrass, *Lolium multiflorum* with greater N uptake (Moir *et al.* 2013). Grasses such as the Italian ryegrass, which grow more in cool season, may increase N uptake which subsequently results in lower N leaching losses (Maxwell *et al.* 2018). Compared with conventional mixtures of perennial ryegrass white clover mixture, Malcolm *et al.* (2014) found the Italian ryegrass-white clover pastures in Canterbury, New Zealand had an 26% higher DM production in winter and showed a 41% lower nitrate leaching loss where Italian ryegrass was included in the mix. This result is expected given Italian ryegrass' ability to actively grow during cooler months. This is in agreement with Moir *et al.* (2013) who reported leaching losses in Italian ryegrass were 75% lower than perennial ryegrass and tall fescue pastures. The Italian ryegrass was able to capture a larger proportion of soil N, which otherwise would have been susceptible to leaching.

Further, forage herbs such as chicory and plantain as part of a diverse pasture mix have been suggested as a tool to reduce nitrate leaching losses in grazed pasture systems (Pembleton *et al.* 2015). This may be associated with two mechanisms, first, a deeper rooting system to capture N in soil (Malcolm *et al.* 2014) or second, by altering N partitioning in animals and leading to lower N excretion in cows (Totty *et al.* 2013). When compared to conventional ryegrass-white clover pastures, cows grazing on a diverse pasture mixture including chicory, plantain, lotus, high sugar ryegrass and white clover showed a 17.1% reduction in urinary N excretion (Totty *et al.* 2013). Further, in an indoor feeding trial, cows grazing diverse pastures partitioned more of the feed nitrogen intake into milk (23% versus 15% in conventional perennial white clover pasture) and hence excreted less of feed N in urine (29% in diverse pasture and 43% in conventional perennial ryegrass white clover pasture) (Woodward *et al.* 2012). Further, studies have shown reduced nitrate losses (24-58% less leaching losses) from diverse pasture mixtures, which include chicory, plantain, and an Italian ryegrass (Moir *et al.* 2013; Malcolm *et al.* 2014; Woods *et al.* 2016) compared to the conventional perennial ryegrass white clover mixtures. In this context, if defoliation management can be used to manipulate botanical composition of species with desirable traits for environmental mitigation, it may enhance environmental mitigation. Further, grazing management may be used to increase DM production. In particular, as autumn urine patches are most at risk of nitrate leaching, it raises the possibility of using defoliation in autumn to increase DM production and N uptake. Pastures which grow rapidly after defoliation may have greater potential to increase N uptake during the late autumn period, thereby reducing the risk of nitrate leaching.

2.8 Milk production

There is growing literature of the effect of diverse pastures on milk production. Milk production from cows grazing diverse pastures was reported to be similar or greater than from cows grazing conventional perennial ryegrass white clover pastures (Totty *et al.* 2013; Woodward *et al.* 2013; Bryant *et al.* 2017). In one study, Bryant *et al.* (2017) compared a perennial ryegrass white clover mixture with a diverse mixture that included perennial ryegrass, white clover, chicory, plantain, red clover and prairie bromegrass (*Bromus willdenowii*) on milk production. The differences in milksolids production were attributed to the legume content (35% DM of the diverse diet) of the protein limiting diet in the summer from the perennial ryegrass white clover mixture (136 g CP/kg DM versus 109 g CP/kg DM; Bryant *et al.* 2017). In another study, Totty *et al.* (2013), found cows grazing a diverse pasture mix (chicory, plantain, lotus, high sugar ryegrass and white clover) had increased milk production (16.9 kg/d) compared to cows grazing the conventional perennial ryegrass-white clover mixture (15.2 kg/d); although no differences were observed in milksolids production (Table 2.6). Cows on the diverse pasture mixture produced more milk protein (655g milk protein/day) and less milk fat (819g milk fat/day) than cows on perennial ryegrass white clover mixtures (628g milk protein/day and 920g milk fat/day), resulting in similar milksolids production (Table 2.6, Totty *et al.* 2013). However, other studies showed no increase in milk production, milk composition and milksolids production for dairy cows offered a simple binary grass-legume mix and a more diverse pasture mixture, containing additional alternative grasses, chicory, plantain and lucerne (Table 2.6, Soder *et al.* 2006; Edwards *et al.* 2015). When an increased in milk production has occurred, it is typically associated with an increase in CP and a decrease in the NDF concentration of the diet, reflecting proportions of legumes (red clover and lucerne) and herbs (chicory and plantain) (Chapman *et al.* 2008; Totty *et al.* 2013; Woodward *et al.* 2013; Bryant *et al.* 2017). More importantly, there are no reports of a decrease in milk production from cows grazing a diverse pasture mixture compared perennial ryegrass white clover mixtures. Swards based on alternative species to perennial ryegrass are capable of supporting milk production that is at least comparable over an annual cycle (Chapman *et al.* 2008).

Table 2.6 Effect of diverse pasture mixtures on milksolids production compared to perennial ryegrass white clover mixture

Pasture mixture	Season	Change in milksolids production	Author
Diverse (perennial ryegrass, white clover, chicory, plantain, lotus)	Autumn 2010	No difference	(Totty *et al.* 2013)
Diverse (perennial ryegrass, white clover, chicory, plantain, prairie grass and red clover)	Spring 2010	No difference	(Bryant *et al.* 2017)
	Summer 2011	+ 0.25 kg /cow/day	
	Autumn 2011	No difference	
Diverse (perennial ryegrass, white clover, chicory, plantain and lucerne)	Summer 2014	No difference	(Edwards *et al.* 2015)
Diverse (perennial ryegrass, white clover, chicory, plantain and lucerne)	Summer 2014	No difference	(Engelbrecht *et al.* 2014)
Diverse (orchardgrass, white clover, chicory, tall fescue, red clover, birdsfoot trefoil)	Spring 2002/2003	No difference	(Soder *et al.* 2006)*

*compared to orchardgrass white clover mixture

However, there is limited information to date on the effects of various grazing management strategies of alternative pasture mixtures on milk production in New Zealand. Engelbrecht *et al.* (2014) reported the effect of different herbage allocations to dairy cows grazing either a binary perennial ryegrass white clover mixture or a more diverse mixture that also contained chicory, plantain and lucerne on milksolids production. Herbage feed allowance is an important factor in determining DM intake and leads to greater animal performance. Engelbrecht *et al.* (2014) found increasing herbage allowance from 20 to 60 kg DM/cow/day, resulted in milksolids production increasing in a curvilinear manner regardless of pasture mixture offered. However, additional energy did not translate into additional milk production, but possibly to live weight gain (Engelbrecht *et al.* 2014). Diverse pastures containing legumes and herbs may have a greater feed intake potential (i.e., bite rate; Bryant *et al.* 2012) and therefore research around feed allowance and grazing management of diverse pastures needs to be addressed to maintain an economically feasible production system for farmers.

2.9 Diverse pastures in farm systems

Grazing management plays an important role in influencing feed supply which is a key determinant of the economic viability of dairy farm systems. Grazing management strategies are designed to ensure a year-round balance of forage supply and demand to reduce the effect of seasonal and annual variability in weather. As reviewed earlier in the chapter, dairy farming in New Zealand is primarily based on grazed pastures comprising of perennial ryegrass and white clover mixtures. However, such sward mix is subjected to seasonal variations in growth rate and nutrient composition, causing herbage to be insufficient to meet the animal requirements during some periods (Burke *et al.* 2002b). The inclusion of grasses, legumes and herbs in a diverse mix sward has the potential to provide a more even distribution of dry matter production and feed quality throughout the grazing season (Sanderson *et al.* 2007; Nobilly *et al.* 2013). However, quantifying the usefulness of given strategies in a farming system and for multiple seasons is risky, expensive and impractical to do in many situations (Jones *et al.* 2017).

With the development of a growing range of farm modelling tools, computer simulations are increasingly used to optimise and improve farm management practices (Jones *et al.* 2017). Results of farm simulations are used to complement experimental studies and help to understand the implications of various management options in different environmental conditions (Snow *et al.* 2014). For example, Sanderson *et al.* (2006a) modelled the economic returns on establishing four mixtures of various species of grasses, legumes and chicory with pasture stand lives of 3-10 years. The increase in net returns ranged from US$57/cow for the grass and legume mixture to US$191/cow for the grasses, legume and chicory mixture with a three-year stand life. The increased forage production from the mixtures reduced purchased feed costs (Sanderson *et al.* 2006a). In addition, Beukes *et al.* (2014) modelled annual DM production, milk production and N leaching from two hypothetical farms with a proportion of diverse pasture sown (i.e., perennial ryegrass, white clover, prairie grass, chicory, plantain and lucerne): (Farm 1), a farm with 20% diverse pasture sown and the remaining percentage with conventional ryegrass white clover pasture, and (Farm 2), a farm with 50% diverse pasture sown and the remaining percentage with conventional ryegrass white clover pasture. Modelling predictions showed annual DM production decreased with increasing proportion of the farm sown in diverse pastures, but no negative impact on milk solid production (Beukes *et al.* 2014). Interestingly, results also showed an 11% and 19% reduction in N leaching from urine patches, depending on the proportion of diverse pasture sown, 20% or 50% respectively (Beukes *et al.* 2014). Simulations from computer models offer the opportunity of predicting farm system changes, such as grazing management strategies, on production and financial profitability for diverse pasture mixtures. However, economic evaluation (e.g. pasture production, milk production and profitability) is limited on grazing management strategies of diverse pasture mixtures that include alternative legumes and herbs.

2.10 Conclusions

Diverse pastures have potential benefits in reducing nitrate leaching losses and improving seasonal distribution of high quality feed supply. However, there is a lack of knowledge on the impact of grazing management practices for diverse pasture systems on environmental sustainability and their ability to maintain or to improve the long-term production capacity of pastoral grazing systems.

Key conclusions from literature review:

1. Diverse pastures can increase DM production. However, there is limited data on grazing management strategies to maintain persistence of herbs and alternative legumes in a diverse mixture.

2. Despite the perceived benefits of diverse mixtures, there is a need to understand how grazing management might alter nutrient retention (through uptake) in farm systems.

3. There is limited information on the effects using conventional or alternative grazing management practise on milk production responses of diverse pasture.

4. System models should include parameters which account for pasture type and grazing management strategies to assess risk and determine profitability of incorporating diverse pastures in farm systems.

Chapter 3

Effect of seasonal grazing management strategies on herbage yield, botanical composition and nutritive value of irrigated diverse pastures

3.1 Introduction

The review of the literature (Chapter 2) highlighted the paucity of information around appropriate grazing management regimes for diverse pastures containing mixtures of grasses, legumes and herbs. While there is published information around the effects of grazing management of individual legume (e.g. white clover and red clover) and herb (e.g. chicory and plantain) species (Li and Kemp 2005; Black *et al.* 2009; Lee *et al.* 2012) there is limited information on the management of diverse pastures containing the combination of herbs, legumes and grasses.

In New Zealand dairy pasture systems, grazing management strategies are well developed for perennial ryegrass white clover pastures (Macdonald and Penno 1998). It is recommended that a post-grazing herbage mass of 1500-1600 kg DM/ha in spring, equivalent to 3.5 cm compressed sward height with a rising plate meter, is recommended to reduce reproductive material and manage quality throughout the grazing season (Brougham 1960; Fulkerson and Michell 1987; Holmes *et al.* 1992; Hoogendoorn *et al.* 1992; Lee *et al.* 2007). However, the adoption of a more lenient grazing management of 4 to 5 cm compressed pasture height of perennial ryegrass in the spring to allow seedhead development improved pasture persistence, assisted in daughter tiller survival and increased summer herbage mass (Matthew *et al.* 1989; Matthew 1991; Da Silva *et al.* 1994; Hernández Garay *et al.* 1997). A lenient post-grazing (greater than 3.5 cm) increased grass DM intake and milksolids production of grazing lactating dairy cows compared to a post-grazing height of 2.7 cm (Ganche *et al.* 2013).

While a lenient grazing approach may improve the production of the perennial ryegrass sward, there is a compromise in pasture quality due to the accumulation of stem material during anthesis combined with difficulty of harvesting at higher herbage mass (Holmes *et al.* 1992; Hoogendoorn *et al.* 1992; Da Silva *et al.* 1994); this may lead to lower milk production. However, there are likely to be smaller compromises in quality in diverse pasture. The high proportion of herbs and legumes are anticipated to maintain quality at greater herbage mass compared with grass dominant pastures (Waghorn *et al.* 2007), though to achieve and maintain this diverse botanical composition will require careful management (Pembleton *et al.* 2015). The adoption of a more lenient grazing regime in a diverse pasture mixture may be beneficial for the herbs, but the variation in defoliation requirements as reflected in current literature, make it difficult to predict how species may respond in a mixture.

A further important aspect is autumn grazing management. Two views exist for a perennial ryegrass white clover mixture, 1) a severe grazing <30 mm, or 2) graze more lenient > 40 mm. A severe grazing to low herbage height (<30 mm) before the onset of winter was proposed to increase DM herbage mass (Brougham 1960) and the long regrowth periods in winter may increase herbage growth through an increase in light interception (Brougham 1957; Robson 1973). However, plants defoliated to low post-grazing height with insufficient leaf area, are unable to replenish energy demands for growth and respiration solely through photosynthesis (Booysen and Nelson 1975; Grant *et al.* 1981; Li *et al.* 1997) and suggest that a greater residual leaf mass may increase herbage growth rate. A further strategy to increase herbage production and quality is to alter species composition. In the context of diverse pastures, there is interest in including Italian ryegrass to increase herbage production. For example, Moir *et al.* (2013) showed greater DM production of Italian ryegrass compared with 12 other grass species in the cool season. Also, Malcolm *et al.* (2014) showed including Italian ryegrass may decrease nitrate leaching through greater winter growth. However, there is little information on effects of appropriate grazing management of pastures that contain high proportions of Italian ryegrass (Hickey and Baxter 1989).

The objective of this experiment was to investigate the effects of grazing management strategies in spring and autumn on seasonal and annual DM production, botanical composition and nutritive value of diverse pastures under irrigation.

3.2 Materials and methods

3.2.1 Experimental site

The experiment was conducted over two years between 10 April 2015 and 10 May 2017 at the Lincoln University Research Dairy Farm (LURDF) in Canterbury, New Zealand (43°38S’, 172°27E). The soil type was Templeton silt loam over sandy loam (Hewitt 2010). The design was a randomised complete block design replicated three times where each plot was 9 x 6.3 m (Table 3.1). Treatments consisted of factorial combination of three grazing regimes and two pasture types. The three grazing treatments were: conventional grazing (CG, pasture consistently grazed to a compressed height of 3.5 cm year-round); spring lenient grazing (SL, grazed leniently to a compressed height of 5-6 cm during spring until perennial ryegrass reached anthesis, followed by a switch to CG for the remainder of the year); and autumn lenient (AL, pasture grazed similar to CG, except during autumn when grazed leniently to a compressed height of 5-6 cm). Spring lenient grazing occurred from late August/September to November (when anthesis occurred). Autumn lenient grazing occurred from

March to May. All grazing was with carried out with 3 dairy cows/plot. The two pasture treatments were: diverse pasture (DP) consisting of perennial ryegrass, white clover, red clover, chicory and plantain or DP plus Italian ryegrass (DP+Ita). The plant species, cultivars and sowing rates are shown in Table 3.2. Temporary steel fence posts with electric polywire were used to separate the plots and cows had *ad libitum* access to water. The area was irrigated with k-line irrigator between October and March each year, with 15-20 mm of water applied each week with an annual application of 300-400 mm giving a total of approximately 900 mm including precipitation. Plots were fertilised with 155 kg N/ha/annually with urea (46% N), split over 6 equal applications each year, in March, April, August, October, December, February.

Table 3.1 Experimental design with two pasture mixtures and three grazing management. Pasture mixtures are diverse pasture (DP) or the same mixture with Italian ryegrass (DP+Ita). Grazing management treatments are autumn lenient (AL), conventional hard grazing (CG), and spring lenient (SL).

	Block 3			Block 2			Block 1		
Plot	15	14	13	9	8	7	3	2	1
Pasture mixture	DP	DP+Ita	DP+Ita	DP+Ita	DP	DP+Ita	DP	DP+Ita	DP
Grazing management	AL	AL	CG	SL	CG	CG	SL	SL	CG
Irrigation Gap									
Plot	16	17	18	10	11	12	4	5	6
Pasture mixture	DP	DP+Ita	DP	DP+Ita	DP	DP	DP+Ita	DP+Ita	DP
Grazing management	CG	SL	SL	AL	SL	AL	AL	CG	AL
Shoulder Belt Hedge									

Table 3.2 Plant species, cultivar and sowing rate (kg seed/ha) of diverse pasture mixtures at Lincoln University Research Dairy Farm

Species	Common name	Cultivar	Sowing rate (kg/ha)	
			DP	DP+Ita
Lolium perenne	Perennial Ryegrass	One-50 AR37	20	10
Lolium multiflorum	Italian Ryegrass	Asset AR37	-	10
Trifolium repens	White Clover	Kopu 2	3	3
Trifolium pratense	Red Clover	Sensation	4	4
Cichorium intybus	Chicory	Choice	1	1
Plantago lanceolata	Plantain	Tonic	1.5	1.5

3.2.2 Establishment

Initial soil analysis was determined in December 2014 to a depth of 75 mm showing a pH of 6.1 and nutrient content of Olsen P 21 mg/L, K 0.28 me/100g, Ca 7.8 me/100g, Mg 0.47 me/100g and Na 0.17 me/100g. Plots were sown following cultivation on 22 October 2014. During establishment, the area was mown once to 3.5 cm in April 2015 before the start of the two year experiment and irrigated with k line irrigators.

3.2.3 Grazing management

Experimental treatments commenced seven months after establishment. Friesian x Jersey dairy cows (3 cows/plot) were used to rotationally graze plots between August and May. Grazing typically took 5-7 hours, between morning and afternoon milking. Prior to each grazing pasture compressed height was measured using an electronic rising plate meter (RPM, Jenquip, New Zealand). Each grazing was scheduled to occur when the average RPM reading, across all treatments, reached a compressed pasture height of 9-10 cm, with the exception of SL treatment in spring. For SL, grazing occurred when perennial ryegrass reached seed head (anthesis) development in spring. This created different grazing dates in October 2015, November 2016, December 2016 (Table 3.3).

Table 3.3 Grazing management and grazing schedule of the spring grazing period from 2015 to 2016. Values are target compressed pasture height grazed by dairy cows.

Spring 2015	Grazing management	25-Sep	18-Oct	20-Oct	7-Nov			
	CG	3.5 cm	3.5 cm	3.5 cm	3.5 cm			
	AL	3.5 cm	3.5 cm	3.5 cm	3.5 cm			
	SL	5 cm	---	5 cm	3.5 cm			
Spring 2016	**Grazing management**	**23-Aug**	**26-Sep**	**23-Oct**	**11-Nov**	**22-Nov**	**12-Dec**	**17-Dec**
	CG	3.5 cm	3.5 cm	3.5 cm	3.5 cm	---	3.5 cm	---
	AL	3.5 cm	3.5 cm	3.5 cm	3.5 cm	---	3.5 cm	---
	SL	5 cm	5 cm	5 cm	---	3.5 cm	---	3.5 cm

Cows were removed from the plots once the respective average post-grazing defoliation height had been reached (compressed height of 3.5 cm year-round in CG management; compressed height of 5-6 cm during spring, followed by a switch to CG for the remainder of the year in SL management; compressed height of 5-6 cm during autumn, followed by a switch to CG for the remainder of the year in AL management). Plots were grazed by dairy cows on nine occasions in year one (June 2015 to May 2016) and 10 occasions in year two (June 2016 to May 2017).

3.2.4 Herbage measurements

3.2.3.1 Herbage DM production

Herbage mass was determined each grazing from quadrat cuts. Before and after each grazing, three 0.2 m^2 quadrats were randomly placed in each plot, two RPM readings were recorded for each quadrat before harvesting all herbage within the quadrat to ground level using an electronic headpiece (n = 2043 for all treatments). Harvested herbage was oven dried at 60°C for 48 hours for determination of DM yield. Dry matter accumulation for each regrowth (kg DM/ha) was calculated from quadrat cuts as the difference between pre-grazing and post- grazing values from each grazing. Herbage DM production was then calculated on an annual and seasonal basis: (autumn: March-May, winter: June-August, spring: September-November and summer: December-February).

Pasture growth rate (kg DM/ha/d) was calculated as pre-grazing herbage mass from current grazing – post-grazing herbage mass from previous grazing/ number of days from previous grazing to current grazing.

3.2.3.3 Botanical composition and nutritive value analyses

Botanical composition was determined on pre-grazing herbage cut to ground level from quadrats taken for herbage mass. A fresh subsample of approximately 200g was taken from each pre-grazing quadrat to measure botanical composition. Samples were hand dissected into sown perennial ryegrass, Italian ryegrass, chicory, plantain, red clover, weeds and dead material before the dry weight of each component was determined. Samples were dried at 60°C for 48h, weighed and the percentage botanical composition determined on a DM basis. A second subsample was taken from the pre-grazing quadrat to determine nutritive value analysis on pre-grazing herbage. The dry weights of the two subsamples was added to the bulk dry weight of their respective quadrats for determination of herbage mass (section 3.2.3.1).

Samples taken for nutritive value were oven dried at 60°C for 48h and passed through a 1 mm sieve (ZM200 rotor mill; Retsch Inc., Pennsylvania, USA). Crude protein (CP), *in vitro* organic matter digestibility in the dry matter (DOMD), neutral detergent fibre (NDF) and water-soluble carbohydrate (WSC) were analysed using near-infrared spectroscopy (NIRS; Foss Feed and Forage Analyser 5000, Maryland, USA) at the Lincoln University Analytical Laboratory. An NIRS calibration model had been created by the Lincoln University Analytical Laboratory to include ryegrass, clovers and lucerne. Metabolisable energy (ME) was calculated as ME MJ/kg DM = 0.16 x %DOMD (McDonald *et al.* 2010).

3.2.3.4 Plant population

The plant population of each sown species was measured on three occasions in each year, in the middle of autumn (April), spring (November), summer (January). A 0.01 m^2 quadrat was placed randomly in each plot and perennial and Italian ryegrass tillers, legume growing points were individually counted. At the same time, a 0.5 m^2 quadrat was placed randomly in each plot and the number of chicory and plantain crowns were counted. Three counts were conducted in each plot. The total number of plant tillers or growing points on a m^2 basis was calculated.

3.2.5 Meteorological measurements

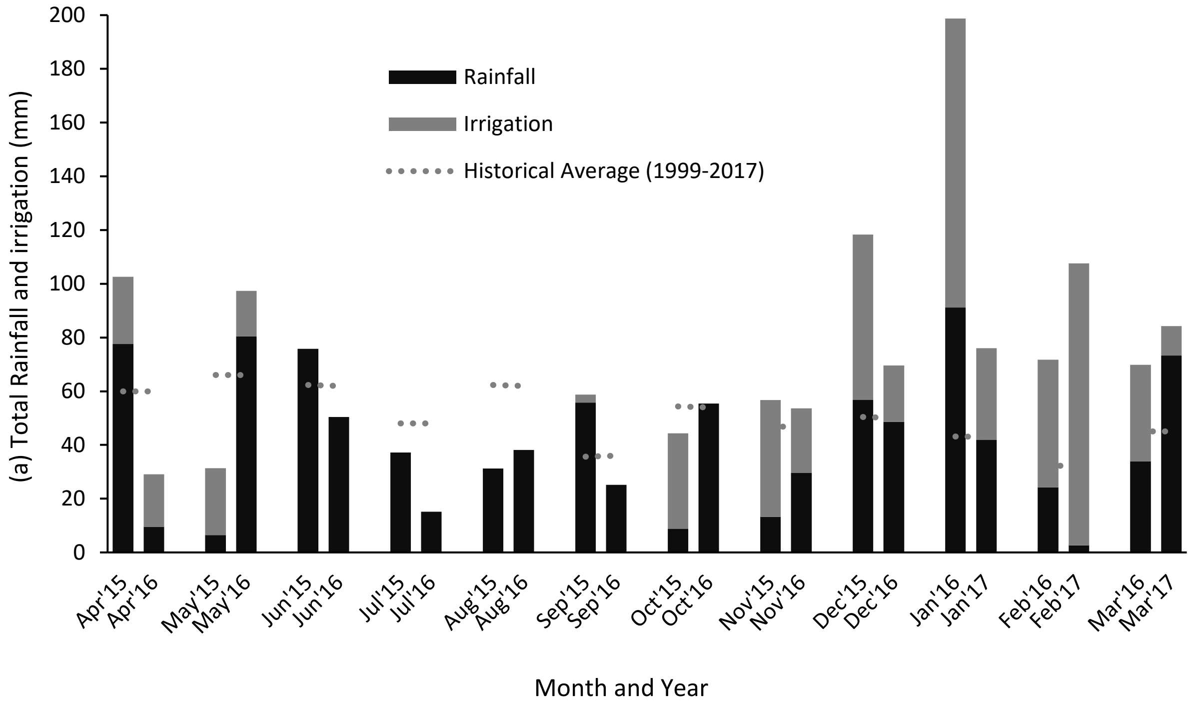
Climate data, including 24 hour maximum and minimum temperatures (°C), 24-hour rainfall (mm) and radiation (MJ/m^2) were recorded from Lincoln Broadfields weather station daily over the trial period at a weather station less than (1 km) from the trial site.

3.3 Statistical analysis

All data analyses were conducted using GenStat 18.1, VSN International, Hemel, Hempstead, UK. The effect of grazing management and pasture mixture on annual and seasonal DM production were analysed by two-way ANOVA. Grazing management and pasture mixture and their interactions were fixed effects in the ANOVA model and block was a random effect. The effects of grazing management and pasture mixture on pasture growth rate, botanical composition and nutritive value were analysed by a General Linear Model, including the fixed effects of grazing management, pasture mixture, season and their interactions, and the random effect of block. Botanical composition data, collected at each grazing, were averaged across season prior to analysis. Plant population data was analysed by repeated measures ANOVA with grazing management and pasture mixture as fixed effects. Means were separated using Fisher's protected least significant difference test whenever ANOVA indicated a significant treatment effect.

3.4 Meteorological data

Rainfall and air temperature in the experimental period and averaged over the last 18 years are represented in Figure 3.1. Total rainfall during the first year (512 mm/year) and second year (471 mm/year) of the experiment were both lower than the long term historical average (606 mm/year). Air temperatures were similar to long term historical average, except greater temperatures in February, May and June 2016.



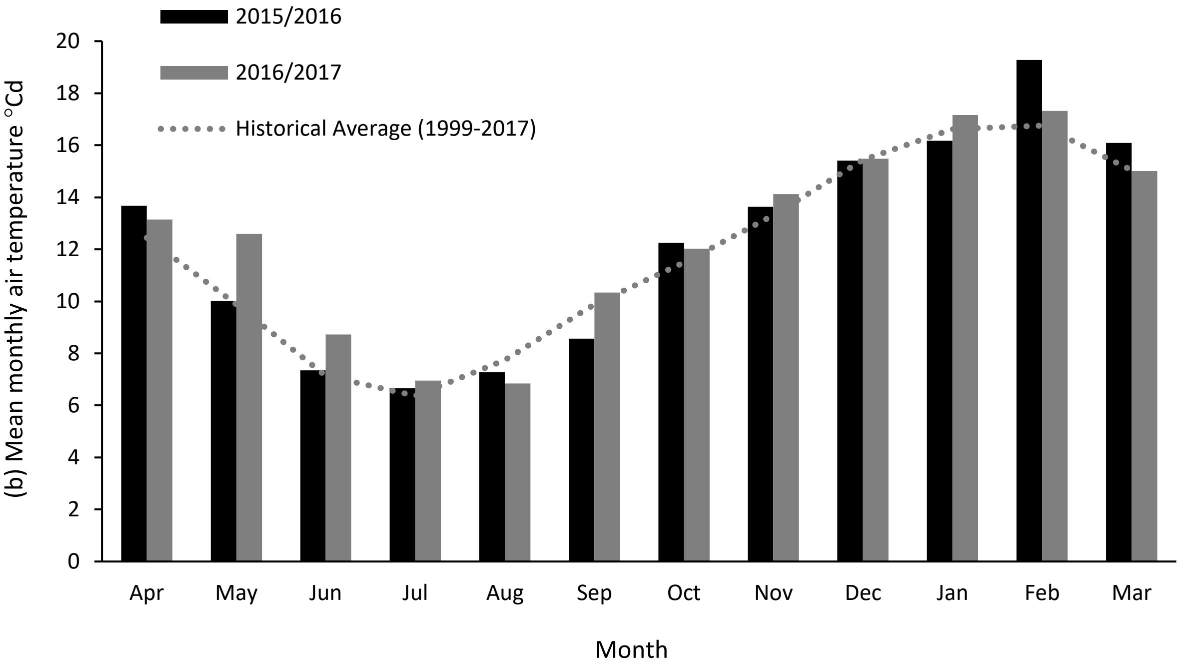


Figure 3.1 **Rainfall and irrigation (a) and average air temperature (b), by month at the experimental site from April 2015-March 2017. The historical average distribution of rainfall and average air temperature over the past 18 years (1999-2017), by month are represented with gray dashes.**

3.5 Results

3.5.1 Pasture height

Pre-grazing and post-grazing compressed pasture height (cm) readings for each grazing management treatment from April 2015 to May 2017 are shown in Figure 3.2. Post-graze height in each of the treatments achieved their target heights of 3 to 5 cm compressed height during critical periods, except the first year for SL treatment. Italian ryegrass pastures had greater pre-grazing compressed height of 11 to 13 cm in August and September of both years. Post-grazing height ranged from 3 to 5 cm compressed height. For SL, treatment effects were not observed in the first spring, but were achieved in the second spring with higher post-grazing height on 23 August, 26 September and 23 October and a higher pre-grazing height on 22 November 2016. This was followed by a switch to CG on 22 November 2016.

For AL, leaving a higher post-grazing height in March of both years resulted in a greater pre-grazing height the following grazing rotation in April, but the continuous lenient post-grazing did not increase pasture height in early spring. Average pre-graze compressed height was variable ranging from 6 cm to 15 cm compressed height. The general pattern for low pre-graze compressed height of 6 cm was found in May of each year.

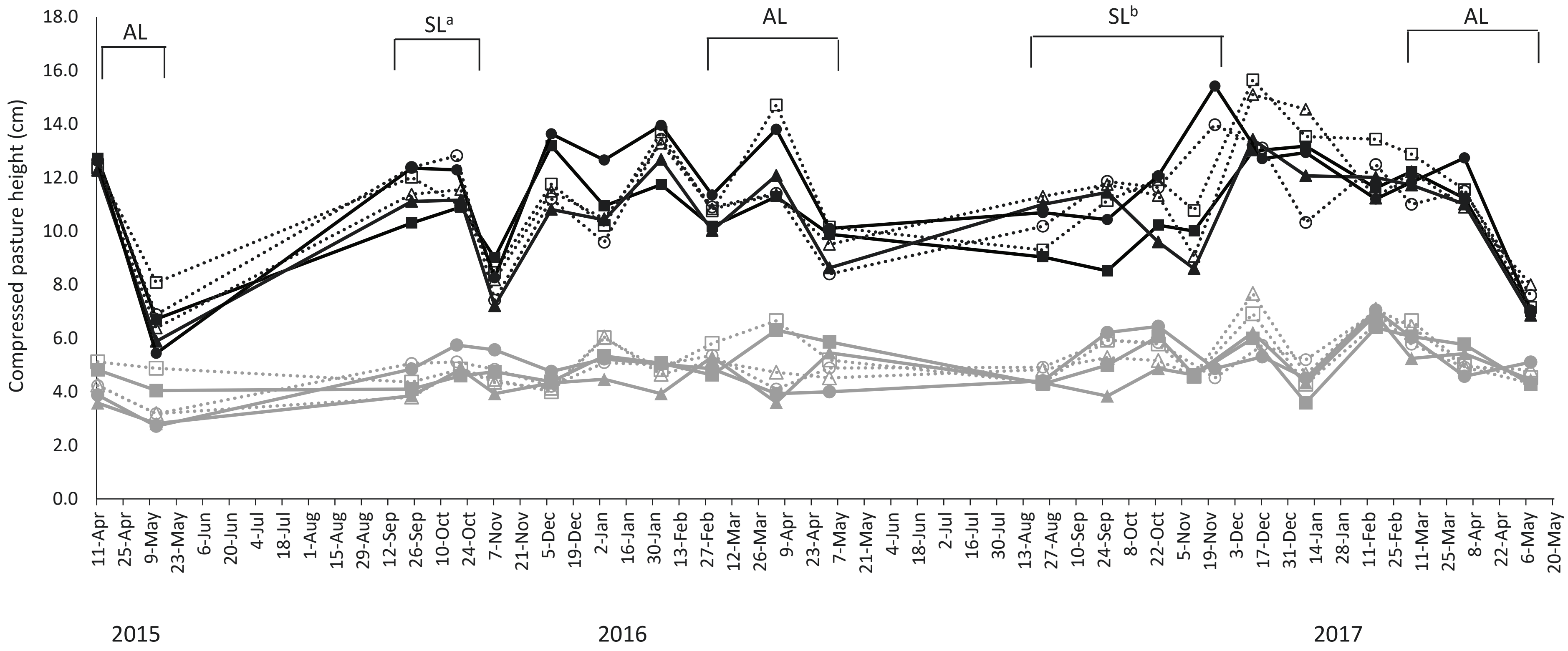


Figure 3.2 **Pre- and post-grazing compressed pasture height (cm) for each grazing management treatments and pasture mixture from April 2015-May 2017 measured by quadrat cuts. Symbols represent grazing management: Conventional Grazing (CG) (▲ or △), Autumn Lenient (AL) (■ or □), and Spring Lenient (SL) (● or ○). Filled symbols and solid lines represent diverse pasture mixture and unfilled symbols and dotted lines denote diverse pasture with Italian ryegrass mixture. Black lines represent pre-grazing pasture height and grey lines represent post-grazing pasture height. [a]SL on 25 Sep, 20 Oct with a switch to CG on 7 Nov 2015. [b]SL on 23 Aug, 26 Sep, 23 Oct with a switch to CG on 22 Nov 2016.**

3.5.2 Dry matter production

Annual herbage DM production ranged from 12.4 to 13.8 t DM/ha among grazing management treatments. In the first year, annual herbage DM production was greater in SL (14.0 ± 0.4 t DM/ha) and CG (13.7 ± 0.4 t DM/ha) than AL (12.4 ± 0.4 t DM/ha, $P<0.05$). This effect did not occur in the second year (Table 3.4). There were no significant differences in annual DM production between CG and SL, though a lenient grazing in autumn reduced ($P=0.03$) annual DM production by 1.2 t DM/ha. The lower annual DM production in AL is reflected by lower seasonal herbage DM production in both winters, spring 2015 and autumn 2015.

Annual herbage DM production was greater in DP (13.4 ± 0.3 t DM/ha, $P<0.01$) than DP+Ita (12.4 ± 0.3 t DM/ha) in the first year. Annual herbage DM production in the second year was not significantly different between DP and DP+Ita. Averaged over two years, annual herbage DM production was greater in DP (13.4 ± 0.2 t DM/ha) than DP+Ita (12.8 ± 0.2 t DM/ha, $P=0.006$). The effect appeared to be related to greater production in summer and autumn of year 1 in DP, where Italian ryegrass was not sown.

There was tendency for an interaction between grazing management and pasture mixture (GM x PM) for mean annual DM production, averaged across the two years of study ($P=0.10$). Within three of the eight seasons measured, significant grazing management x pasture mixture interactions were observed (Table 3.4). Herbage DM production was lower ($P<0.05$) in AL of spring 2015 than CG and SL. There was also an interaction between grazing management and pasture mixture for spring herbage DM ($P=0.03$). In spring 2015, differences in herbage DM production between pasture mixture was small in CG and SL, but in AL, herbage DM yield was 878 kg DM/ha greater in DP than DP+Ita (3043 versus 2165 kg DM/ha; Table 3.4). The result reflected the difference in annual herbage between DP and DP+Ita; difference in CG grazing (13929 versus 13806 kg DM/ha) was small compared to the difference in SL grazing (14901 versus 12725 kg DM/ha) and AL grazing (13354 versus 11895 kg DM/ha) (Table 3.4).

Table 3.4 The effect of grazing management and pasture mixture on annual herbage DM production and seasonal DM production (kg DM/ha) from June 2015-May 2017 at the Lincoln University Research Dairy Farm, Canterbury, New Zealand.

P-values from ANOVA for main effects of grazing management and pasture mixture are shown. Means followed by a different letter within a row are significantly different (*P*<0.05).

	Grazing management			Pasture mixture		SEM			*P-value*		
Season	AL	CG	SL	DP	DP+Ita	Management	Mixture	Management *Mixture	Management	Mixture	Management *Mixture
Year 1											
Winter 2015	1875[a]	2341[b]	2226[b]	2167	2127	64	52	90	<0.01	0.60	0.38
Spring 2015	2604[a]	3045[b]	3022[b]	3024	2757	117	96	165	0.04	0.08	0.03
Summer 2016	4608	4514	4708	5065	4154	312	254	441	0.91	0.03	0.43
Autumn 2016	3353[a]	3792[a,b]	4037[b]	4054	3400	158	129	224	0.04	<0.01	0.04
Year 2											
Winter 2016	716[a]	1317[b]	1230[b]	1148	1026	107	88	152	<0.01	0.35	0.38
Spring 2016	2768	3478	3391	3211	3213	211	173	299	0.08	0.99	0.88
Summer 2017	5350	5208	5145	5271	5197	202	165	286	0.77	0.76	0.03
Autumn 2017	3977	4041	3869	4182	3742	381	311	539	0.95	0.34	0.99
Year 1	12439[a]	13692[b]	13992[b]	13374	12439	389	317	550	0.04	<0.01	0.21
Year 2	12811	14043	13634	13496	13178	581	474	822	0.35	0.37	0.47
Mean	12625[a]	13868[b]	13813[b]	13435	12809	310	253	439	0.03	0.006	0.10

*CG=conventional grazing, SL=spring lenient grazing, AL=autumn lenient grazing, DP=diverse pasture mixture, DP+Ita=diverse pasture mixture with Italian ryegrass
**Significant interactions are shown in Table 3.5.

Table 3.5 The interactions of grazing management (AL, CG, SL) and pasture mixture (DP, DP+Ita) on mean annual herbage DM production and seasonal DM production (kg DM/ha) from June 2015-May 2017 at the Lincoln University Research Dairy Farm, Canterbury, New Zealand.

P-values from ANOVA for main effects of grazing management and pasture mixture are shown. Means followed by a different letter within a row are significantly different (*P*<0.05).

	AL		CG		SL		SEM			*P-value*		
Season	DP	DP+Ita	DP	DP+Ita	DP	DP+Ita	Grazing management	Mixture	Grazing management *Mixture	Grazing management	Mixture	Grazing management *Mixture
Spring 2015	3043^{a}	2165^{b}	2975^{a}	3115^{a}	3054^{a}	2990^{a}	117	96	165	0.04	0.08	0.03
Autumn 2016	3411^{b,c}	3294^{c}	4017^{b}	3567^{b,c}	4733^{a}	3340^{b,c}	158	129	224	0.04	0.01	0.04
Summer 2017	5550^{a,b}	5150^{a,b}	4724^{b}	5692^{a}	5539^{a,b}	4750^{b}	202	165	286	0.77	0.76	0.03
Mean of annual herbage DM production	13354^{c}	11895^{e}	13929^{b}	13806^{b}	14901^{a}	12725^{d}	310	253	439	0.03	0.0006	0.10

*CG=conventional grazing, SL=spring lenient grazing, AL=autumn lenient grazing, DP=diverse pasture mixture, DP+Ita=diverse pasture mixture with Italian ryegrass

3.5.3 Seasonal herbage DM production

Grazing management was significant (*P*<0.05) on seasonal herbage DM production in winter 2015, spring 2015, autumn 2016 and winter 2016 (Table 3.4). Pasture mixture was significant (*P*<0.05) on seasonal herbage DM production in summer 2016 and autumn 2016.

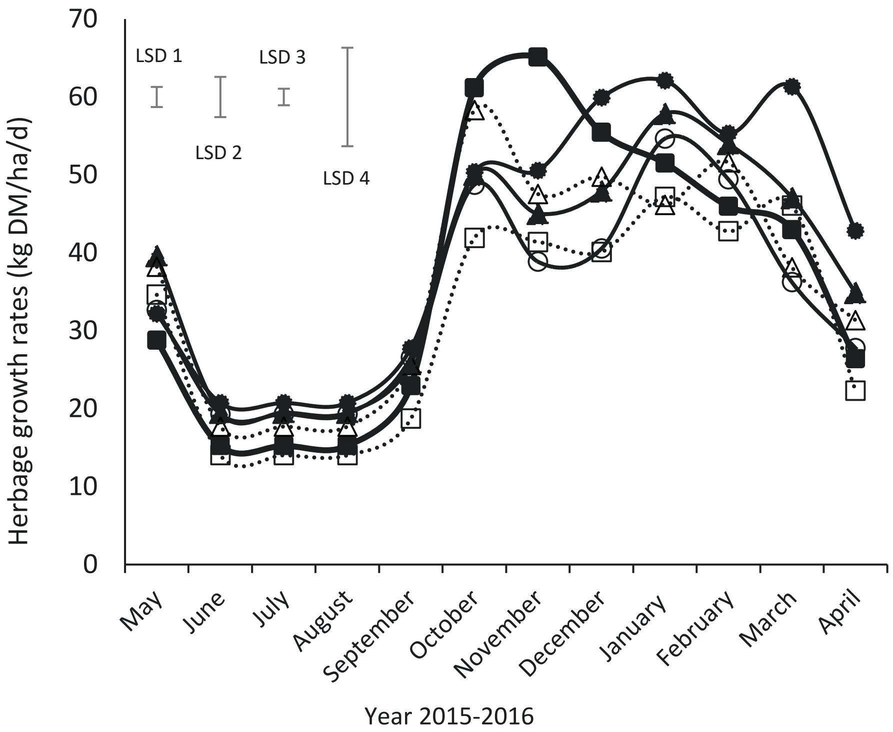
Herbage DM production was not different between CG and SL (Table 3.4). There appeared to be no carry over effects of early (SL) and late (AL) season grazing management on herbage production in the summer. However, in the cooler months of winter and spring, there were evident DM production benefits of seasonal lenient grazing, as both AL and SL improved DM production compared with CG. In the first year, lenient spring grazing had more pronounced benefits on DM production in autumn than autumn lenient grazing.

In the first winter, Italian ryegrass in DP+Ita had the same DM production as DP and not statistically significant (*P*>0.05; Table 3.4). Beyond winter year one, there was a net reduction in seasonal DM yield in plots where Italian ryegrass had been sown. However, in the second year, more than two years after establishment (October 2014), there was no longer an effect of Italian ryegrass on herbage yield (*P*>0.05). There was an interaction between grazing management and pasture mixture for autumn 2016 DM yield (*P*=0.03). This interaction reflected that the greatest herbage DM yield (4733 kg DM/ha) occurred in DP pastures that were grazed by the SL treatment (Table 3.5). Though pasture mixture was not statistically significant, the difference in seasonal herbage between DP and DP+Ita in CG (4017 versus 3567 kg DM/ha) and AL (3411 versus 3294 kg DM/ha) was small compared to the difference in SL grazing (4733 versus 3340 kg DM/ha; Table 3.5).

There was no significant effect on grazing management or pasture mixture on herbage DM production in summer 2017. Though there was an interaction between grazing management and pasture mixture for summer 2017 DM yield (*P*=0.03). This interaction reflected a significant difference between DP and DP+Ita in herbage DM yield in CG (4724 versus 5692 kg DM/ha) but not in SL (5539 versus 4750 kg DM/ha) and AL (5550 versus 5150 kg DM/ha; Table 3.5).

3.5.4 Herbage growth rates

Herbage growth rates ranged from 15.2 kg DM/ha/d in winter to 65.1 kg DM/ha/d in late spring during the 2015-2016 year (Figure 3.3). Herbage growth rates were affected by grazing management (*P*=0.006), pasture mixture (*P*<0.001) and month (*P*<0.001) and the interaction (*P*=0.09). Regardless of grazing management treatments, DP mixtures had higher herbage growth rates (*P*<0.001) than DP+Ita throughout the year. In 2016-2017, herbage growth rates ranged from 6.3 kg DM/ha/d in winter to 70.1 kg DM/ha/d in late spring/early summer with the greatest growth rates in November. A significant difference in herbage growth rate was seen by month (*P*<0.001) but unaffected by grazing management (*P*<0.09) or mixture (*P*<0.29) (Figure 3.4).



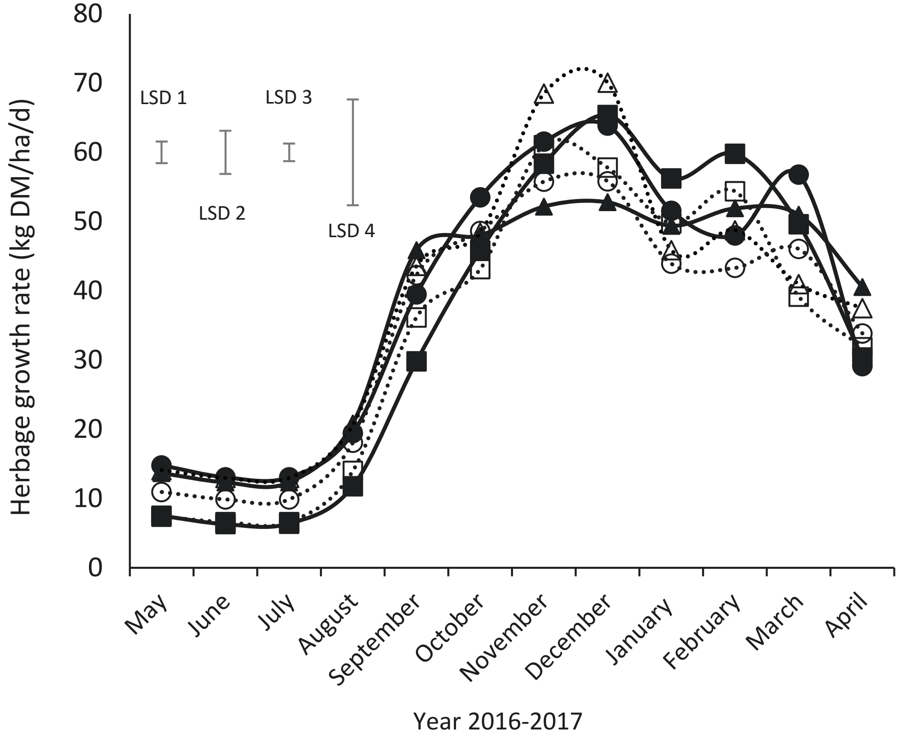


Figure 3.3 Herbage growth rate (kg DM/ha/day) of six pastures from May 2015-April 2016 at the Lincoln University Research Dairy Farm, Canterbury, New Zealand. Symbols represent grazing management: Conventional Grazing (CG) (▲ or △), Autumn Lenient (AL) (■ or □), Spring Lenient (SL) (● or ○). Filled symbols and solid lines represent diverse pasture mixture and unfilled symbols and dotted lines denote diverse pasture with Italian ryegrass mixture. Vertical bars represent least significant difference (LSD) (α = 0.05). LSD 1 = main effect of grazing management, LSD 2 = main effect of month, LSD 3 = main effect of mixture, LSD 4 = Grazing management, mixture, month interaction.

Figure 3.4 Herbage growth rate (kg DM/ha/day) of six pastures from May 2016-April 2017 at the Lincoln University Research Dairy Farm, Canterbury, New Zealand. Symbols represent grazing management: Conventional Grazing (CG) (▲ or △), Autumn Lenient (AL) (■ or □), and Spring Lenient (SL) (● or ○). Filled symbols and solid lines represent diverse pasture mixture and unfilled symbols and dotted lines denote diverse pasture with Italian ryegrass mixture. Vertical bars represent least significant difference (LSD) (α = 0.05). LSD 1 = main effect of grazing management, LSD 2 = main effect of month, LSD 3 = main effect of mixture, LSD 4 = Grazing management, mixture, month interaction.

3.5.5 Botanical composition

The main effects of grazing management and pasture mixture of botanical composition of pasture are shown in Table 3.6 and 3.7. Figure 3.5 highlights the grazing management and pasture mixture interaction of each pasture species in each season when a significant effect occurred.

In the first year (Table 3.6), grazing management affected some of the species sown (perennial ryegrass, red clover and plantain). Conventional grazing (CG) resulted in a greater (P<0.01) proportion of perennial ryegrass than AL or SL grazing. Autumn lenient grazing favoured red clover proportion more than CG (P≤0.01). Lenient grazing in autumn and spring also resulted in more plantain (P=0.03) than CG in the first year, indicating greater diversity in AL.

In year one, including Italian ryegrass in DP+Ita reduced the proportion of perennial ryegrass, herbs (plantain and chicory) and legumes (red clover and white clover) compared with DP mixtures. Across seasons, the proportion of perennial ryegrass was consistently highest (30%), followed by plantain (20%) and red clover (14%). Italian ryegrass accounted for 26.0% in the DP+Ita mixture, with the lowest proportions in summer (8.7% of the DM). Chicory ranged between 8 and 11% of the DM in the DP+Ita mixture. The proportion of chicory was greatest in autumn at 13% DM of the mixture. The greatest proportion of red clover occurred in the summer (15.7%) and lowest proportion in spring (10.5%).

In the second year (2016-2017; Table 3.7) the proportion of herbs and legume content declined to 8% herbs and 4% legumes, respectively with grasses accounting for over 50% of the DM. Lenient grazing in autumn (AL) and spring (SL) resulted in a greater proportion of chicory (P=0.03), red clover (P<0.001) and white clover (P=0.02) compared to CG. The diverse pasture mixture with Italian ryegrass (DP+Ita) declined in Italian ryegrass from 26% in the first year to 16.5% in the second year. Inclusion of Italian ryegrass resulted in a greater proportion of the herbs, chicory and plantain and lower proportions of perennial ryegrass compared to DP.

Season had a significant effect (P≤0.01) on the botanical composition. The proportion of plantain and red clover were greatest in the autumn season and diversity was negligible in winter. Grazing management and pasture mixture interaction at each time point was graphed in Figure 3.5. Red clover and chicory contributed to DM production during the first experimental year but was gradually replaced by predominately perennial ryegrass in winter 2016. In DP+Ita mixtures, when Italian ryegrass declined in autumn 2016, white clover and plantain increased.

Table 3.6 The effect of three grazing management, two pasture mixtures and season on botanical composition (% of DM in pre-grazing herbage mass) of perennial ryegrass (PRG), Italian ryegrass (IRG), white clover (WC), red clover (RC), chicory (CHI), plantain (PLA), dead material (dead) and weeds from June 2015 - May 2016.

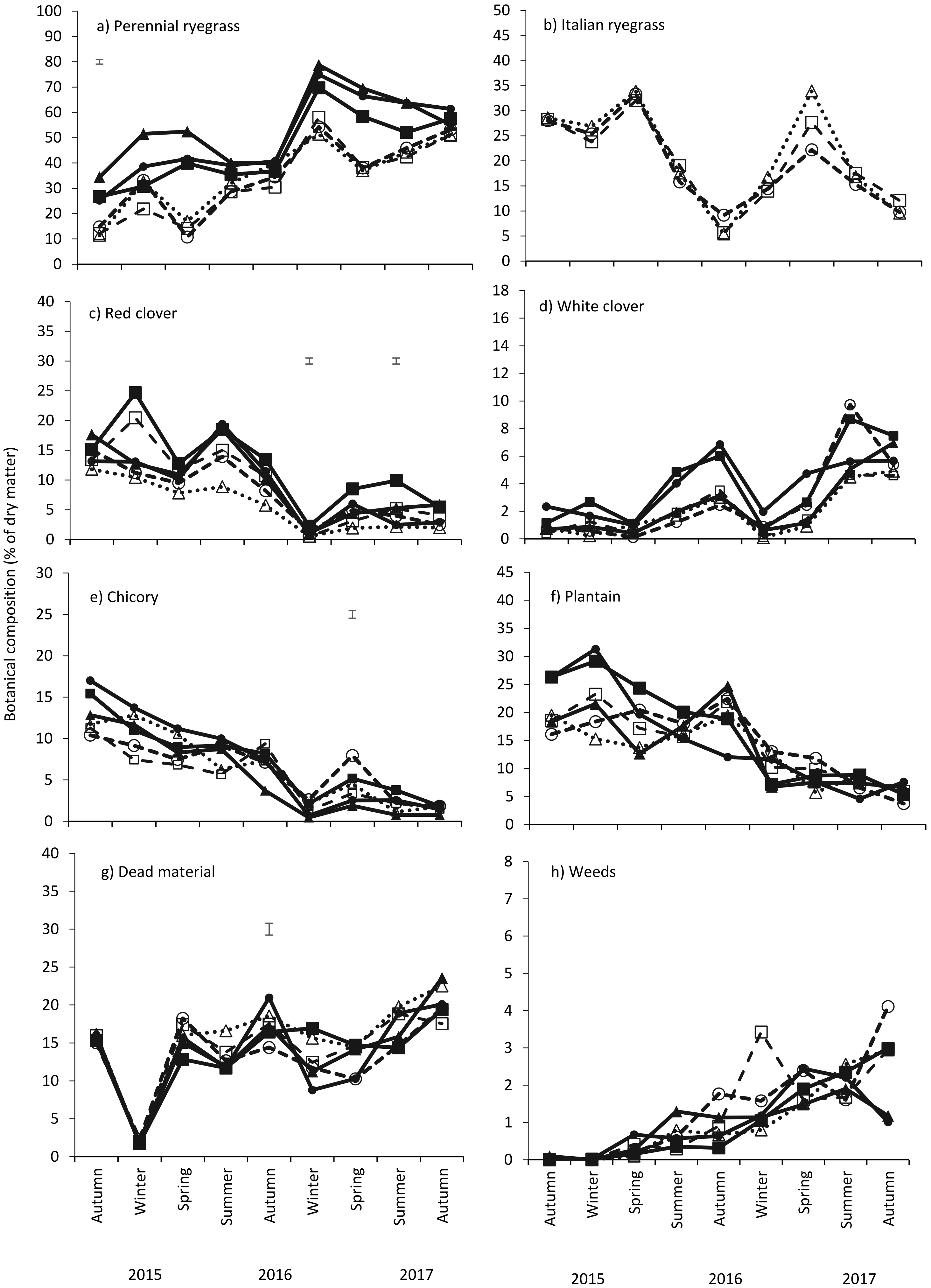
P-values from ANOVA for the main effects of grazing management, pasture mixture and season are shown. Values are statistically significant within a column at ($P \leq 0.05$).

Grazing management	PRG	IRG	WC	RC	CHI	PLA	DEAD	WEEDS
Autumn lenient	26.2	12.9	1.7	16.5	9.5	21.8	11.3	0.2
Conventional grazing	33.9	13.4	1.0	12.3	10.4	16.8	11.9	0.3
Spring lenient	29.0	12.8	1.5	13.2	11.0	20.7	11.7	0.3
SEM	1.54	0.66	0.23	0.88	0.76	1.36	0.65	0.08
Pasture mixture								
Diverse pasture + Italian ryegrass	21.4	26.0	0.9	12.4	9.1	17.7	12.3	0.2
Diverse pasture	38.0	0.0	1.9	15.5	11.5	21.9	10.9	0.3
SEM	1.26	0.54	0.19	0.72	0.62	1.11	0.53	0.06
Season								
Winter	34.7	12.7	1.2	15.4	11.0	23.1	1.9	0.0
Spring	29.3	16.5	0.7	10.5	8.9	18.0	15.9	0.3
Summer	34.0	8.7	2.6	15.7	8.2	17.1	13.1	0.7
Autumn	20.8	14.1	1.0	14.4	13.1	20.8	15.7	0.0
SEM	1.78	0.77	0.26	1.02	0.88	1.57	0.75	0.09
***P*-value**								
Grazing management	<0.01	0.81	0.07	0.01	0.36	0.03	0.84	0.30
Mixture	<0.001	<0.001	<0.001	<0.01	0.01	0.01	0.07	0.33
Season	<0.001	<0.001	<0.001	<0.01	<0.001	0.04	<0.001	<0.001
Grazing management*Mixture	0.17	0.81	0.04	0.32	0.16	0.43	0.83	0.54
Grazing management*Season	0.38	0.97	0.34	0.03	0.87	0.80	0.90	0.12
Mixture*Season	<0.001	<0.001	0.15	0.37	0.74	0.33	0.43	0.90
Grazing management*Mixture*Season	0.86	0.97	0.89	0.90	0.89	0.67	0.92	0.73

Table 3.7 The effect of three grazing management, two pasture mixtures and season on botanical composition (% of DM in pre-grazing herbage mass) of perennial ryegrass (PRG), Italian ryegrass (IRG), white clover (WC), red clover (RC), chicory (CHI), plantain (PLA), dead material (dead) and weeds in June 2016 - May 2017.

P-values from ANOVA for the main effects of grazing management, pasture mixture and season are shown. Values are statistically significant within a column at ($P \leq 0.05$).

Grazing management	PRG	IRG	WC	RC	CHI	PLA	DEAD	WEEDS
Autumn lenient	48.3	8.09	3.48	6.69	4.43	11.7	15.7	1.66
Conventional grazing	53.1	9.11	2.31	3.91	2.74	11.6	15.9	1.40
Spring lenient	52.3	7.63	4.34	4.90	4.13	11.2	13.8	1.73
SEM	1.25	0.93	0.47	0.48	0.45	1.01	0.65	0.28
Pasture mixture								
Diverse pasture + Italian ryegrass	42.9	16.55	2.81	4.03	4.27	12.5	15.3	1.71
Diverse pasture	59.6	0.00	3.94	6.30	3.26	10.5	15.0	1.48
SEM	1.02	0.76	0.39	0.39	0.36	0.83	0.53	0.23
Season								
Winter	64.5	7.52	0.75	1.10	1.55	10.2	12.8	1.53
Spring	51.3	14.0	2.23	4.81	4.22	8.54	13.1	1.89
Summer	52.0	8.26	6.37	4.83	2.10	7.29	17.1	2.05
Autumn	37.1	3.37	4.16	9.92	7.18	19.9	17.5	0.90
SEM	1.44	1.07	0.55	0.55	0.52	1.17	0.75	0.33
***P*-value**								
Grazing management	0.02	0.52	0.02	<0.001	0.03	0.94	0.04	0.69
Mixture	<0.001	<0.001	0.05	<0.001	0.06	0.09	0.72	0.48
Season	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.08
Grazing management*Mixture	0.07	0.52	0.43	0.07	0.07	0.30	0.06	0.81
Grazing management*Season	0.86	0.57	0.91	0.20	0.69	0.34	0.30	0.67
Mixture*Season	<0.001	<0.001	0.55	0.27	0.35	0.83	0.57	0.67
Grazing management*Mixture*Season	0.47	0.57	0.12	0.67	0.36	0.33	0.05	0.60



a) Perennial ryegrass
b) Italian ryegrass
c) Red clover
d) White clover
e) Chicory
f) Plantain
g) Dead material
h) Weeds
Botanical composition (% of dry matter)
Autumn
Winter
Spring
Summer
Autumn
Winter
Spring
Summer
Autumn
2015
2016
2017

Figure 3.5 **Botanical composition (% of DM in pre-grazing herbage mass) of a) perennial ryegrass, b) Italian ryegrass, c) red clover, d) white clover, e) chicory, f) plantain, g) dead material and h) weeds for three grazing management and 2 pasture types between Autumn 2015-Autumn 2017. Symbols represent grazing management: Conventional Grazing (CG) (▲ or △), Autumn Lenient (AL) (■ or □), and Spring Lenient (SL) (● or ○). Filled symbols and solid lines represent diverse pasture mixture and unfilled symbols and dotted lines denote diverse pasture with Italian ryegrass mixture. Vertical bars represent the standard error (*P*<0.05) for grazing management and pasture mixture interaction.**

3.5.6 Plant population

The number of perennial ryegrass tillers were affected by the pasture mixture and season (Figure 3.6) but unaffected by grazing management. Perennial ryegrass tiller populations peaked in summer of year 2 with up to 11,000 tillers in CG. The inclusion of Italian ryegrass into the mixture decreased perennial ryegrass tiller numbers in the mixture, predominately in spring with the lowest counts less than 300 tillers/m^2. In Autumn 2016 and 2017, there was similar number of perennial ryegrass tillers in both DP and DP+Ita mixtures.

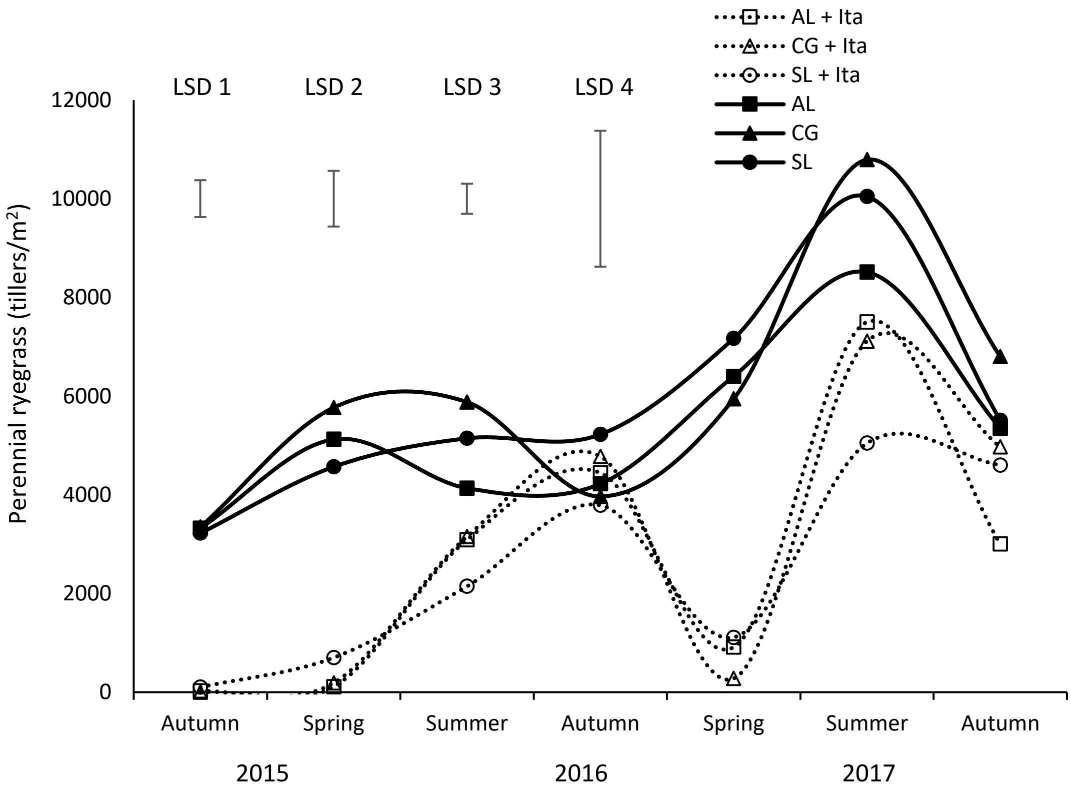


Figure 3.6 The effect of three grazing management severity, two pasture mixtures on seasonal perennial ryegrass population (tillers/m^2) from Autumn 2015 through Autumn 2017. Symbols represent grazing management: Conventional Grazing (CG) (▲ or △), Autumn Lenient (AL) (■ or □), and Spring Lenient (SL) (● or ○). Filled symbols and solid lines represent diverse pasture mixture and unfilled symbols and dotted lines denote diverse pasture with Italian ryegrass mixture. Vertical bars represent least significant difference (LSD) (α = 0.05). LSD 1 = main effect of grazing management, LSD 2 = main effect of month, LSD 3 = main effect of mixture, LSD 4 = Grazing management, mixture, month interaction.

Italian ryegrass tiller populations were affected by grazing management in spring 2015, with more tillers ($P \leq 0.05$) in CG (6000 tillers/m^2) than SL (3000 tillers/m^2) and AL (4500 tillers/m^2). There was a marked increase in Italian ryegrass tiller population in spring of each year (Figure 3.7; $P \leq 0.05$). When there was an increase in the number of Italian ryegrass tillers, the number of perennial ryegrass levels declined (Figure 3.7). There is a decline in the number of tillers summer and autumn, reflecting the seasonal growth patterns of Italian ryegrass.

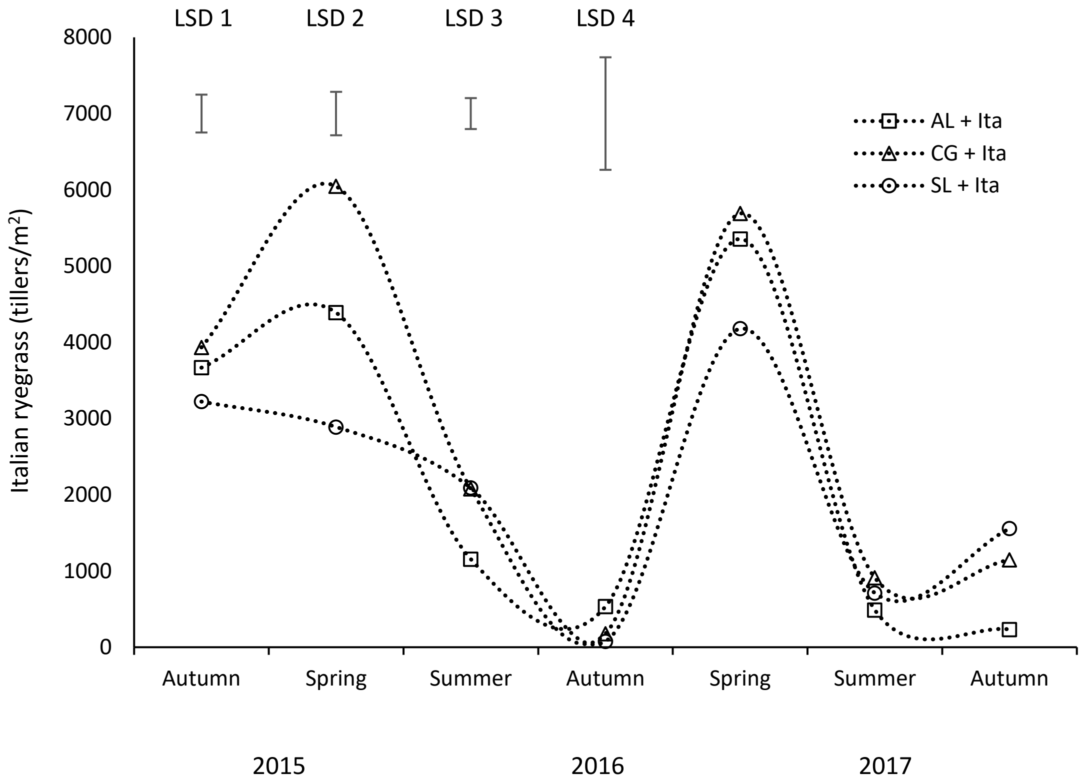


Figure 3.7 The effect of three grazing management severity, two pasture mixtures on seasonal Italian ryegrass population (tillers/m^2) from Autumn 2015 through Autumn 2017. Symbols represent grazing management: Conventional Grazing (CG) (▲ or △), Autumn Lenient (AL) (■ or □), and Spring Lenient (SL) (● or ○). Filled symbols and solid lines represent diverse pasture mixture and unfilled symbols and dotted lines denote diverse pasture with Italian ryegrass mixture. Vertical bars represent least significant difference (LSD) (α = 0.05). LSD 1 = main effect of grazing management, LSD 2 = main effect of month, LSD 3 = main effect of mixture, LSD 4 = Grazing management, mixture, month interaction.

The number of white clover stolons increased in the summer of both years with AL of the DP mixture, with the greatest number of stolons/m^2 in the second summer (956 stolons/m^2; Figure 3.8). With CG management of both mixtures, white clover populations remained relatively low across all seasons except in summer 2017. In DP mixtures, white clover paralleled perennial ryegrass seasonal fluctuations with AL and SL management. In DP+Ita mixtures, white clover stolons and Italian ryegrass had an inverse relationship. This was shown when the number of white clover stolons increased in the summer and the number of Italian ryegrass tillers decreased. When white clover stolon population decreased in spring, Italian ryegrass population increased.

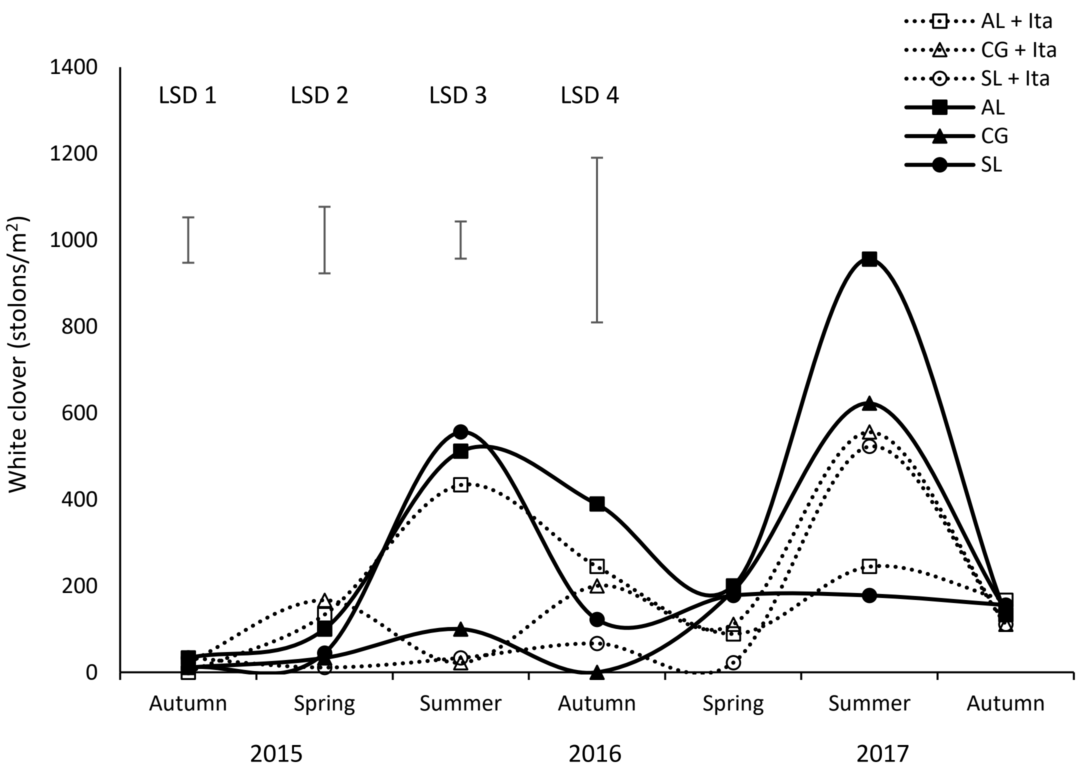


Figure 3.8 The effect of three grazing management severity, two pasture mixtures on seasonal white clover (stolons/m^2) from Autumn 2015 through Autumn 2017. Symbols represent grazing management: Conventional Grazing (CG) (▲ or △), Autumn Lenient (AL) (■ or □), and Spring Lenient (SL) (● or ○). Filled symbols and solid lines represent diverse pasture mixture and unfilled symbols and dotted lines denote diverse pasture with Italian ryegrass mixture. Vertical bars represent least significant difference (LSD) (α = 0.05). LSD 1 = main effect of grazing management, LSD 2 = main effect of month, LSD 3 = main effect of mixture, LSD 4 = Grazing management, mixture, month interaction.

The number of red clover growing points was greater in AL than SL and CG in the first spring in both mixtures, averaging 1333 growing points/m^2. There was an increase in the number of red clover growing points in the first summer with over 1270 growing points/m^2 in DP, but not in DP+Ita mixture (Figure 3.9). After the increase in the number of red clover growing points in the first summer, the number of red clover growing points declined to <344 growing points/m^2 in all treatments.

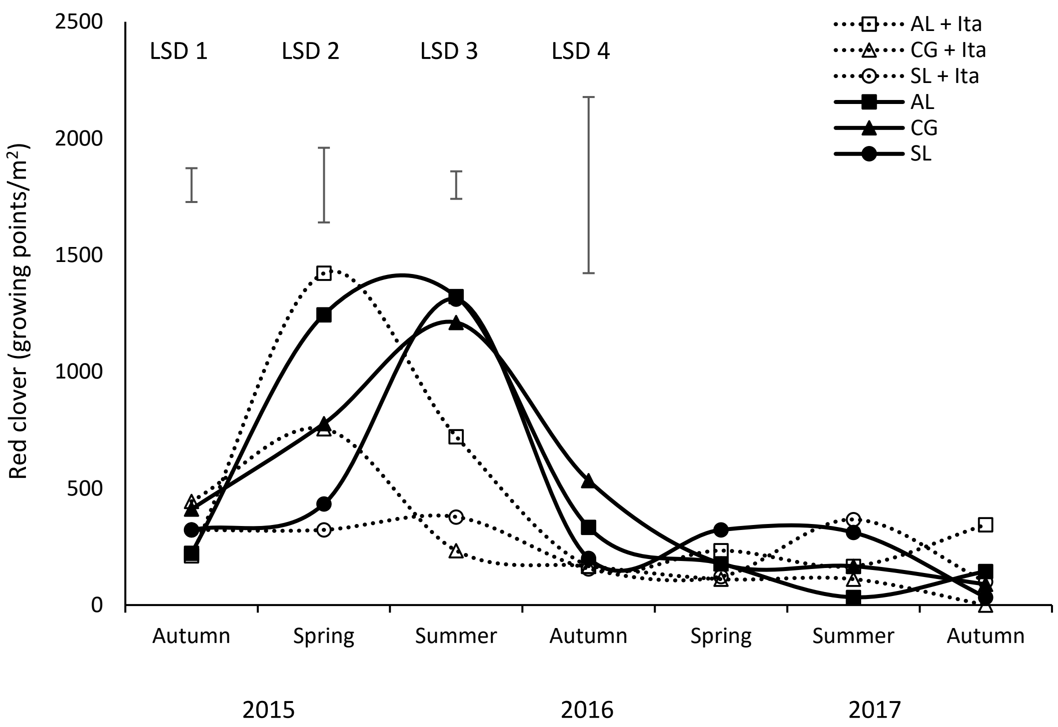


Figure 3.9 **The effect of three grazing management severity, two pasture mixtures on seasonal red clover (growing points/m^2) from Autumn 2015 through Autumn 2017. Symbols represent grazing management: Conventional Grazing (CG) (▲ or △), Autumn Lenient (AL) (■ or □), and Spring Lenient (SL) (● or ○). Filled symbols and solid lines represent diverse pasture mixture and unfilled symbols and dotted lines denote diverse pasture with Italian ryegrass mixture. Vertical bars represent least significant difference (LSD) (α = 0.05). LSD 1 = main effect of grazing management, LSD 2 = main effect of month, LSD 3 = main effect of mixture, LSD 4 = Grazing management, mixture, month interaction.**

The number of chicory crowns fluctuated least of the species sampled and also was not affected by grazing management or pasture mixture (Figures 3.10). On average, plant populations of chicory did not exceed 15 crowns/m^2. Though not statistically significant (*P*>0.05), the greatest number of chicory crowns were found in spring of both years in DP+Ita and where pastures were managed leniently in spring (SL). Conventional grazing resulted numerically, not statistically (*P*=0.10) in the lowest chicory populations in summer 2016 in both mixtures.

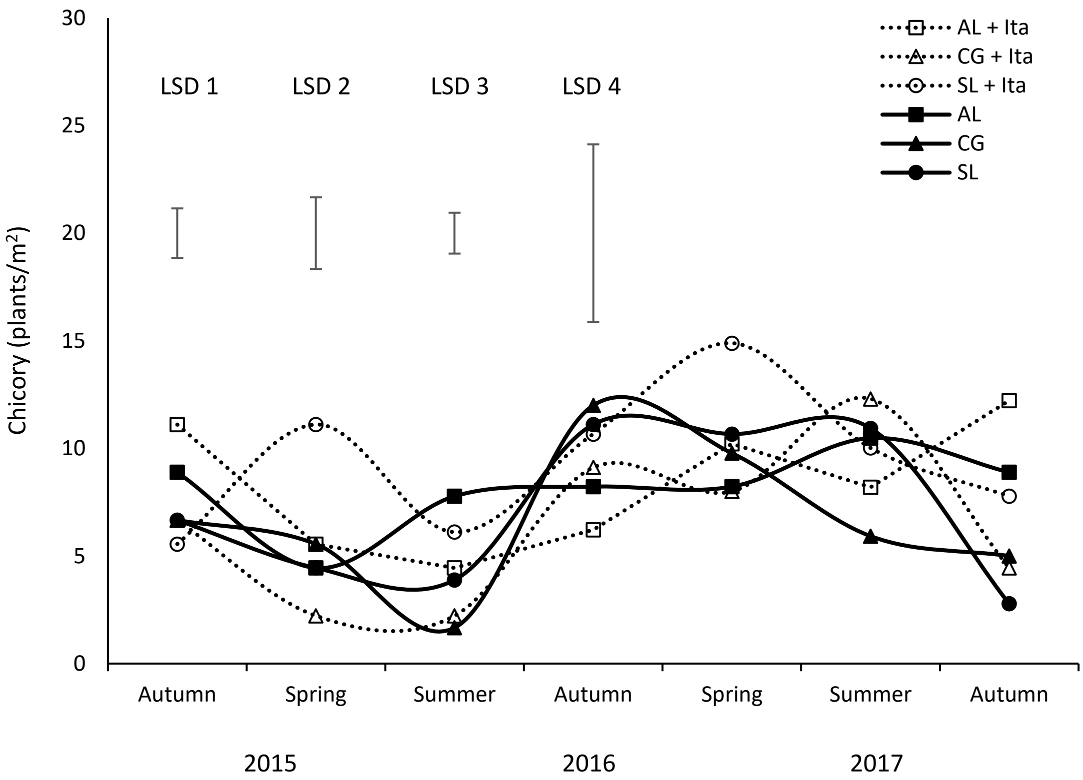


Figure 3.10 The effect of three grazing management severity, two pasture mixtures on seasonal chicory population (plants/m^2) from Autumn 2015 through Autumn 2017. Symbols represent grazing management: Conventional Grazing (CG) (▲ or △), Autumn Lenient (AL) (■ or □), and Spring Lenient (SL) (● or ○). Filled symbols and solid lines represent diverse pasture mixture and unfilled symbols and dotted lines denote diverse pasture with Italian ryegrass mixture. Vertical bars represent least significant difference (LSD) (α = 0.05). LSD 1 = main effect of grazing management, LSD 2 = main effect of month, LSD 3 = main effect of mixture, LSD 4 = Grazing management, mixture, month interaction.

The number of plantain crowns exceeded that of chicory with numbers ranging between 10 and 60 plantain plants/m^2 across the two years of this study. Plantain population was not affected by grazing management or pasture mixture (Figures 3.11). There was an increase in plantain population in summer 2017, particularly in AL and SL managed mixtures containing Italian ryegrass compared to CG, although this was not statistically significant.

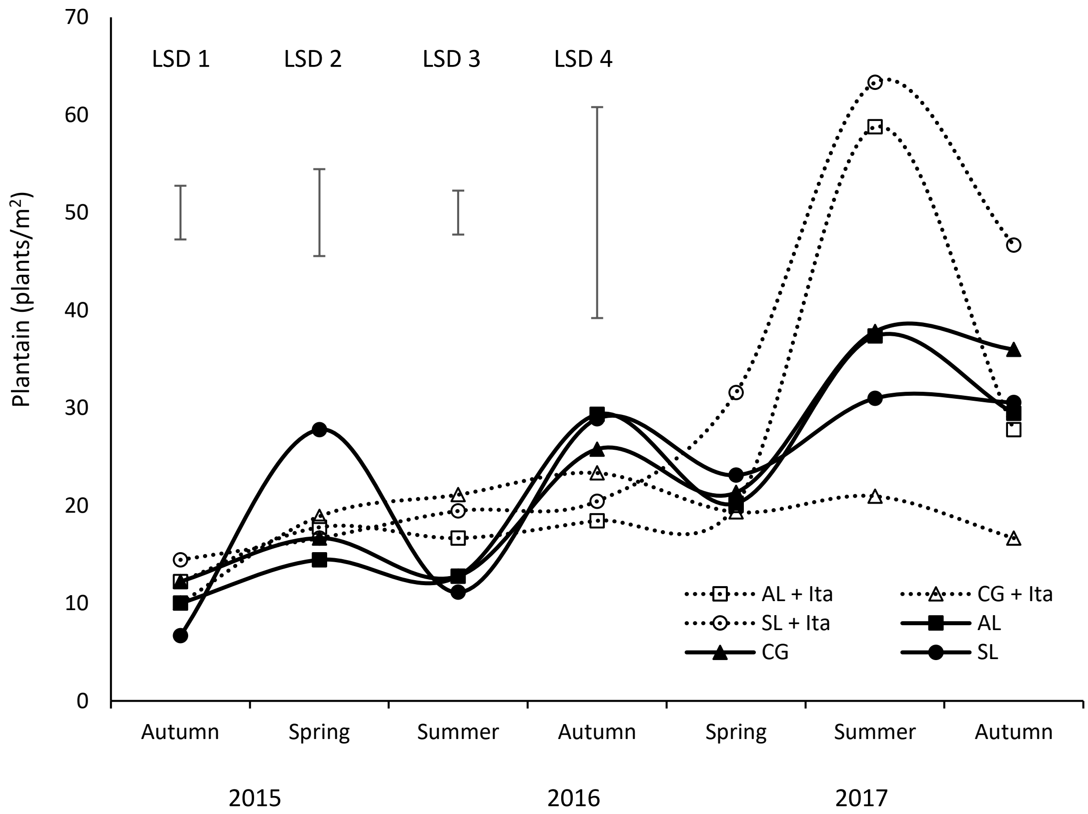


Figure 3.11 The effect of three grazing management severity, two pasture mixtures on seasonal plantain population (plants/m^2) from Autumn 2015 through Autumn 2017. Symbols represent grazing management: Conventional Grazing (CG) (▲ or △), Autumn Lenient (AL) (■ or □), and Spring Lenient (SL) (● or ○). Filled symbols and solid lines represent diverse pasture mixture and unfilled symbols and dotted lines denote diverse pasture with Italian ryegrass mixture. Vertical bars represent least significant difference (LSD) (α = 0.05). LSD 1 = main effect of grazing management, LSD 2 = main effect of month, LSD 3 = main effect of mixture, LSD 4 = Grazing management, mixture, month interaction.

3.5.7 Nutritive value

In the first year, there were negligible effects of grazing management or pasture type on nutrient content (Table 3.8). On average, fibre accounted for 40% of the DM, while crude protein averaged 17% and WSC averaged 15%. Season had a greater effect on nutritive value with winter herbage having higher CP and WSC and the lower fibre than other seasons. ME content was greater in winter (12.1 MJ ME/kg DM) and lower in the autumn (10.2 MJ ME/kg DM).

Table 3.8 The effect of three grazing management and season on acid detergent fibre (ADF), neutral detergent fibre (NDF), water-soluble carbohydrates (WSC), crude protein (CP) and metabolisable energy (ME) of two diverse pasture swards from June 2015 - May 2016.

P-values from ANOVA for the main effects of grazing management, pasture mixture and season are shown. Values are statistically significant within a column at ($P \leq 0.05$).

2015-2016	ADF (g/kg DM)	NDF (g/kg DM)	WSC (g/kg DM)	CP (g/kg DM)	ME (MJ ME/ kg DM)
Grazing management					
Autumn lenient	252	414	149	166	11.0
Conventional grazing	252	423	153	165	10.9
Spring lenient	247	409	151	169	11.0
SEM	1.47	4.19	6.59	1.70	0.04
Pasture mixture					
Diverse pasture+ Italian ryegrass	251	418	151	166	11.0
Diverse pasture	250	412	151	168	10.9
SEM	1.20	3.42	5.38	1.39	0.04
Season					
Winter	217	398	260	145	12.1
Spring	246	401	133	181	11.1
Summer	272	448	144	139	10.4
Autumn	266	414	67.1	201	10.2
SEM	1.70	4.84	9.33	1.96	0.05
***P*-value**					
Grazing management	0.04	0.07	0.70	0.31	0.98
Mixture	0.87	0.20	0.55	0.30	0.54
Season	<0.01	<0.01	<0.01	<0.01	<0.01
Grazing management*Mixture	0.17	0.13	0.61	0.39	0.30
Grazing management*Season	0.05	0.42	0.18	0.08	0.10
Mixture*Season	0.56	<0.01	<0.01	0.17	0.64
Grazing management*Mixture*Season	0.65	0.56	0.47	0.08	0.29

In the second year (June 2016 – May 2017), grazing management did not affect the nutritive value (Table 3.9). However, nutritive value (ADF, NDF, WSC, CP and ME) were significantly affected by the pasture mixture and season ($P \leq 0.01$). Water soluble carbohydrate and metabolisable energy were greater ($P \leq 0.01$) in DP+Ita than DP. Crude protein was greater ($P < 0.05$) without Italian ryegrass (17.1% DM) than DP+Ita (16.4% DM). NDF concentrations were unaffected by the pasture mixture ($P = 0.28$), though ADF levels were greater ($P \leq 0.01$) without Italian ryegrass. Season also affected nutritive value in the second year, with the greatest CP concentrations in autumn (18.5% DM) and the lowest concentration in winter (15% DM). WSC concentration in winter was greatest (23.8% DM) than in autumn (9.0% DM).

Table 3.9 The effect of three grazing management and season on acid detergent fibre (ADF), neutral detergent fibre (NDF), water-soluble carbohydrates (WSC), crude protein (CP) and metabolisable energy (ME) of two diverse pasture swards from June 2016 - May 2017.

P-values from ANOVA for the main effects of grazing management, pasture mixture and season are shown. Values are statistically significant within a column at ($P \leq 0.05$).

2016-2017	ADF (g/kg DM)	NDF (g/kg DM)	WSC (g/kg DM)	CP (g/kg DM)	ME (MJ ME/ kg DM)
Grazing management					
Autumn lenient	258	437	154	167	10.9
Conventional grazing	260	451	149	167	10.9
Spring lenient	257	441	153	169	11.0
SEM	1.78	4.40	2.89	1.81	0.04
Pasture mixture					
Diverse pasture+ Italian ryegrass	253	446	169	164	11.1
Diverse pasture	263	440	135	171	10.8
SEM	1.46	3.59	2.36	1.48	0.04
Season					
Winter	218	397	238	150	11.9
Spring	252	448	146	180	11.1
Summer	292	486	134	155	10.6
Autumn	271	440	89.7	185	10.2
SEM	2.06	5.08	3.34	2.09	0.05
***P*-value**					
Grazing management	0.60	0.08	0.51	0.60	0.08
Mixture	<0.01	0.28	<0.01	<0.01	<0.01
Season	<0.01	<0.01	<0.01	<0.01	<0.01
Grazing management*Mixture	0.03	<0.01	0.23	0.01	0.63
Grazing management*Season	0.79	0.98	0.02	<0.01	0.94
Mixture*Season	0.01	0.02	<0.01	<0.01	<0.01
Grazing management*Mixture*Season	0.70	0.73	0.07	0.11	0.22

The interaction effects on season and pasture mixture of nutritive value are shown in Figure 3.12. The interaction of pasture mixture and season was significant (*P*<0.01) for NDF in autumn 2015 and winter 2015. NDF concentrations increased in autumn 2015 in DP+Ita, though decreased in winter 2015 than DP. A significant interaction (*P*<0.01) for WSC in winter 2015 was also observed between pasture mixtures, with greater WSC concentrations in DP. Significant interactions (*P*<0.01) were detected in both pasture mixtures and seasons on ADF, NDF, CP, WSC and ME values in the second year, specifically occurred in winter 2016.

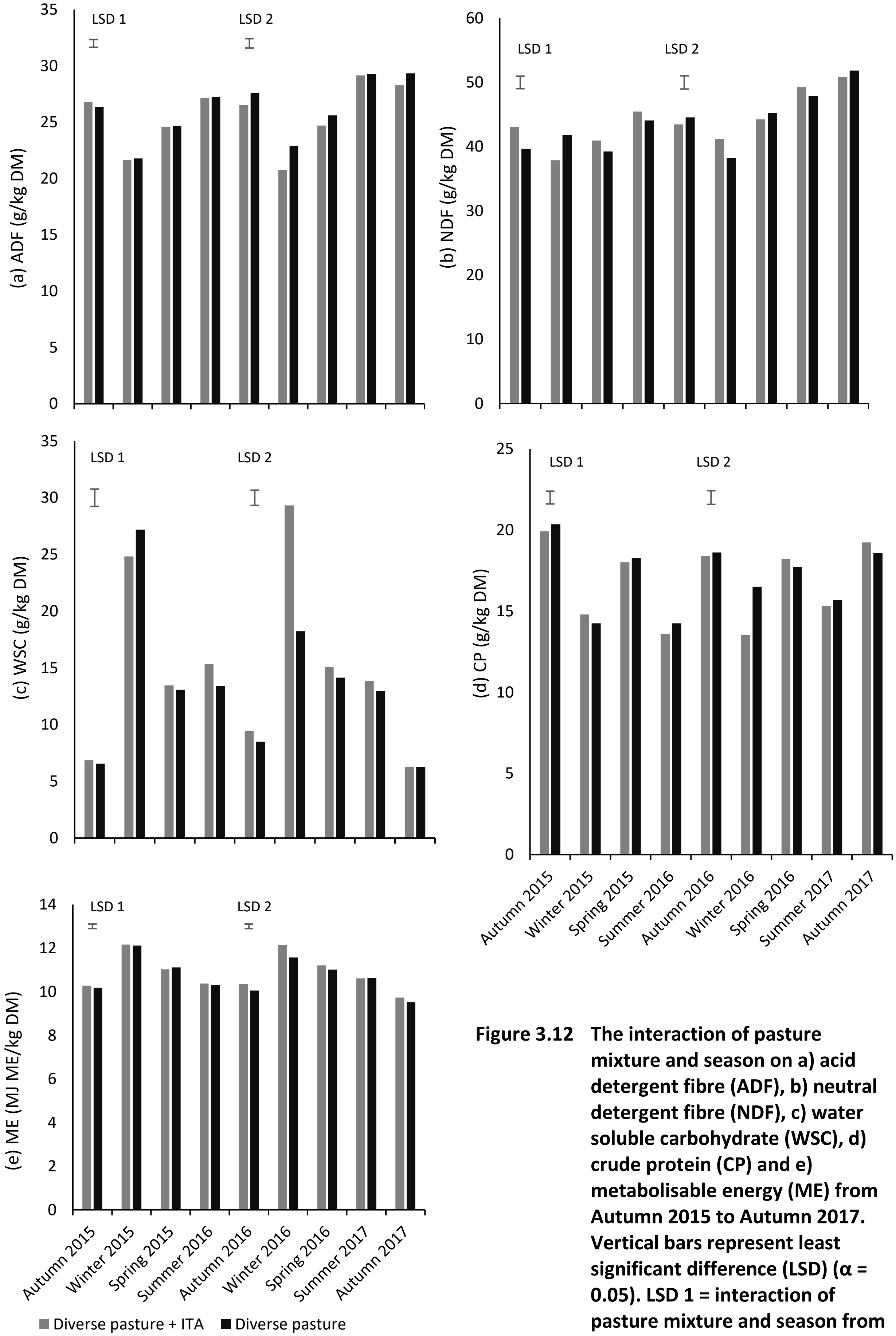


Figure 3.12 The interaction of pasture mixture and season on a) acid detergent fibre (ADF), b) neutral detergent fibre (NDF), c) water soluble carbohydrate (WSC), d) crude protein (CP) and e) metabolisable energy (ME) from Autumn 2015 to Autumn 2017. Vertical bars represent least significant difference (LSD) (α = 0.05). LSD 1 = interaction of pasture mixture and season from 2015-2016. LSD 2 = interaction of pasture mixture and season from 2016-2017.

3.6 Discussion

This experiment provides new information on the effects of grazing management and the addition of Italian ryegrass on herbage DM production, botanical composition and nutritive value of diverse pastures. Strategic use of lenient grazing can improve species diversity if carried out in the autumn, or it can improve DM production, at the expense of diversity, if carried out in spring. Including Italian ryegrass in a sowing mix does not have any long-term benefits on pasture production but may improve herbage quality in cooler months.

3.6.1 Herbage DM production and growth rate

Under the conditions of this study with dairy cows grazing, irrigation and application of 155 kg N/ha/year, herbage DM production ranged from 12.8 t DM/ha/year in DP+Ita to 13.4 t DM/ha/year in DP. Annual herbage DM production found in this study are lower than annual herbage DM production reported (16.7 t DM/ha) by Nobilly *et al.* (2013) for irrigated pastures using comparable mixtures at the same site and managed under dairy cow grazing. The lower annual herbage DM production in our study may be due to a lower N fertiliser application of 155 kg N/ha/year compared to 200 kg N/ha/year applied in the experiment by Nobilly *et al.* (2013). Interestingly, adding Italian ryegrass at a sowing rate of 10 kg/ha to a diverse pasture mix, reduced herbage DM production in the first year of the study. Diverse pasture mixtures had a 0.6 t DM/ha greater annual herbage DM production than DP+Ita. The greater annual herbage DM production in DP was from greater summer and autumn (5065 kg DM/ha and 4054 kg DM/ha, respectively) herbage DM production compared to herbage DM production in summer and autumn of DP+Ita mixture (4154 kg DM/ha and 3400 kg DM/ha, respectively) in the first year. It is noteworthy that in summer 2017, there was an interaction between grazing management and pasture mixture herbage DM production. This interaction reflected a significant difference between DP and DP+Ita in herbage DM yield in CG (4724 versus 5692 kg DM/ha). The production benefit in DP+Ita primarily reflected an increased proportion of the highly productive drought tolerant species, chicory (4.3%) and plantain (12.5%), compared to DP (3.3% and 10.5%, respectively). Chicory and plantain have been shown to have increased summer herbage DM production due to their high drought tolerance and heat tolerance (Ruz-Jerez *et al.* 1991; Moorhead and Piggot 2009; Nobilly *et al.* 2013). Extra winter and early spring herbage DM production was expected when Italian ryegrass was included in the diverse pasture mixture. Italian ryegrass is rapid to establish and grows well during the winter and spring (Brougham 1956; Moir *et al.* 2013) compared to perennial ryegrass. However, in this study, the inclusion of Italian ryegrass did not increase herbage DM production. Similarly, a study in New Zealand, Stevens and Hickey (2000), confirmed the combination of three temperate grasses (perennial ryegrass, cocksfoot or tall fescue) sown together did not improve herbage DM production compared to pure swards of the grasses. The reason for the lack of an effect of including Italian ryegrass in the mixture is unclear but may reflect that competition for resources from similar species may have caused the lower herbage DM yield in the first summer and autumn of the experiment. The growth of herbs, particularly plantain in DP accounted for most of the yield increase in autumn compared to DP+Ita. Herbage accumulation rate in plantain is greater in autumn compared to chicory (Powell *et al.* 2007). Red clover is typically short lived with a biannual lifecycle (Black *et al.* 2009) and contributed to the herbage DM production during the first experimental year in DP (15.5%) and DP+Ita (12.4%), but was gradually replaced by other species, e.g., predominately perennial ryegrass. In year two, pasture mixture did not affect the seasonal and annual herbage DM production.

Herbage DM production is driven by the size and density of growing points of plants within a sward, and as grazing management can alter the balance between size and density, we would expect to see effects of treatments here. We hypothesized that a lenient grazing prior to and during the reproductive stage would increase tiller population, and subsequently herbage mass in summer (Matthew 1991; Da Silva *et al.* 1994; Hernández Garay *et al.* 1997). Previous work (e.g., Matthew 1991; Da Silva *et al.* 1994; Hernández Garay *et al.* 1997) has indicated a lenient grazing in spring (e.g., allowing perennial ryegrass tillers to reach anthesis) followed by a hard-conventional grazing will lead to increased herbage DM production. Interestingly, annual and seasonal herbage DM production was similar between conventional grazing (the control) and spring lenient grazing management across all seasons. This lack of difference may reflect defoliation responses of mixtures containing multiple species. Previous studies demonstrated the effect of lenient spring grazing have been with perennial ryegrass-white clover pastures, rather than the diverse pasture mixture used in this study. Here, perennial ryegrass made up 40% of the pasture mixture. In this context, it is interesting to note that there was a tendency of interaction (P=0.10) between grazing management and pasture mixture, with greater herbage production in SL than CG (14.9 t DM/ha versus 13.9 t DM/ha, respectively) in DP but not in DP+Ita. This suggests that if perennial ryegrass is a greater proportion of the pasture mixture, SL may have had a greater effect on herbage DM production, and the inclusion of herbs and Italian ryegrass may dilute the impact of SL. This may reflect different responses to grazing management and pasture species. However, in this study, we did not find an increase in summer or autumn DM production in SL management nor any evidence of greater tiller population of perennial ryegrass in SL than CG and AL.

There was lower DM production with AL in both DP and DP+Ita mixtures compared with CG and SL (12.6 versus 13.9 and 13.8 t DM/ha, respectively). This reflected lower herbage growth rates in spring 2015, autumn 2016 and winter of both years. Previous works suggest that a greater post-grazing height with greater leaf mass may increase pasture growth rate and consequently, herbage DM production (Booysen and Nelson 1975; Grant *et al.* 1981). In this study, it was found that a higher post- grazing height in autumn contributed to higher pre-grazing mass at the one grazing in spring. However, the higher post- grazing in autumn contributed to overall lower herbage DM production, with this effect carrying over to later seasons. Tainton (1973) found a single lenient grazing of predominately perennial ryegrass-white clover pasture in early autumn, when the pasture was made up of almost exclusively of young vegetative tillers, assisted in the development of the perennial ryegrass tillers into a vigorous population and yielded more DM throughout winter than pastures which had been repeatedly hard grazed. The lower growth rates in AL could be attributed to a lower perennial ryegrass content relative to other species in the botanical composition compared to CG and SL. The rapid establishment of perennial ryegrass from winter to early spring is more likely to have contributed to the growth rates in this time period rather than the herbs and legumes (Goh and Bruce 2005). It appears for the mixture tested that AL did not promote greater herbage DM production. This conclusion is considered further in chapter 4 where the effect of range of post- grazing heights (20 to 60 cm) on winter and autumn herbage DM yield and nutritive value is considered.

3.6.2 Botanical composition and plant population

Among pasture mixtures, DP had greater proportions of all sown species, except for Italian ryegrass, than DP+Ita in the first year of the experiment. When Italian ryegrass was not included in the mixture, legumes (17.4%) and herbs (33.4%) proportions were greater than the proportion in DP+Ita mixture. In the second year, there was no difference in chicory and plantain population among mixtures. With the exception of perennial ryegrass, the plant population of all species (chicory, plantain, red clover, white clover and Italian ryegrass) decreased over time. This has previously been observed in pure swards of chicory (Li and Kemp 2005; Powell *et al.* 2007), plantain (Powell *et al.* 2007) and the combination of plantain, chicory, red clover and white clover in a mixture (Cranston *et al.* 2015b). In this study, the decline in plantain population was slower than that seen in chicory and red clover. This result is similar to findings by Cranston *et al.* (2015b). Previous research reported low herbage growth rates once chicory population decreased to 25 plants/m^2 (Li *et al.* 1997). In this study, chicory populations never exceeded 15 plants/m^2 resulting in a low proportion (e.g.<13.1%) of chicory in the botanical composition. Red clover is typically short lived with a biannual lifecycle (Charlton and Stewart 1999) and contributed 15.5% in DP compared to 12.4% in DP+Ita during the first year, but was gradually replaced by other species, predominately perennial ryegrass. By year two, red clover had declined to 6.3% in DP and 4.0% in DP+Ita. This is in agreement with findings from Daly *et al.* (1996) where the legume proportions decreased from 37% DM to 18% DM from the first to second year of the study, and where the red clover mixed swards (grasses, legumes and herbs) became dominated by perennial ryegrass. In pasture mixtures, animals show a partial preference for legumes and herbs over grass (Rutter 2006; Edwards *et al.* 2008; Pain *et al.* 2010), and this may result in the dominance of a grass species with a reduction of chicory and legume components in a forage mixture (Sanderson *et al.* 2005; Jing *et al.* 2017). However, this result may be expected to be minimised in this study due to rotational grazing used, which reduces the impact of selective grazing. In the DP+Ita mixture, plantain increased in autumn 2016 which was associated with a decline in the sown Italian ryegrass or possibly from the natural reseeding of plantain (Phillips *et al.* 2016). The low herbage growth rate in autumn and decline in Italian ryegrass tiller populations after flowering in spring would have contributed to the low botanical content and reflects the seasonal growth patterns of Italian ryegrass (Hickey and Baxter 1989; Ryan-Salter and Black 2012).

Grazing management treatments effects on botanical composition were apparent across winter, spring and autumn of year one of the experiment. Although AL had the lowest annual herbage DM production, it is important to note that in this study, AL grazing altered species diversity of both DP and DP+Ita mixtures. This is shown by the botanical composition with a greater proportion of herbs (31.3%) and legumes (18.8%) in the first year in AL than in CG (herbs-27.2% and legumes-13.3%). Also, pastures managed with AL and SL contained a greater proportion of red clover (14.9%) than CG (12.3%). It is well established that red clover yields more and persist better under lenient grazing >50 mm than hard grazing (Brock *et al.* 2003). A lenient grazing in autumn and spring may allow herbs and legumes to replenish root or crown stores of carbon so they are potentially more resilient to spring grazing defoliation (Cosgrove and White 1990; Li *et al.* 1997). In contrast to AL and SL, in this study, CG showed a lower abundance of plantain in year 1 (16.8%) and red clover in both years (12.3% and 3.9% in year 1 and year 2, respectively). This may reflect that heavily grazed plants have to use carbohydrate energy reserves for new growth and survival (Fulkerson and Donaghy 2001). Also, with a lower leaf area for light interception, a hard conventional grazing in autumn may not allow sufficient time for maximum average growth rate to be achieved (Gay and Thomas 1995; Parsons and Chapman 2000). During the late autumn, chicory is sensitive to hard selective grazing and livestock treading (Li *et al.* 1997). Spring and autumn grazing management has been shown to be critical for chicory persistence and in this study, a lax grazing in spring and autumn was able to maintain greater herb production in the second year compared to a hard-conventional grazing. Herb population in a diverse mixed sward still decreased from 31% DM to 16% DM and is similar to the decrease found in a previous study (Daly *et al.* 1996).

3.6.3 Pasture quality

Both the botanical composition and the morphological characteristics of the sward created by grazing management are likely to affect the nutritive value of the sward. Pasture quality or nutritive value is defined in terms of how well the needs of the herbivore are met. Typically pastures are regarded as having good quality when plants are high in cell contents, such as WSC and CP, and low in fibre (or NDF), as NDF and digestibility are negatively correlated (Akin 1989). In this study across two years, metabolisable energy ranged from 10.2 to 12.1MJ ME/kg DM and crude protein ranged from 139 to 201 g CP/kg DM dependent on the season. These values are slightly lower than those by Nobilly *et al.* (2013) who reported ME of diverse pasture ranged from 11.5 to 12.9 MJ ME/kg DM dependent on the season. An ME within the range of 11.5 to 13.0 MJ ME/kg DM is expected to meet the energy requirement of grazing dairy cows for milk production (Waghorn *et al.* 2007). However, it is important to note in this study, nutritive value was measured in herbage cut to ground level and not grazing height. This would contribute to slightly lower nutritive value in herbage cut to ground level than harvesting herbage to grazing height and will most likely result in greater ME values than the ones present. For example, lower ME were reported in herbage harvested to ground level compared to herbage samples plucked, representing the herbage selected by the animals (Litherland *et al.* 2002).

Under dairy cows grazing in this study, there was negligible effects of pasture mixture in the first year. There was no difference in the ME content (11.0 MJ ME/kg DM) of both DP and DP+Ita mixtures in the first year. Though in farming systems, the ME produced per ha is a key driver of dairy farm productivity and profitability. In this context, the DP mixture produced a greater ME (147 GJ ME/ha/yr) than DP+Ita (137 GJ ME/ha/yr) due to the greater DM production in DP mixtures. Season was more influential on the nutritive value of the sward than the mixture with lower ME in autumn (10.2 MJ ME/kg) and summer (10.4 MJ ME/kg) than ME in the winter (12.0 MJ ME/kg DM). In the second year, crude protein was greater for DP than DP+Ita and an interaction between pasture mixture and season showed greater CP in autumn (185 g CP/kg DM) than in winter (150 g CP/kg DM). The greater CP in autumn reflected an increase in red clover in the botanical composition of the DP mixture (6.3%) compared to DP+Ita (4.0%). It is well known that an abundance of a legume such as red clover will increase the CP content of a sward (Brown *et al.* 2005; Ryan-Salter and Black 2012). An interaction occurred between pasture mixture and season, reflecting lower metabolisable energy and WSC in DP than DP+Ita in autumn. The greater ME in the DP+Ita than DP mixture was due to the inclusion of Italian ryegrass and the lower ME in autumn reflects the low proportions of Italian ryegrass present in the botanical composition during that time period. A study by Hickey and Baxter (1989) compared the nutritive value of Italian ryegrass mixtures with perennial ryegrass mixtures during autumn and winter and results showed a greater digestibility and protein content in mixtures with Italian ryegrass.

Except for lower ADF in SL grazing management than CG and AL grazing management, there was negligible effects of grazing management on pasture quality in the first year. Nutritive value was influenced by the season, with greater CP and WSC and lower fibre in the winter. Despite differences in pre-grazing herbage height, in the second year, grazing management had no effect on annual pasture quality as measured by ADF, NDF, WSC, CP and ME. Past research has found crude protein concentrations across a spectrum of forages, including legumes and herbs, ranged between 135 to 300 g/kg DM (Burke *et al.* 2000; Fulkerson *et al.* 2007). Crude protein concentration changed throughout the year, with the highest concentrations in autumn, then spring and were significantly lower in the summer and winter. There was no effect of grazing management on CP concentration, with values ranging from 165 to 169 g/kg DM, providing sufficient CP for dairy cows producing above 20 kg of milk volume (NRC 2001). Though these values are significantly lower than those found by Nobilly *et al.* (2013) and Soder *et al.* (2006) of 196-261 g/kg DM, it is important to note that the herbage was cut to ground level and not grazing height. Litherland *et al.* (2002) found lower CP concentration (189 g/kg DM) in herbage cut to ground level compared to CP concentration (220 g/kg DM) of plucked pastures in the Canterbury region of New Zealand. The herbage sampled to ground level has likely contributed to the low CP concentrations found in this study. Studies showed protein levels in ryegrass varied significantly, however pastures that typically contain a legume or herb species increased protein levels to acceptable levels without hindering milk production (Soder *et al.* 2006; Nobilly *et al.* 2013; Totty *et al.* 2013).

3.7 Conclusions

This experiment highlights some key differences in DM production, botanical composition and pasture quality under lenient grazing in spring and autumn and hard conventional grazing year-round. With these diverse pasture mixtures that include herbs and alternative legumes, a lenient grazing management in spring and conventional grazing of the sward showed similar DM production without hindering pasture growth and quality for irrigated Canterbury dairy farm systems. Although, an autumn lenient grazing decreased herbage DM production, an autumn lenient grazing was beneficial to herbs and legume species abundance. The inclusion of Italian ryegrass in the mixture did not increase the DM production due to the low botanical content and from competition for resources of other species in the sward. Our results revealed the importance of balancing grazing management regimes and species diversity in a mixture to achieve high DM production without compromising nutritive value. However, additional experiments are essential to optimise grazing management practices for all sown functional groups to maintain sustainable livestock production systems. Further, it is necessary to consider the effects on milk production of alternative grazing management strategies. This is considered in Chapters 5 and 6. In addition, financial implications at the farm scale need consideration. These are considered further in Chapter 7.

Chapter 4

Effect of defoliation height in autumn on herbage production, nutritive value, botanical composition and nitrogen uptake of diverse pasture mixture

4.1 Introduction

In farm systems which graze year round under a seasonal supply regime, late autumn pasture management can influence early spring pasture growth and feed supply (Brougham 1960). Increasing feed supply in early spring is an important focus for management of temperate pasture systems to meet the high feed demand associated with earlier part of lactation. Overcoming feed deficits requires a multi-facet approach, with various strategies differing in cost. For example, farmers can supplement livestock with conserved or purchased feed (Wales and Kolver 2017). Alternatively, farmers can reduce feed demand early in the autumn and build herbage mass as standing feed which is carried through winter into spring (Macdonald and Penno 1998). The cost associated with this approach can lead to loss of autumn milk production due to reduced stocking rate or reduced feed quality as a result of high herbage mass (Holmes *et al.* 1992; Holmes and Roche 2007). Ideally, practices which encourage active cool season growth, or at least do not hinder growth, through into spring, offer low cost, high quality solutions.

Grazing management decisions in autumn, such as the post-grazing defoliation height is an important factor affecting regrowth and plant sward mass (Brougham 1970). Thus, the final defoliation in autumn may influence early spring herbage mass. Recommended grazing management during autumn has traditionally been to achieve defoliation to low herbage height to improve light interception at the base of the plant and reduce tissue decomposition (Brougham 1960). There is a general agreement that for predominately perennial ryegrass-white clover-based pastures, severe grazing (defoliation to <30 mm) improves herbage quality in the subsequent regrowth (Brougham 1960; Fulkerson and Michell 1987; Holmes *et al.* 1992; Lee *et al.* 2007). However, for alternative species (e.g., chicory, plantain, alternative legumes) or mixtures of these, there are conflicting reports to date on defoliation severity on herbage mass over late autumn to early spring (Harris and Brown 1970; Cranston *et al.* 2015a; Lee *et al.* 2015) and there are no reports to date on the impact of defoliation severity on diverse pasture mixtures on DM production in winter and early spring.

Due to the high nitrate leaching risk from autumn deposited urine (Di and Cameron 2002a), minimizing nutrient losses during periods of high drainage, as typically experienced in winter, is necessary to meet regulations to reduce nitrate leaching (Ministry for the Environment 2017). Pastures which grow rapidly after defoliation may have a better chance of capturing soil mineral N during the late autumn period (Moir *et al.* 2013), thereby reducing the risk of nitrate leaching (Malcolm *et al.* 2014). The objective of this experiment to examine the effects of five defoliation heights in late autumn on herbage mass, herbage regrowth, botanical composition, nutritive value and N uptake in autumn and winter of a diverse pasture mixture undersown with Italian ryegrass. We hypothesised a more lenient defoliation would increase herbage growth rate over the winter period and total herbage mass in early spring with no effect on nutritive value. Further, we hypothesised that due to greater herbage growth, nitrogen uptake would increase with lenient defoliation.

4.2 Materials and methods

The experimental design was a randomized complete block design with five defoliation heights (20, 30, 40, 50, 60 mm) and four blocks. This gave 20 plots in total, each 2m x 4m. The experiment was conducted between 14 May and 03 September 2015 (late autumn-early spring). The experimental site was established within a 1.5 ha paddock at the Lincoln University Research Dairy Farm (LURDF) in Canterbury, New Zealand (43°38S’, 172°27E’) on imperfectly drained Wakanui silt loam over sand (Hewitt 2010). A diverse pasture species mixture of perennial ryegrass, white clover, lucerne, chicory, plantain was sown on 17 October 2013 (Table 4.1). Waratah steel standards with an electric wire fencing were set up 2 m around the experimental area. Each plot corner was marked with 5 cm x 5 cm wooden stakes to ensure plot boundaries. Prior to the experiment, pasture was grazed by rotational grazing (e.g., to a 35 mm compressed height on a rising plate meter, on 21-28 d rotation) with dairy cows. On 28 February 2015, 20 kg/ha of Italian ryegrass was direct drilled into the established pasture which had been mown to 3 cm before being grazed by livestock. An additional 2 kg/ha each of plantain and chicory seed was direct drilled into diverse pasture treatments on the same date as Italian ryegrass sowing. Following a severe grazing, in April 2015, a month prior to the experiment, the plots were grazed by cows to a compressed height of 35 mm as measured by a rising plate meter and a single application of N was applied as urea at a rate of 25 kg N/ha.

Table 4.1 Plant species, cultivar and sowing rate of diverse pasture mixture during the autumn-winter season

Species	Common name	Cultivar	Sowing rate (kg/ha)	
			October 2013	February 2015
Lolium perenne	Perennial ryegrass	Arrow AR1	12.0	-
Lolium multiflorum	Italian ryegrass	Asset AR37		20.0 undersown
Trifolium repens	White clover	Weka	3.0	
Medicago sativa	Lucerne	Torlesse	8.0	
Cichorium intybus	Chicory	Choice	1.5	2
Plantago lanceolata	Plantain	Tonic	1.5	2

On May 2015, defoliation treatments were imposed using a rotary mower with an adjustable cutting height lever (Briggs & Stratton 650 I/C series, Milwaukee, USA) to achieve the five defoliation heights. Sward surface height was then measured with a ruler to confirm the target defoliation heights. Pastures were then allowed to regrow.

The site had an annual rainfall of 606 mm/year (18-year average) and was supplemented with 420 mm irrigation/season from a centre-pivot irrigator from November to March. Climate information was collected from the Broadfields weather station located approximately 1.0 km away.

4.2.1 Herbage DM mass

To determine variation in herbage growth over winter, herbage DM mass, was measured on 0, 22, 41, 64, 90 and 112 days after defoliation treatments were imposed. Within each plot three random locations of 0.2 m^2, avoiding previously harvested locations were selected, and herbage harvested to ground level using electric hand shears. Harvested herbage samples were dried at 60°C for 48 h and weighed. Herbage growth rate was calculated by the difference of the initial herbage mass (day 0) and herbage mass to ground level at each respective harvest time point (day 22, 41, 64, 90, 112) divided by the number of days of regrowth.

To determine the effect of autumn defoliation height on feed supply in spring, total herbage mass was measured above a simulated grazing height of 35 mm. On day 112, one strip, 0.45 m x 3 m, within each plot was harvested using a rotary mower. The total catcher fresh weight from each strip was weighed using portable scales and a 200 g fresh weight subsample removed. The sub-sample was dried at 60°C for 48 h for determination of DM percentage (DM%). Herbage mass (kg DM/ha) was calculated as fresh weight x DM% x area harvested.

4.2.2 Botanical composition and nutritive value

To determine botanical composition, herbage samples were collected between 11:00 and 13:00 h on days 0 and 112 days. All herbage was cut to ground level in three randomly placed quadrats (0.2 m^2) in each plot using electric hand shears. A fresh subsample of approximately 200g was dissected into sown grasses, herbs, legumes, weeds and dead material before dry weight of each component was determined. Samples were then dried at 60°C for 48h and weighed and the botanical composition percentage was determined on a DM basis. The remaining bulk was oven-dried at 60°C for 48 h and weighed. Samples were passed through a 1mm sieve using a ZM200 rotor mill (Retsch Inc., Pennsylvania, USA) and analysed for organic matter (OM), crude protein (CP), nitrogen (N) %, water soluble carbohydrates (WSC), neutral detergent (NDF) and acid detergent fibre (ADF) digestible OM in DM (DOMD), using near-infrared spectroscopy (NIRS; Model: NIRSystems 5000, Maryland, USA) by the Lincoln University Analytical Laboratory. Metabolisable energy (ME) was calculated as MJ/kg DM = 0.16 x %DOMD (McDonald *et al.* 2010).

4.2.3 N uptake

Herbage DM mass above ground level at the final harvest (day 112) was multiplied by N% of herbage above ground level to calculate N herbage uptake in each plot.

N uptake = (N% at day 112 x DM mass at day 112) - (N% at day 0 x DM mass at day 0)

4.3 Statistical analysis

The effects of defoliation height on herbage mass, botanical composition, nutritive value and N uptake was analysed as a randomized complete block design using the General Linear Model procedure of Genstat. The effects of defoliation height on herbage DM mass and nutritive value were analysed by a repeated measures ANOVA with defoliation treatments (20, 30, 40, 50, 60 mm) and regrowth day as fixed terms and replicates as a random term. A planned contrast was embedded in the ANOVA treatment structure to compare severe-conventional (20, 30, 40 mm) versus lax (50 and 60 mm) defoliation height on DM mass. Means were separated using Fisher's protected least significant difference test whenever ANOVA indicated a significant treatment effect at $P \leq 0.05$. All statistical analyses were performed using GENSTAT 18 (VSN International, Hemel Hempstead, UK).

4.4 Results

Mean climate data are presented in Table 4.2. Mean temperatures were similar to the long term 18-year average from May to September. Total rainfall was lower in the months of May, July and August in this experiment compared to long term 18-year averages.

Table 4.2 Mean weather data for the experimental period and 18-year average (1997-2015).

	Regrowth period				
	14 May- 05 June Days 0-22[a]	05 June- 24 June Days 22-41	24 June- 17 July Days 41-64	17 July- 12 August Days 64-90	12 August- 03 September Days 90-112
Maximum air temperature (°C)	14.1	12.3	11.7	12.6	11.8
Minimum air temperature (°C)	2.6	1.6	1.1	1.7	3.1
Radiation (MJ/m²)	5.6	4.9	5.2	7.0	7.6
Soil temperature at 100 mm (°C)	5.9	4.3	3.3	4.2	5.8
Total rainfall (mm)	17.6	55.2	25.6	36.2	15.2
Long term average (1997-2015)					
Maximum air temperature (°C)	13.4	12.5	11.7	11.9	12.5
Minimum air temperature (°C)	3.6	2.2	1.8	2.3	3.0
Total rainfall (mm)	45.7	43.0	35.4	47.3	43.4

[a]Regrowth beginning May 14, 2015

4.4.1 Herbage mass above ground level and regrowth

Herbage mass above ground level from the five defoliation heights is shown in Figure 4.1. Post-grazing herbage mass after initial defoliation (day 0) ranged from 190 kg DM/ha for the 20 mm defoliation height to 800 kg DM for the 60 mm defoliation height and were significantly different among defoliation treatments (*P*<0.001). There is a positive relationship between increasing defoliation height and herbage mass with increasing days of regrowth. Herbage growth rates during 112 days of regrowth from 12.7 to 15.0 kg DM/ha/d, averaging 14.0 kg DM/ha/d and was unaffected (*P*=0.97) by defoliation height. Thus, herbage accumulation was not different among defoliation treatments, ranging from 1422 to 1676 kg DM/ha, averaging 1564 kg DM/ha over the 112 d experimental period.

Final herbage mass above ground level on day 112 was not affected by defoliation severity (*P*=0.22). However, a planned contrast identified a significant difference on day 112 herbage mass between low defoliation treatments: 20, 30, and 40 mm compared with more lenient defoliation treatments: 50 and 60 mm (*P*=0.04, 1860 vs 2408 ± 262 kg DM/ha, respectively).

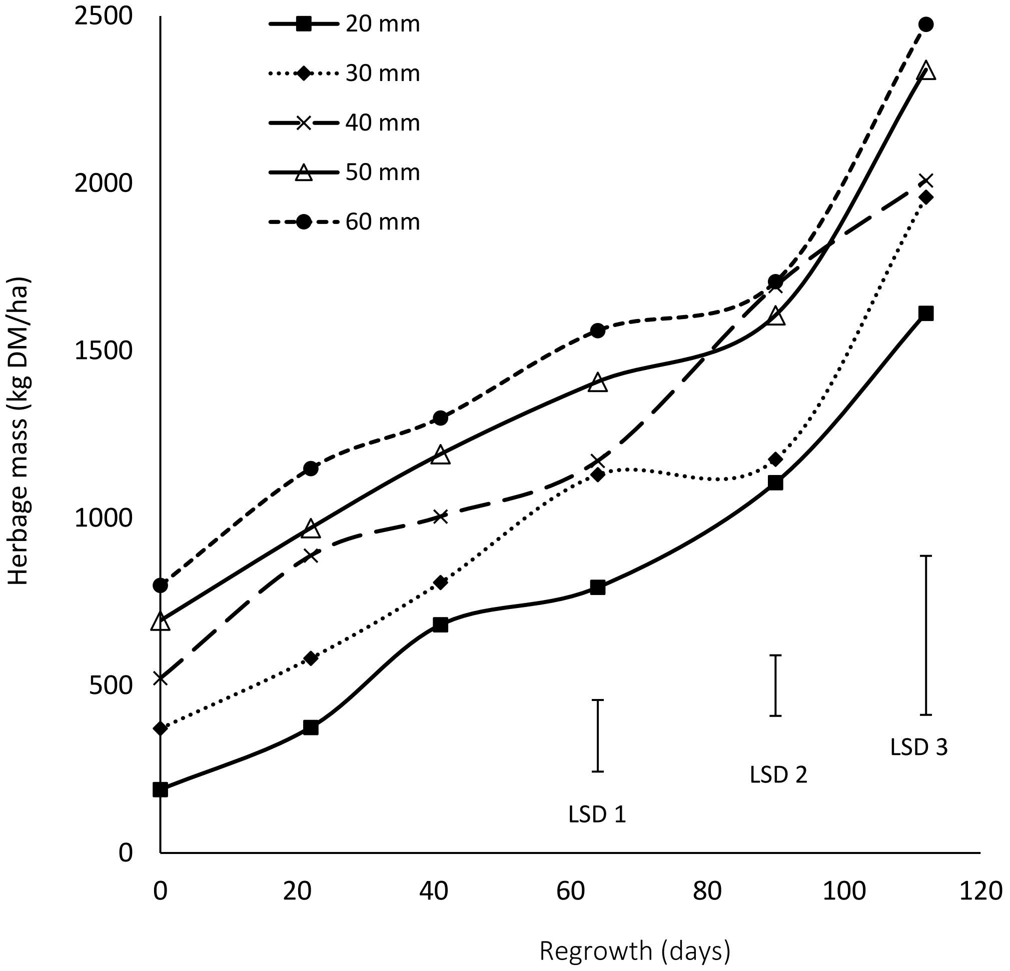


Figure 4.1 **Herbage mass (kg DM/ha) above ground level during regrowth of diverse pastures initially defoliated to different heights. LSD from ANOVA on days, defoliation treatment and interaction are shown as error bars. LSD = least significant difference (α=0.05). LSD 1 = treatment effect, LSD 2 = day effect, LSD 3 = treatment within a day interaction.**

4.4.2 Botanical composition

The effect of defoliation height on botanical composition above ground level throughout the regrowth period is shown in Table 4.3. From the initial defoliation (day 0), botanical composition did not differ among defoliation, except for perennial ryegrass which ranged from 13.3% to 43.3%, (*P*<0.001). During the 112 d regrowth period of this study, the pastures were dominated by perennial ryegrass (36%) and plantain (27%). The Italian ryegrass which was undersown two months prior to the study accounted for less than 5% of the herbage mass as plants were still small. All treatments remained relatively stable in composition except for a trend for an increased proportion of Italian ryegrass (*P*=0.09) in the severe defoliation (≤ 40 mm) where the proportion increased from 3.4% on day 0 to 5.3% on day 112. Although there were differences between defoliation for post-graze herbage mass on day 0 there was no effect of treatment on dead material content at day 112.

Table 4.3 Botanical composition (% of DM) of perennial ryegrass, Italian ryegrass, white clover, lucerne, plantain, chicory, dead material and weeds for defoliation treatments on initial (d 0) and final regrowth period (d 112).

	Initial defoliation height (mm)						
Botanical composition at day 0	20	30	40	50	60	LSD	*P*-value
Perennial ryegrass	13.3[a]	29.8[b,c]	28.8[b]	40.1[c]	43.3[c]	10.64	<.001
Italian ryegrass	3.1	3.5	3.7	2.3	1.1	3.79	0.57
White clover	16.1	8.8	15.7	11.4	11.9	9.97	0.49
Lucerne	0.0	0.0	0.0	0.0	0.0	-	-
Chicory	3.5	5.8	6.0	4.1	2.7	4.13	0.39
Plantain	14.7	9.9	15.1	13.1	11.1	9.80	0.73
Dead	48.9	41.0	29.3	28.8	29.4	21.53	0.21
Weed	0.43	1.17	1.56	0.19	0.54	1.77	0.46
Botanical composition at day 112							
Perennial ryegrass	34.9	39.0	29.9	39.3	37.5	10.46	0.37
Italian ryegrass	5.3	3.7	6.8	3.2	3.0	3.13	0.09
White clover	7.1	9.0	9.4	9.3	7.7	5.97	0.91
Lucerne	2.9	0.6	1.2	0.9	1.4	1.94	0.16
Chicory	6.4	4.2	1.9	1.8	3.4	3.97	0.13
Plantain	26.2	25.7	34.4	23.9	26.8	13.73	0.59
Dead	16.2	16.9	16.2	21.1	20.1	10.25	0.80
Weed	1.02	1.01	0.20	0.57	0.14	1.36	0.54

Means within the same row with different superscripts are significantly different (*P*<0.05)

4.4.3 Harvested herbage DM and nutritive value

Total harvestable DM mass above 35 mm tended (P=0.06) to increase from 955 kg DM/ha for the 20 mm defoliation height to 1874 kg DM/ha for the 60 mm defoliation height (Table 4.4). On day 112, all pastures were harvested to 35 mm and analysed for nutritive values. While there were similar tendencies (P<0.10) for ADF and OM to increase with increasing defoliation height, otherwise herbage nutritive value characteristics (NDF, DOMD, WSC, CP and ME) were not affected by defoliation height (Table 4.4).

Table 4.4 The effect of defoliation height on total herbage mass and herbage acid detergent fibre (ADF), neutral detergent fibre (NDF), organic matter (OM), digestible DM in organic matter (DOMD), water-soluble carbohydrates (WSC), crude protein (CP) and metabolisable energy (ME) on day 112 when all pastures harvested to 35 mm.

	Initial defoliation height (mm)					LSD	*P*-value
	20	30	40	50	60		
Herbage DM mass (kg DM/ha)	955	1262	1437	1694	1874	645	0.06
ADF (%DM)	20.1	20.4	20.9	21.2	21.5	1.07	0.07
NDF (%DM)	37.3	36.3	39.4	38.3	39.8	2.92	0.12
OM (%DM)	88.4	88.8	89.2	89.1	89.6	0.79	0.052
DOMD (%DM)	74.7	75.5	75.6	75.4	76.6	1.37	0.11
WSC (%DM)	21.8	21.2	22.6	21.5	22.7	2.53	0.64
CP (%DM)	17.0	17.1	16.4	15.8	15.7	1.96	0.41
ME (MJ ME/kg DM)	12.0	12.1	12.1	12.1	12.3	0.22	0.11

4.4.4 Herbage N uptake

Herbage mass and herbage N uptake at each defoliation height over 112 d are presented in Table 4.5. Herbage mass at day 0 differed among defoliation heights, ranging from 189 to 799 kg DM/ha (P<0.001), but by day 112, herbage mass was similar across all treatments, averaging 2079 kg DM/ha (P=0.20). The N% at day 0 was similar across all treatments, but differed on day 112 (P=0.005). Herbage defoliated to 20 and 40 mm had greater N concentration (2.8 N%) than herbage N concentration in those defoliated to 30, 50 and 60 mm (2.4 N%; P=0.005). Nitrogen uptake across all treatments averaged 40.8 kg N/ha over the total 112 day period and was not significantly different among defoliation heights (P=0.99).

Table 4.5 Herbage mass above ground level (kg DM/ha) and herbage nitrogen uptake (kg N/ha) of herbage following defoliation heights.

	Initial defoliation height (mm)						
	20	30	40	50	60	LSD	*P*-value
Herbage mass at day 0 (kg DM/ha)	189^{a}	372^{b}	522^{b}	694^{c}	799^{c}	171.9	<0.001
Herbage mass at day 112 (kg DM/ha)	1612	1959	2009	2340	2476	807.0	0.20
N% at day 0	2.56	2.35	2.40	2.41	2.41	0.627	0.96
N% at day 112	2.88^{b}	2.49^{a}	2.79^{b}	2.33^{a}	2.41^{a}	0.295	0.005
Nitrogen uptake (kg N/ha)	42	39	44	39	40	22.1	0.99

Means within the same row with different superscripts are significantly different (P<0.05)

4.5 Discussion

The objective of this experiment was to determine the effects of post-grazing defoliation height on herbage mass, herbage growth, botanical composition, nutritive value and N uptake of a diverse pasture mixture during the late autumn and winter season.

4.5.1 Herbage growth rates, herbage DM mass and nutritive values

The average herbage growth rates in this experiment of 14 kg DM/ha/day were low, but similar to values reported in the Canterbury region of New Zealand, ranging from 10-16 kg DM/ha/day from June-August (Monaghan *et al.* 2004). Regrowth is expected to be reduced in response to depleted reserves and if there is less leaf area to capture light (Parsons and Penning 1988; Fulkerson *et al.* 1994). However, in this study, defoliation height in late autumn did not appear to affect herbage growth rate of the diverse pasture. The reason for this lack of effect of defoliation height is unclear, but may reflect in a mixed sward containing legumes and herbs, there are sufficient reserves present to allow regrowth to proceed unhindered (Sanderson *et al.* 2003; Labreveux *et al.* 2006). This is also consistent with findings from Lee *et al.* (2007) who measured pasture mass in perennial ryegrass based pastures during winter and concluded that defoliation to low post-grazing mass (1260 ± 101 kg DM/ha) and defoliation to high post-grazing mass (1868 ± 139 kg DM/ha) provided similar herbage regrowth potential. Earlier work (eg., Brougham 1957, 1959; Brougham 1970) found a more intensive grazing was beneficial to growth over the winter with no detrimental effects on herbage mass in early spring. In this experiment, since herbage growth rate was not affected by defoliation treatment, this resulted in similar overall herbage DM mass when measured to ground level (1612 versus 2476 kg DM/ha, P=0.22). Though herbage DM mass measured to ground level was not statically significant (P=0.22), the numerical differences among herbage mass was large (864 kg DM/ha difference between 20 mm and 60 mm defoliation height). Explanation for the large variation between the defoliation height could be from the small area sampled in this study (SEM=262 kg DM/ha) and does not mean no response occurred as suggested by Matthew *et al.* (2009). Matthew *et al.* (2009), in their review on plant response to gibberellins, measured herbage mass by three methods, a) rising plate meter, b) lawnmower cuts and c) quadrat cuts and found no significant response in their quadrat cut data (1480 versus 2540 ± 160 kg DM/ha; P=0.822) compared to herbage mass measured by a lawnmower (980 versus 1540 ± 66 kg DM/ha; P=0.001). They suggested a larger number of quadrats per plot would need to be collected to achieve a standard error comparable to that achieved by a lawnmower (SEM=66 kg DM/ha) (Matthew *et al.* 2009).

Pastures were defoliated to a constant height of 35 mm on day 112 to indicate the potential harvestable herbage at first grazing in spring. When measured to a constant defoliation height of 35 mm at the end of the regrowth period (day 112), there was a trend in harvestable herbage mass towards a 2-fold difference with a lenient (60 mm, 1874 kg DM/ha) versus severe (20 mm, 955 kg DM/ha) defoliation (P=0.06). In addition, a planned contrast comparison showed a significant difference between severe to conventional defoliated (20, 30, 40 mm) versus lenient defoliated (50, 60 mm; P=0.01) for harvestable herbage DM mass on day 112. Tainton (1973) found a single lenient grazing of predominately perennial ryegrass-white clover pasture in early autumn, when the pasture was made up of almost exclusively of young vegetative tillers, assisted in the development of the perennial ryegrass tillers into a vigorous population and yielded more DM throughout winter than pastures which had been repeatedly hard grazed. The results showed a lenient grazing in autumn would be important because animals have access to a greater proportion of harvestable material within the grazing horizon, which subsequently may influence milk production in early spring. Though herbage regrowth was similar, defoliation to a low height (20 - 40 mm) in this trial may have been too low to maximize the amount of herbage at a harvestable height to meet animal demands in early spring.

Nutritive characteristics (NDF, ADF, OM, WSC, CP or ME) at final harvest on day 112 were not affected by defoliation height. Previous research has found improved herbage quality with increasing severity (<1500 kg DM/ha; <40 mm post-grazing height) in perennial ryegrass swards (Fulkerson and Michell 1987; Lee *et al.* 2007). However, the inclusion of chicory and plantain is likely to improve the nutritive values of the sward (Sanderson *et al.* 2003). In this study, the average ME ranged from 12.0 to 12.3 MJ ME/kg DM, within the range of 11.5 to 13.0 MJ ME/kg DM, suggested to meet requirement of grazing dairy cows for milk production (Waghorn *et al.* 2007). This would suggest that pasture nutritive values will not likely affect milk production in early lactation in spring.

4.5.2 Botanical composition

Grazing management has the ability to alter the botanical composition of the pasture (Shakhane *et al.* 2013). It has been suggested that severe grazing of less than 80 mm in late autumn and winter of a herb clover mix may have impacts on plant density and persistence (Cranston *et al.* 2015a). Cranston *et al.* (2015b) showed the more lenient management (80 mm) better supported the persistence of the four species in the herb and clover mix (i.e., chicory, plantain, red clover, white clover) over 2 years under sheep grazing. However, in this study, botanical composition was not affected on the final harvest of the experiment by autumn management. Though diverse pastures with at least 20% herbs have been found to decrease urinary N concentration (Woodward *et al.* 2012; Totty *et al.* 2013; Box *et al.* 2017), there was no evidence from this study to suggest autumn grazing management could be used to control plantain and or chicory content in the sward and diet in order to influence urine N excretion.

4.5.3 Herbage N uptake

In this study, herbage N uptake was calculated to estimate the potential impact of grazing management on N leaching. This was calculated as the product of N percent in the herbage and herbage growth over the regrowth period. The N concentration in the herbage at final harvest was significantly greater (P=0.005) in pastures defoliated to 20 mm (new younger leaves) than lenient defoliated (older leaves) pastures. Nitrogen is easily translocated within the plant, so this is not surprising as N is mobilised from older mature leaves to young new leaves for growth (Brady and Weil 2008). However, when N% was multiplied by the final herbage DM mass, the total N uptake was not significant among all treatments (P=0.99), averaging 40.8 kg N/ha. Nitrogen uptake was similar among all defoliation height treatments during the winter season. Generally, N uptake is dependent on the relative growth rate of the plants and the initial defoliation treatments changes the remaining residual leaf area (Lestienne *et al.* 2006). This will undoubtedly affect day to day N uptake rates over the measurement period. This level of N uptake is equivalent to the range (0.16-0.62 kg N/ha/d) found by Woods *et al.* (2016) during a winter lysimeter trial comparing a perennial ryegrass-white clover mixture, Italian ryegrass and lucerne. Woods *et al.* (2016) hypothesised that gibberellic acid could be used to promote pasture growth and thereby increase the N uptake and subsequently reduce N leaching loss. However, no effect of gibberellic application on growth was found (Woods *et al.* 2016). Pastures which grow rapidly after defoliation may have a greater potential to increase N uptake during the late autumn period. However, there is no evidence in this study to suggest grazing management could be used to increase herbage growth rates and therefore decrease the risk of nitrate leaching. It seems that larger differences in growth over the winter are required to create differences in N uptake and consequently, reduce N loading.

Italian ryegrass has shown potential to increase growth and N uptake over winter (Moir *et al.* 2013; Malcolm *et al.* 2014; Woods *et al.* 2016; Maxwell *et al.* 2018). Maxwell *et al.* (2018) measured the effects of undersowing Italian ryegrass into established perennial ryegrass swards and found a trend of reduced nitrate leaching losses compared to pure perennial ryegrass swards, though not statistically significant. The effect was not shown in this trial due to the low Italian ryegrass content (5%) of the herbage in the pasture, because of the more dominant and established perennial ryegrass (36% of herbage mass). Though Italian ryegrass has the potential to reduce N leaching as shown by (Moir *et al.* 2013; Malcolm *et al.* 2014; Woods *et al.* 2016; Maxwell *et al.* 2018), further work on how to integrate this into diverse pasture mixtures that include plantain, chicory and alternative legumes, such as red clover and lucerne would be beneficial.

4.6 Conclusion

Diverse pasture mixtures can maintain high quality through winter and defoliation height had no significant effect on herbage grown, botanical composition or N uptake. However, it is important to note, leaving a greater herbage mass in autumn increased the harvestable herbage mass for early spring. Additional research with dairy cows grazing a diverse pasture mixture to different defoliation heights in late autumn will help us further understand plant N uptake along with animal related effects and ultimately nitrate leaching.

Chapter 5

Impact of grazing severity and mowing in early spring on intake and milk production

Part of this chapter has been published:

Cun GS, Edwards GR, Bryant RH. 2017. The effect of pre-graze mowing on milk production of dairy cows grazing grass-herb-legume pastures managed under contrasting spring defoliation regimes. Animal Production Science 57, 1414-1418.

5.1 Introduction

Previous chapters (Chapters 3 and 4) highlighted the importance of grazing management throughout the season. Results in chapter 3 and 4 demonstrated that there was little impact of grazing management on herbage quality, though these conclusions were drawn in the absence of diet selection. Offering a diverse pasture creates substantially more opportunity for diet selection particularly under lenient grazing, hence chapter 5 is focussed on strategic grazing management in the spring and the effects on milk production.

Pasture-based dairy farming in New Zealand requires a balance between managing pastures for dry matter (DM) production and quality and managing cows to maximize DM intake (McCarthy *et al.* 2014). Effective grazing pasture management has a significant influence on pasture production and pasture quality (McCarthy *et al.* 2014). The dairy industry has set a target to increase profit by NZD$65/ha/year by the year 2020 (DairyNZ 2015). One fundamental strategy in achieving this is by increasing the amount of high quality pasture grown on each hectare of land and converting this efficiently to milksolids (DairyNZ 2015). Grazing management strategies (severity and frequency) are well developed for ryegrass-white clover pastures (Macdonald and Penno 1998) but options to increase future herbage mass and quality with milksolids production are still needed (Pembleton *et al.* 2015).

One strategy suggested to increase DM production is through tactical spring defoliation. By allowing the reproductive parent tiller of grass to develop to anthesis (i.e., early flower stage) before removal by grazing or mowing ("late control"; Matthew 1991) daughter tiller survival is aided (Matthew *et al.* 1989) resulting in greater herbage mass (Da Silva *et al.* 1994). This is possibly through better nutrition of daughter tillers owing to the strongly growing parent tiller and reabsorption of nutrients from the decapitated flowering stem base. Da Silva *et al.* (1994) noted a 20% greater herbage mass in subsequent grazing in spring and summer using late control grazing. However, the concern with this approach is that at high herbage mass, pasture quality may decline. It is well known the reproductive stem has a lower quality than the green leaf portion (Ball *et al.* 2001). Also, high pre-graze herbage mass shades the base of the plant and limits the production of new tillers and can induce aerial tillers production (Korte *et al.* 1987). Further, herbage DM intake from livestock may be reduced as animals are required to grazed through more fibrous material and into a lower horizon. Moreover, if herbage is left behind, herbage in subsequent grazing rotations may be of lower quality (Holmes *et al.* 1992).

One approach that may alleviate this is pre-graze mowing. Mowing removes reproductive material and creates a consistent post-grazing height. This may prevent depression of DM intake associated with grazing down through the sward and increase pasture quality through reductions in senescent material and increase in leafy material in the subsequent regrowth cycle (Kolver *et al.* 1999). However, previous work gives no clear response of pre-graze mowing with positive effects on milk production in predominately ryegrass-white clover pasture (Bryant 1982; Holmes and Hoogendoorn 1983; Kolver *et al.* 1999; Irvine *et al.* 2010).

Compared to the standard perennial ryegrass-white clover mixture used on dairy farms, diverse pastures typically contain perennial ryegrass as dominant species and additional herbs such as chicory and plantain. Pre-graze mowing of herbage is one strategy used with which cows can consume pasture that is readily available, but how effective this may be in diverse pastures is unclear.

The objective of this experiment was to determine the effect of pre-graze mowing on milk production and milk composition of mid lactation dairy cows grazing grass-herb-legume pastures managed under contrasting spring defoliation regimes.

5.2 Materials and methods

5.2.1 Experimental site and design

The experimental site was established within a 3.0 ha paddock at the Lincoln University Research Dairy Farm (LURDF) in Canterbury, New Zealand (43°38S’, 172°27E’) with the approval of the Lincoln University Animal Ethics Committee on imperfectly drained Wakanui silt loam over sand (Hewitt 2010). The experimental design was a randomized complete block design with three grazing management and three replicate groups. There were three pasture treatments: (1) Norm (cows graze to a target compressed pasture height of 3.5 cm); (2) Lax (perennial ryegrass reached anthesis and cows graze to a target compressed pasture height of 3.5 cm); and (3) Mow (perennial ryegrass reached anthesis, area was mowed with sickle bar mower to a target compressed height of 3.5 cm five hours prior to cows grazing). Animals were randomly assigned to nine groups, each containing four cows which were randomly allocated to three replicates of three treatments. Thirty-six mid lactation Friesian x Jersey dairy cows were blocked into 9 groups of 4 cows according to milk solids production (2.66 ± 0.004 kg MS/cow/day), live weight (501 ± 23.2 kg), days in milk (79 ± 2.6 days) and age (5.81 ± 0.5 years) (all means ± SEM).

The pastures were established in October 2013 (Table 5.1) and was a mixture of perennial ryegrass, *Lolium perenne* (cv. Arrow AR1); white clover, *Trifolium repens* (cv. Weka); lucerne, *Medicago sativa* (cv. Torlesse); chicory, *Cichorium intybus* (cv. Choice); plantain, *Plantago lanceolata* (cv. Tonic). The pasture was irrigated and fertilised with 35 kg N/ha as urea 14 days before the trial commenced.

Table 5.1 Plant species, cultivar and sowing rate of diverse pasture mixture during the spring season. Pastures were established in October 2013.

Species	Common name	Cultivar	Sowing rate (kg/ha)
Lolium perenne	Perennial ryegrass	Arrow AR1	12.0
Lolium multiflorum	Italian ryegrass	Asset AR37	
Trifolium repens	White clover	Weka	3.0
Medicago sativa	Lucerne	Torlesse	8.0
Cichorium intybus	Chicory	Choice	1.5
Plantago lanceolata	Plantain	Tonic	1.5

The experiment was conducted between September 2015 and November 2015 (early spring to late spring). An initial set-up phase (September to October) in the experimental area was grazed to generate replicated pastures representing each defoliation regime. Grazing was staggered among treatments to ensure the experimental area would be grazed at the same time for the experimental period (November 10-17, 2015). The Norm treatment was grazed to a pasture height of 3.5 cm on 30 September and again on 22 October. The Lax and Mow treatments were grazed to a pasture height of 5 cm on 30 September and again on 17 October. Paddocks were then left to regrow until the start of the experimental period on 10 November 2015 (Table 5.2).

Table 5.2 An initial set-up phase (September–October) in the experimental area was grazed by cows to create different pasture masses, so as to allow the area to be grazed at the same time during the trial period (10–17 November).

Grazing pasture heights shown are target heights. See text for explanation of treatments

Treatment	10 September	30 September	17 October	22 October	10-17 November
Norm	Graze to 3.5 cm	Graze to 3.5 cm	----	Graze to 3.5 cm	Graze to 3.5 cm
Lax	Graze to 3.5 cm	Graze to 5 cm	Graze to 5 cm	---	Graze to 3.5 cm
Mow	Graze to 3.5 cm	Graze to 5 cm	Graze to 5 cm	---	Pre-mow to 3.5 cm

Cows were milked twice daily (approximately 0700 and 1500 h) and were offered a target herbage allowance of 35 kg DM/cow/day above ground level. Cows received one fresh allocation of herbage per day after each afternoon milking. Each daily allocation was back-fenced with temporary electric fencing to prevent grazing of pasture regrowth. Pre-graze mown pastures were cut five hours before the cows were put on the new area. Cows had *ad lib* access to water through a portable water trough. Daily herbage allocation during the experiment was based on estimated herbage mass calibrated against compressed height of a rising plate meter (RPM) where herbage mass (kg DM/ha) corresponded to the manufacturers recommendation for mixed ryegrass pastures of 140 x RPM reading + 500, (Jenquip, Fielding, New Zealand). At least 90 compressed pasture height measurements were taken daily pre- and post-grazing in each allocated area using the RPM.

The RPM was re-calibrated for the current pasture types during the experiment by cutting three random 0.2 m^2 quadrats, per group, pre- and post-grazing to ground level with an electric hand piece every second day (n=144). Two RPM measurements were recorded in each quadrat prior to harvesting the herbage. Cut herbage was oven dried at 60°C for 48h to determine DM content and herbage mass (kg DM/ha). Regression of compressed height against herbage mass resulted in the following non-linear calibration equations: Norm (kg DM/ha) = 1791*ln (RPM height) – 2442, R^2 = 0.83 (n = 48); Lax/Mow (kg DM/ha) = 2129*ln (RPM height) – 3198, R^2 = 0.87 (n = 96). Refusals from the pre-mown treatment were collected in three 1m^2 quadrats in each allocated area every second day during the experiment. Collected refusals were oven dried at 60°C for 48h for determination of

DM content and herbage mass (kg DM/ha). These values were also used in estimating apparent group dry matter intake for the Mow treatment.

Using data derived during the experiment, the actual daily herbage allocation was calculated as 29.7 ± 0.2 kg DM/cow/day for all treatments. Apparent cow group DM intake for Norm and Lax treatments were calculated from the difference between pre- and post-grazing calibrated RPM measurements and areas allocated divided by the number of cows. Apparent group DM intake for Mow treatment was calculated from herbage disappearance between pre- and post-grazing including the refusals collected from the Mow treatment and the areas allocated divided by the number of cows.

5.2.2 Botanical composition and nutritive value

Samples of standing herbage pre-grazing were cut from 15 random points in each replicate area to ground level and to grazing height and post-graze herbage samples were cut to ground level every day of the experiment. Each sample was thoroughly mixed and divided into two subsamples. One subsample of approximately 100g was freeze dried and passed through a 1mm sieve using a ZM200 rotor mill (Retsch Inc., Newtown, Pennsylvania, USA) and analysed for organic matter (OM), crude protein (CP), neutral detergent (NDF) and acid detergent fibre (ADF) digestible DM in OM (DOMD), using near-infrared spectroscopy (Corson *et al.* 1999) calibrated using perennial ryegrass, clover, lucerne, chicory and plantain. Metabolisable energy (ME) was calculated as MJ/kg DM = 0.16 x %DOMD (McDonald *et al.* 2010). The second fresh subsample of approximately 100g was hand sorted into perennial ryegrass, herbs, legumes, weeds and dead material. Samples were then oven dried at 60°C for 48h and weighed and the botanical composition percentage was determined on a DM basis.

5.2.3 Animal measurements

Milk production were recorded daily at both morning and afternoon milking for individual cows with an automated system (DeLavel Alpro Herd management system, DeLavel, Tumba Sweden). Milk samples were collected on days 0, 5, 6, 7, 8 of the experiment. Samples were analysed by Livestock Improvement Corporation Ltd (LIC; Christchurch, New Zealand) to determine milk fat, protein and lactose by MilkoScan (Foss Electric, Hillerød, Denmark).

5.3 Statistical analysis

The effect of grazing management on botanical composition, nutritive value, DMI, milk production and milk composition was analysed by a one-way ANOVA (GenStat 15.1, VSN International Ltd 2012) with grazing management as the fixed term (n=3) and replicates as the random term (n=3). The data point analysed was the mean value averaged across cows and paddocks in each treatment groups. Means were separated using Fisher's protected least significant difference test whenever ANOVA indicated a significant treatment effect.

5.4 Results

The target post-grazing heights for all treatments were 3.5 cm, however actual heights measured for Norm, Lax and Mow treatments were 4.8, 5.3, and 4.6 cm (SEM = 0.32), respectively. Pre-grazing herbage mass was greater (P<0.001) in Lax and Mow treatments compared with Norm (Table 5.3). There was no difference in CP or ME content in pre-graze herbage (sampled to ground level) offered across treatments (Table 5.3). The Lax and Mow treatments had a greater (P=0.04) WSC concentration than the Norm treatment (Table 5.3). The concentration of ADF in herbage was lower (P=0.04) in Norm than Lax at ground level, although no difference in NDF concentration was observed (Table 5.3).

Table 5.3 Pre-grazing herbage mass, pre-grazing forage dry matter (DM), acid detergent fibre (ADF), water-soluble carbohydrates (WSC), digestible DM in organic matter (DOMD), neutral detergent fibre (NDF), organic matter (OM), OM digestibility (OMD), crude protein (CP), metabolisable energy (ME) of Norm, Lax and Mow treatments (see text for explanation of treatments)

	Norm	Lax	Mow^{A}	s.e.m	*P*-value
Pre-grazing herbage mass (kg DM/ha)	3105^{b}	4190^{a}	4108^{a}	84.30	0.001
DM (%)	17.9^{a}	18.3^{a}	21.1^{b}	0.006	0.004
ADF (DM%)	23.2^{b}	24.4^{a}	23.3^{b}	0.24	0.04
WSC (DM%)	22.1^{b}	25.5^{a}	26.7^{a}	0.83	0.04
DOMD (DM%)	76.4	75.9	76.9	0.21	0.07
NDF (DM%)	38.0	41.0	39.6	0.81	0.13
OM (DM%)	91.1^{b}	92.1^{a}	92.0^{a}	0.14	0.01
OMD (DM%)	82.9^{b}	81.5^{a}	82.6^{b}	0.22	0.03
CP (DM%)	17.3	14.9	15.5	0.69	0.14
ME (MJ ME/kg DM)	12.2	12.1	12.3	0.03	0.07

^{A}Forage nutritive value of pre-graze mowed material

Means within the same row with different superscripts are significantly different (P<0.05)

Lax grazing management tended (*P*=0.09) in greater post-grazing herbage mass versus Norm/Mow grazing management. There was no difference in the post-grazing forage composition among treatments except in NDF concentration, which was greater (*P*=0.01) for Mow treatments than Norm and Lax (Table 5.4).

Table 5.4 Post-grazing herbage mass, acid detergent fibre (ADF), water-soluble carbohydrates (WSC), digestible dry matter in organic matter (DOMD), neutral detergent fibre (NDF), organic matter (OM), OM digestibility (OMD), crude protein (CP) and metabolisable energy (ME) of Norm, Lax and Mow treatments.

	Norm	Lax	Mow	s.e.m	*P*-value
Post grazing herbage mass (kg DM/ha)	1591	1802	1524	68.1	0.09
ADF (DM%)	27.1	27.9	28.5	0.29	0.054
WSC (DM%)	28.3	30.4	27.6	1.74	0.56
DOMD (DM%)	73.6	73.1	71.8	0.62	0.22
NDF (DM%)	46.9^{b}	47.6^{b}	49.2^{a}	0.26	0.01
OM (DM%)	92.1	92.8	92.5	0.44	0.60
OMD (DM%)	79.0	78.0	76.9	0.43	0.06
CP (DM%)	10.8	9.5	10.1	0.59	0.39
ME (MJ ME/kg DM)	11.8	11.7	11.5	0.10	0.22

Means within the same row with different superscripts are significantly different (*P*<0.05)

There was no effect of grazing treatment on pre-grazing botanical composition (Table 5.5). Perennial ryegrass accounted for 63% of the herbage mass while legumes and herbs accounted for 14% and 17%, respectively. There are no statistically significant differences between the treatments for any of the species (Table 5.5).

Table 5.5 Botanical composition (% of DM in pre-grazing mass) of Norm and Lax-Mow treatments.

Species	Norm	Lax-Mow	s.e.m	*P*-value
Perennial Ryegrass	59.9	65.8	1.71	0.13
White Clover	9.2	9.1	1.90	0.99
Lucerne	4.8	4.7	0.44	0.88
Chicory	7.1	8.3	1.22	0.56
Plantain	11.4	6.9	0.88	0.07
Dead	7.5	4.7	0.59	0.08
Weeds	0.2	0.4	0.11	0.23

There was no effect of grazing treatment on post-grazing botanical composition, except for greater weeds in the mow treatment (0.74%) compared to norm and lax, 0.06% and 0.22%, respectively (Table 5.6). Perennial ryegrass accounted for 66% of the post-grazing herbage mass while legumes and herbs accounted for 0.23% and 1.6%, respectively. Dead material accounted for 26.1 % of the post-grazing botanical composition. Though not statistically significant, there was a greater amount of white clover in the mow treatment compared to Norm and Lax.

Table 5.6 Botanical composition (% of DM in post grazing mass) of Norm, Lax and Mow treatments.

Species	Norm	Lax	Mow	s.e.m.	*P*-value
Perennial Ryegrass	65.3	70.1	61.9	2.74	0.23
White Clover	3.9	3.4	6.2	1.14	0.29
Lucerne	0.4	0.1	0.2	0.09	0.25
Chicory	2.8	1.1	0.2	0.84	0.20
Plantain	2.0	2.3	1.2	0.79	0.61
Dead	25.7	22.9	29.7	2.19	0.21
Weeds	0.06^{a}	0.22^{a}	0.74^{b}	0.11	0.03

Means within the same row with different superscripts are significantly different ($P<0.05$)

There was no effect of grazing treatment on milk production or milk composition. There was a tendency (*P*=0.07) for reduced milk solids production (kg MS/cow/day) in the Lax and Mow compared with Norm treatments. There was no difference in estimated DMI (*P*=0.95) among all three treatments (Table 5.7).

Table 5.7 Mean milk production and milk composition of Norm, Lax and Mow treatments

Parameter	Norm	Lax	Mow	s.e.m.	*P*-value
Dry Matter Intake (kg DM/cow/day)	16.0	15.2	15.3	7.41	0.95
Milk Production (kg/cow/day)	26.4	25.8	25.1	0.67	0.48
Fat (%)	5.61	5.46	5.36	0.27	0.82
Crude protein (%)	3.71	3.69	3.67	0.06	0.86
Lactose (%)	5.21	5.24	5.25	0.02	0.50
Milk fat production (kg/cow/day)	1.46	1.39	1.34	0.04	0.19
Milk crude protein production (kg/cow/day)	0.97	0.95	0.92	0.01	0.13
Milk lactose production (kg/cow/day)	1.38	1.35	1.32	0.04	0.58
Total milksolids production (kg/cow/day)	2.43	2.34	2.25	0.04	0.07

5.5 Discussion

5.5.1 Herbage DM yield and composition

The grazing management during the set-up phase in early spring was designed to create a difference in pre-grazing herbage mass at the time of the experiment. Pastures that reached anthesis and previously grazed to higher post-grazing herbage mass (*ie.,* Lax and Mow) had a greater pre-grazing herbage mass of 1000 kg DM/ha greater than Norm when pasture when allocated on November 10 (mid Spring). The greater herbage mass was due to a longer regrowth period in Lax/Mow treatments (17 October to 10 November, 24 days) compared to Norm treatment (22 October to 10 November, 17 days). Despite a greater pre-grazing herbage mass (4149 ± 84 kg DM/ha) in Lax and Mow treatments than the Norm treatment, the botanical composition of the herbage offered was very similar. This was inconsistent with Hoogendoorn *et al.* (1992) where high pasture mass have greater dead material (17.6% of DM) than that of lower pasture mass in late spring (9.8% of DM). For example, Hoogendoorn *et al.* (1992) had a high pasture mass of 5.3 t DM/ha compared to a low herbage mass of 2.5 t DM/ha, a difference of 2.8 t DM/ha. However, in this experiment, a 1 tonne difference may not be large enough to cause a significant difference in herbage composition. Also, the senescent material of the pre-grazing herbage sward (0.2% and 0.4% for Norm and Lax/Mow treatment, respectively) was lower in this experiment than those found by (Hoogendoorn *et al.* 1992). The similarity in botanical composition supports the minor differences in chemical composition. However, consistent with Smith (1973) and Waite and Boyd (1953), lax grazing resulted in higher WSC, associated with stem elongation and flower initiation in perennial ryegrass, compared with hard grazing.

Pre-graze mowing resulted in increased DM percentage but no other changes in herbage nutritive value. Irvine *et al.* (2010) found that pre-mown pastures wilted for 12-24 hours resulted in a 3.9% increase in NDF content. In comparison, Kolver *et al.* (1999) found that pre-mown pastures which have been wilted for 24 hours has consistently less NDF than that of control throughout the season. In this experiment, lax and pre-mown, wilted pastures did not differ in the NDF of diet offered. The lack of effect may reflect pasture composition with a high proportion of legumes (14%) and herbs (17%) which, as the plant matures, does not decline in quality or palatability to the same extent as perennial ryegrass (Rutter 2006; Horadagoda *et al.* 2009). Greater effects of treatments on nutritive value might have been expected in ryegrass-white clover pasture with low proportion of legumes or herbs.

5.5.2 Milk production and dry matter intake

In this experiment, the rationale for pre-graze mowing in the Lax treatment was due to concerns over a depression on DM intake during the grazing period in the Lax grazing treatment. It was hypothesised that a lax grazing would lead to higher herbage mass and lower quality pasture; cows would be reluctant to graze into the lower part of sward and depress DMI and ultimately, milk production. It was proposed that mowing would prevent the depression of intake and lead to no effect of lax grazing on DMI. The mowing treatment was designed to test if mowing would increase DM intake and milk production of pasture (Bryant 1982; Holmes and Hoogendoorn 1983; Kolver *et al.* 1999) offered at high herbage mass. However, in this experiment, there was a substantial amount of mown material left in the paddocks from the Mow treatment. On average, 158 kg DM/ha of herbage was refused and suggests pre-graze mowing did not increase DM intake or milk production. The results of the current study is in line with previous work showing that pre-graze mowing of herbage when offered at constant allowance led to reduced milk production compared to pastures that were not mown (Kolver *et al.* 1999; Irvine *et al.* 2010). Although the difference in herbage mass in late spring of close to 1 t DM/ha had little apparent effect (P=0.95) on DMI, CP or ME, there was a trend towards reduced milksolids production, 2.34 and 2.25 kg/cow/day for Lax and Mow, respectively compared to conventional treatment 2.43 kg/cow/day.

The target post-grazing height and mowing height of 3.5 cm was not achieved. Instead, average post-grazing height was 5 cm. This may reflect the allowance offered to the cows. Allowance was 30 kg DM/cow/d; a lower allowance may have helped reach the target post-grazing height. This indicates that cows were able to display some diet selection. Diet selection was evident as herbage composition before grazing was 4.6% legumes and 8.5% herbs, across all treatments compared to 2.4% legumes and 1.6% herbs, after grazing or mowing. Also, a high proportion of dead material across all treatments (26.1%) coincided with greater fibre concentration (47-49%) and lower digestibility (72.8%) of post- grazing herbage compared with pre-grazing herbage (38-41% fibre concentration and 76.4% DOMD).

5.6 Conclusion

While these results showed a lax spring grazing management significantly increased herbage mass due to a longer regrowth period, it had a tendency towards depressed milksolids production. This was not improved by pre-graze mowing. There is no evidence to support the hypothesis that pre-graze mowing herbage increases milk production for dairy cows offered a similar herbage DM allowance.

Chapter 6

Milk production does not benefit from mowing previously lax grazed diverse pastures

Part of this chapter has been published:

Cun GS, Edwards GR, Bryant RH. 2017. Milk production does not benefit from mowing previously lax-grazed diverse pastures. New Zealand Journal of Agricultural Research.

6.1 Introduction

Results from Chapter 5 revealed lenient grazing increased herbage mass but also depressed milk production, which a one-off pre-graze mowing was unable to offset. Chapter 6 will investigate the immediate and carry-over effects of grazing intensity of diverse pastures in spring (Chapter 5) on herbage mass and milk production, with or without the aid of mowing.

Dairy farming, one of New Zealand's largest industries, contributes $14.4 billion NZD of dairy exports to the New Zealand economy (Ballingall and Pambudi 2017). Proposed regulations in NZ are increasing the pressure on intensive pastoral dairy farming to adopt systems that increase productivity and maintain economic viability while reducing environmental footprints, including nitrogen (N) loading into the soil. The inclusion of grasses, legumes (lucerne) and herbs (chicory and plantain) in a diverse mixed sward can reduce urinary N concentration, in lactating dairy cows without negatively affecting milk production (Woodward *et al.* 2013; Edwards *et al.* 2015; Bryant *et al.* 2017) and potentially mitigate the environmental N footprint (Beukes *et al.* 2014). Compared to the conventional perennial ryegrass white clover mixture in a New Zealand farm system, these diverse pasture swards provide a similar herbage DM production and high quality feed throughout the grazing season (Nobilly *et al.* 2013; Woodward *et al.* 2013). Moreover, grazing management regimes which increase herbage DM production indicate improved soil nutrient uptake and a potential role in mitigating nutrient leaching. However, these diverse pastures may require different grazing management strategies than the conventional pasture (Lee *et al.* 2012).

In New Zealand dairy pasture systems, a post-grazing height of 1500 – 1600 kg DM/ha, equivalent to 3.5 – 4.0 cm sward surface height, is recommended for perennial ryegrass-white clover pastures to reduce reproductive material and manage quality (Holmes *et al.* 1992; Hoogendoorn *et al.* 1992). However, others have suggested the adoption of a more lenient management of 5 – 6 cm sward surface height (1700 – 1800 kg DM/ha) in the spring (Matthew *et al.* 1989; Da Silva *et al.* 1994; Hernández Garay *et al.* 1997). A lax defoliation regime which allows the parent grass tiller to reach anthesis prior to mowing or grazing has shown to aid daughter tiller survival and improved persistence ("late control"; Matthew *et al.* 1989; Matthew 1991). With the adoption of a lax grazing regime early in the spring season, Da Silva *et al.* (1994) reported a 20% increase in spring and summer pasture production in ryegrass swards. While this approach may improve the longevity of the ryegrass sward, there is a compromise in pasture quality due to the accumulation of stem material during anthesis. Although quality is compromised in lax grazed ryegrass dominant pastures (Holmes *et al.* 1992; Hoogendoorn *et al.* 1992; Da Silva *et al.* 1994) there are likely to be smaller compromises in quality in a diverse pasture with a high proportion of herbs. However, little research on the optimisation of grazing management practices for dairy cows grazing diverse pastures which contain herbs and alternative legumes has been conducted.

The proposed research is part of an investigation comparing the immediate and carry-over effects of grazing intensity of diverse pastures in spring on herbage mass and milk production with or without the aid of mowing Chapter 5. Initial results revealed lax grazing increased herbage mass but also depressed milk production which one-off pre-graze mowing was unable to offset. The second phase of the study, proposed here in Chapter 6, is to compare the carry-over effect, of having mown or grazed those same pastures, on pasture quality, apparent intake and milk production and evaluate the net benefit of grazing intensity and mowing of diverse pastures in early spring.

6.2 Materials and methods

6.2.1 Experimental site and design

The experiment was conducted at the Lincoln University Research Dairy Farm in Canterbury, New Zealand. The experiment was a completely randomised design with three early spring grazing treatments and three replicates. The three grazing treatments were: Conventional grazing (Norm, pasture consistently grazed to a compressed height of 3.5 cm); Lax grazing (Lax, pasture previously been lax grazed until perennial ryegrass reached anthesis then pasture was grazed to a compressed pasture height of 3.5 cm); and Pre-graze mowing (Mow, pasture previously been lax grazed until perennial ryegrass reached anthesis then pasture was mown to a compressed height of 3.5 cm).

The experimental area (3.0 ha) was an established pasture containing a mixture of perennial ryegrass, *Lolium perenne* (cv. Arrow AR1); white clover, *Trifolium repens* (cv. Weka); lucerne, *Medicago sativa* (cv. Torlesse); chicory, *Cichorium intybus* (cv. Choice); plantain, *Plantago lanceolata* (cv. Tonic). Pasture treatments commenced in early spring (September 2015) when the area was divided into two adjacent 1.5 ha paddocks using permanent fencing material, and these were further divided into 0.75 ha areas using temporary fencing materials. Norm and Lax grazing treatments were randomly allocated within each 1.5 ha area. A large mob of cows (approximately 150 lactating dairy cows), from which experimental animals were later selected, were used to graze pastures to their desired post-grazing height during the pasture preparation period (see Table 6.1 for dates and pasture heights). In November, all treatment areas were grazed or mown to a post-grazing compressed height of 5 cm to investigate the immediate effect of grazing management on milk production and pasture production and these results are reported in Chapter 5. Following the experiment in Chapter 5, the experimental cows were returned to the main mob of cows and the experimental area was left to regrow until 14 December 2015 when the present experiment (Chapter 6) commenced. During the regrowth period the area was irrigated and fertilised with urea at a rate of 45 kg N/ha (Table 6.1).

Table 6.1 **An initial set-up phase (Sep-Oct) in the experimental area was grazed by dairy cows to create different pasture masses to allow the area to be grazed at the same time during the trial period in Nov. Then in Dec, an experiment was designed to determine the effects of pre-graze mowing in the subsequent grazing rotation.**

Grazing pasture heights shown are target compressed heights

Treatment	10-Sep	30-Sep	17-Oct	22-Oct	10-17 Nov	14-21 Dec
Norm	Graze to 3.5 cm	Graze to 3.5 cm	----	Graze to 3.5 cm	Graze to 3.5 cm	Graze to 3.5 cm
Lax	Graze to 3.5 cm	Graze to 5 cm	Graze to 5 cm	---	Graze to 3.5 cm	Graze to 3.5 cm
Mow	Graze to 3.5 cm	Graze to 5 cm	Graze to 5 cm	---	Pre-mown to 3.5 cm	Graze to 3.5 cm

6.2.2 Animals

Animals for this study were reselected from the main mob of cows based on covariate measurements carried out ten days prior to the study. Twenty-seven mid lactation Friesian x Jersey dairy cows were blocked into nine groups of three cows according to milk solids production (1.78 ± 0.01 kg MS/cow/day), live weight (473.8 ± 8.6 kg), days in milk (114.6 ± 1.8 days) and age (4.92 ± 0.4 years) (all means ± SEM). Each group, containing three cows, was randomly allocated to three replicates for each treatment. Cows had *ad lib* access to water through a portable water trough which was shifted daily. Cows were milked twice daily (approximately 0700 and 1500 h) and offered a target herbage allowance of 35 kg DM/cow/day above ground level based on herbage mass measured with an (RPM). Cows received a new allocation daily following the afternoon milking. Herbage allocation during the experiment was based on pasture mass as estimated daily by RPM compressed height which was recorded daily pre- and post- grazing. Because the pastures consisted of 60% ryegrass and clover, the RPM manufacturers calibration (i.e., kg DM/ha = 140 x RPM reading + 500, where an RPM reading = 0.5 cm unit) was used to determine grazing area allocation.

6.2.3 Herbage measurements

Herbage mass was determined retrospectively from calibration harvests collected throughout the study. To calibrate the RPM, a 0.2 m^2 quadrat was placed randomly onto the pasture and two RPM measurements were recorded in the quadrat area. All herbage was harvested to ground level, washed, oven dried and weighed. Best fit regression between RPM and harvested DM production was used to derive calibrations for each treatment:

Norm (kg DM/ha) = 2865*ln (RPM height) – 4891, R^2 = 0.85 (n = 45),
Lax (kg DM/ha) = 2172*ln (RPM height) – 3367, R^2 = 0.68 (n = 45)
Mow (kg DM/ha) = 2252*ln (RPM height) – 3559, R^2 = 0.67 (n = 45).

Apparent herbage DMI was determined from herbage DM disappearance between pre-graze mass and post-graze mass.

Herbage samples for nutritive analysis were collected daily by cutting standing pasture to ground level from random locations (n=15) pre- and post-grazing in each daily herbage allocation. Samples were mixed and divided into two subsamples. One subsample of approximately 100g was freeze dried and passed through a one mm sieve (ZM200 rotor mill Retsch Inc., Pennsylvania, USA) and analysed for chemical composition and *in vitro* organic matter digestibility in the dry matter (DOMD) using near-infrared spectroscopy (NIRS; Model: NIRSystems 5000, Maryland, USA) by the Lincoln University Analytical Laboratory and had been calibrated using pasture species similar to those in this experiment. Metabolisable energy (ME) was calculated as ME MJ/kg DM = 0.16 x %DOMD (McDonald *et al.* 2010). The second fresh subsample of approximately 100g was hand sorted into perennial ryegrass, herbs, legumes, weeds and dead material. Samples were then oven dried at 60°C for 48h and weighed and the botanical composition percentage was determined on a DM basis.

Apparent herbage DMI was determined from herbage DM disappearance between pre-graze mass and post-graze mass. Herbage mass was estimated using calibrated readings of compressed height of the RPM. To calibrate the RPM, a 0.2 m^2 quadrat was placed randomly onto the pasture and two RPM measurements were recorded in the quadrat area. All herbage was harvested to ground level, washed, oven dried and weighed. This process was repeated in all allocations before and after grazing resulting in 135 quadrat cuts. Best fit regression between RPM and harvested DM production was used to derive calibrations for each treatment. The calibration equation used for the Norm treatments were: kg DM/ha = 2865*ln (RPM height) – 4891, R^2 = 0.85 (n = 45), the calibration equation used for the Lax treatments were: kg DM/ha = 2172*ln (RPM height) – 3367, R^2 = 0.68 (n = 45) and the calibration equation used for the Mow treatments were: 2252*ln (RPM height) – 3559,

$R^2 = 0.67$ (n = 45). Using data derived during the experiment, the actual daily herbage allocation was calculated as 34.9 ± 0.13 kg DM/cow/d for all treatments.

Accumulated herbage mass for the entire period was the sum of the difference between pre- and post-graze mass at each grazing event between September and December. Estimation of herbage mass accounted for the change in sward structure over time using three sets of calibrations for each treatment. During the preparation period from September to October, herbage mass (kg DM/ha) was estimated using the RPM manufacturers equation. Herbage mass in November was calculated using equations developed in Chapter 5. Herbage mass in December was determined using calibrations from the present trial stated above.

6.2.4 Animal measurements

Milk production was recorded daily at both morning and afternoon milking for individual cows with an automated system (DeLavel Alpro Herd management system, DeLavel, Tumba Sweden). Milk samples were collected on days 0, 5, 6, 7 and 8 of the experiment. Samples were analysed by Livestock Improvement Corporation Ltd (LIC; Christchurch, New Zealand) to determine milk fat, protein and lactose by MilkoScan (Foss Electric, Hillerød, Denmark).

6.3 Statistical analysis

The effect of grazing management on botanical composition, nutritive value, pasture regrowth, herbage mass, DMI, milk production and milk composition was analysed by a one-way analysis of variance (ANOVA) with three replicates (GenStat 15.1, VSN International Ltd 2012). Pooled means for animals and days were used in the analysis which was carried out on nine experimental units (3 treatments x 3 replicates). Means were separated using Fisher's protected least significant difference test whenever ANOVA indicated a significant treatment effect.

6.4 Results

There was no treatment effect on botanical composition. The most dominant species was perennial ryegrass which accounted for half the biomass with respective proportions of legumes, herbs, dead material and weeds at 22.4, 18.7, 8.8 and 0.16%, of the DM (Table 6.2). There are no statistically significant differences between treatments for any of the species (Table 6.2).

Table 6.2 Botanical composition (% of DM in pre-grazing mass) of Norm, Lax and Mow treatments.

	Norm	Lax	Mow	s.e.m	*P*-value
Perennial Ryegrass	52.3	44.9	52.9	2.46	0.14
White Clover	10.7	10.1	10.6	2.30	0.98
Lucerne	9.4	16.8	9.5	4.20	0.44
Chicory	6.1	4.6	10.0	3.80	0.62
Plantain	12.8	12.8	9.8	3.15	0.75
Dead	8.5	10.8	7.1	1.17	0.20
Weeds	0.3	0.1	0.1	0.13	0.66

In the previous grazing rotation, the grazing and mowing treatments achieved a common compressed post- grazing height of 5 cm (P>0.05) which was greater than the targeted height of 3.5 cm. Following grazing or mowing, herbage growth rates, herbage mass or herbage chemical composition were not affected by previous grazing treatment (Table 6.3). Additionally, there were no differences in post-grazing herbage mass nor herbage chemical composition among treatments (Table 6.3), due to similar post-grazing height of 5.1, 5.2, 5.0 ± 0.14 cm in this experiment for Norm, Lax and Mow, respectively. The accumulated yield for the spring period (September to December) was greatest (P<0.01) for Lax managed pastures (11,657 ± 284 kg DM/ha) compared to Mow (10,751 ± 202 kg DM/ha) or Norm (10,574 ± 79 kg DM/ha).

Table 6.3 Pasture regrowth, pre- and post-grazing herbage mass, pre- and post-grazing forage dry matter (DM), acid detergent fibre (ADF), water-soluble carbohydrates (WSC), digestible DM in organic matter (DOMD), neutral detergent fibre (NDF), organic matter (OM), organic matter digestibility (OMD), crude protein (CP), metabolisable energy (ME) of Norm, Lax and Mow treatments.

	Norm	Lax	Mow	s.e.m	*P*-value
Pasture regrowth (kg DM/ha/d)	40.8	38.5	36.8	8.31	0.94
Pre-grazing pasture					
Pre-graze herbage mass (kg DM/ha)	3614	3582	3401	171.90	0.67
DM (%)	16.3	16.2	14.9	0.004	0.13
ADF (% DM)	26.4	26.7	25.1	0.47	0.15
WSC (% DM)	16.3	15.6	16.9	0.45	0.24
DOMD (% DM)	71.3	70.8	73.1	0.72	0.19
NDF (% DM)	39.3	38.6	36.3	1.16	0.29
OM (% DM)	91.5	91.7	91.3	0.20	0.44
OMD (% DM)	76.6	75.9	78.4	0.74	0.16
CP (% DM)	16.3	17.3	18.2	0.50	0.14
ME (MJ ME/kg DM)	11.4	11.3	11.7	0.12	0.19
Post-grazing pasture					
Post-graze herbage mass (kg DM/ha)	1742	1728	1616	98.10	0.64
ADF (% DM)	30.6	32.1	30.7	0.58	0.22
WSC (% DM)	18.4	17.9	18.2	0.98	0.95
DOMD (% DM)	67.5	65.6	67.4	0.81	0.31
NDF (% DM)	48.8	50.8	47.5	0.82	0.10
OM (% DM)	92.3	92.5	92.2	0.12	0.36
OMD (% DM)	72.0	69.7	71.7	0.93	0.28
CP (% DM)	12.2	11.3	12.5	0.65	0.50
ME (MJ ME/kg DM)	10.8	10.5	10.8	0.13	0.31

Using herbage mass data derived during the experiment, and grazing area, the actual daily herbage allocation was calculated as 34.9 ± 0.13 kg DM/cow/d above ground level, for all treatments. Apparent DMI was unaffected by pasture treatments. Milk production (20.1 kg/cow/d) and milksolids (1.85 kg MS/cow/d) was unaffected by treatment (Table 6.4). Overall, there was no effect of grazing management on average milk production across the two grazing events (Chapter 5 and Chapter 6). Combined milk production for Norm, Lax and Mow were 45.89, 46.26, 45.38 ± 0.36 kg/cow/d, respectively (*P*=0.32). Also, grazing management had no effect on milksolids across the two grazing events where combined average milksolids for Norm, Lax and Mow were 4.23, 4.21, 4.12 ± 0.04 kg MS/cow/d, respectively (*P*=0.28).

Table 6.4 Mean milk production, milk composition and estimated dry matter intake of Norm, Lax and Mow treatments.

	Norm	Lax	Mow	s.e.m	*P*-value
Dry matter intake (kg DM/cow/d)	18.01	17.97	18.08	0.30	0.97
Milk production (kg/cow/d)	19.50	20.46	20.26	0.62	0.57
Combined average milk production (kg/cow/d)*	45.89	46.26	45.38	0.36	0.32
Fat (%)	5.36	5.33	5.25	0.30	0.96
Protein (%)	3.95	3.85	3.96	0.06	0.41
Lactose (%)	5.13	5.08	4.95	0.07	0.29
Milk fat production (kg/cow/d)	1.04	1.09	1.06	0.03	0.68
Milk protein production (kg/cow/d)	0.76	0.79	0.80	0.02	0.26
Milk lactose production (kg/cow/d)	1.00	1.04	1.00	0.04	0.73
Total milksolids (kg MS/cow/d)	1.80	1.87	1.87	0.02	0.17
Combined average milksolids (kg MS/cow/d)*	4.23	4.21	4.12	0.04	0.28

*Combined milk production and milksolids from both Chapter 5 and 6 have been included

6.5 Discussion

This experiment was designed to test the carryover effects of a one-off pre-graze mown diverse pastures, compared with grazing only, on nutritive value, DMI and milksolids production. It was hypothesised that a one-off pre-graze mown pastures in the previous grazing rotation would result in an improved herbage quality of the regrowth material which would lead to greater nutrient intake, increase apparent DMI and greater milksolids production, compared to treatments that only used grazing to control herbage mass. However, in this experiment, grazing management treatments resulted in similar nutritive value and no difference in DMI and consequently no change in milk production when herbage was offered at the same allowance.

Both Bryant (1982) and Kolver *et al.* (1999) concluded that pre-graze mowing of ryegrass and white clover pastures resulted in improved milk production of at least 5% in the subsequent grazing due to improved pasture quality and more uniform grazing. The lack of treatment effect in the current study might be explained by similar post-defoliation sward heights from the previous grazing (5 cm) resulting in similar regrowth characteristics of the herbage (38.7 kg DM/ha/d) and no differences in herbage quality.

Due to the large proportion of dead material and reproductive stem content on pasture-based systems in the summer, energy is often the most limiting nutrient for dairy cows. However, the metabolisable energy content of these diverse pastures was greater (> 11.3 MJ ME/kg DM) than that found by Kolver *et al.* (1999) in their ryegrass white clover pastures for the summer period (9 – 10 MJ ME/kg DM). A diverse pasture is able to maintain a high nutritive value (Ulyatt *et al.* 1976; Barry 1998) and possibly alleviate the magnitude of low energy levels relative to ryegrass. In this experiment, these diverse pastures maintained a ME ≥ 11.3 MJ ME/kg DM. Kolver and Muller (1998) reported a greater milk production is associated with a greater nutrient intake. With the inclusion of alternative legumes and herbs, pasture quality is generally improved to possibly offset the nutritive value and perhaps no great effects in milksolids production.

There was no statistical difference in herbage growth rates or pre-graze herbage mass, though pre-graze herbage mass of mown pastures was numerically (200 kg DM/ha) lower than the conventional ‘Norm’ grazing treatment. Cows in mown treatments were also able to achieve a numerically lower post-grazing herbage mass compared with grazed only treatments which maintained a consistent DM intake across treatments. This raises questions around the cumulative effect of frequent mowing on herbage regrowth and pasture quality. In this study, a one-off mowing to return pastures to an acceptable post-grazing height resulted in similar regrowth between treatments in a single rotation, but over the entire period from September to December accumulated pasture growth was similar for Mow and Norm, and greatest for lax-managed pastures.

In this experiment, the combination of similar post-grazing (5 cm) from the previous grazing rotation and a diverse pasture mixture, an adequate supply of herbage with an adequate nutritive value was available and possibly explain why milk production was similar across all treatments. The plant nutritive value in these diverse pastures may not be of a sufficient magnitude to affect spring management practices.

6.6 Conclusion

This study showed that if grazing or mowing achieved similar post-grazing heights in the previous grazing event, the subsequent quality of regrowth of diverse pastures is unlikely to be affected by early spring grazing management. The similarity in herbage quality results in similar milk production when offered at the same allowance. It has been demonstrated in the current study and our previous study, diverse pastures can be maintained to a greater herbage mass with reproductive development in spring without affecting milksolids production when grazed in the summer.

Chapter 7

Farm system modelling using different grazing management strategies with diverse pastures within an irrigated dairy farm system

Part of this chapter has been published:

Cun GS, Al-Marashdeh O, Edwards GR. 2018. Whole-farm modelling using different grazing-management strategies with diverse pastures within an irrigated dairy-farm system. New Zealand Journal of Animal Science and Production 78, 1-5.

7.1 Introduction

The previous chapters highlighted the effect of specific grazing management regimes throughout the year on DM production, botanical composition and nutritive value. Chapter 7 focuses on the physical and economic feasibility of incorporating diverse pastures at a farm system level using data derived from earlier chapters (i.e., results from chapter 3).

Dairy farming in New Zealand is primarily based on grazed pastures comprised of perennial ryegrass and white clover mixture. However, such a sward mix is subjected to seasonal variations in growth rate and nutrient composition, causing herbage to be insufficient to meet the animal requirements during some periods (Burke *et al.* 2002b). The inclusion of grasses, legumes and herbs in a diverse mix sward has the potential to provide a more even distribution of dry matter production and feed quality throughout the grazing season (Sanderson *et al.* 2007; Nobilly *et al.* 2013) compared with the conventional perennial ryegrass white clover mixture. In addition to the sward mixture, grazing management such as lenient grazing could be used as a strategy to produce more DM per ha (Da Silva *et al.* 1994; Matthew *et al.* 2000) and results from Chapter 3. Conducting farm scale experiments is costly, and the variation can be large between years requiring continuous measurements over a sustained period. Modelling the farm systems provides an opportunity to assess changes in management practises using long term models. There is limited research available on grazing management of diverse mixed swards with a low adoption from farmers due to inappropriate management practices.

Grazing management strategies are designed to ensure a year-round balance of forage supply and demand to reduce the effect of seasonal and annual variability in weather. However, quantifying the usefulness of given strategies in a farming system and for multiple seasons is risky and expensive.

Computer models are increasingly being used to simulate farming systems. Results of simulations are used to complement experimental studies and help to understand the implications of various management options in different environmental conditions (Snow *et al.* 2014). Farmax Dairy Pro is a simulation model which predicts the effects of farming system changes on production and financial performance (Bryant *et al.* 2010). It enables feed supply and demand to be estimated in a farm system. However, evaluation is lacking for diverse pasture mixtures that includes herbs and alternative legumes managed by various grazing management.

In Chapter 3, we identified growth rates based on different grazing management strategies and pasture mixture types. However, the effect of these pasture mixes and grazing managements on farming system profitability is still unclear. Therefore, the objective of this study was to use a commercial modelling tool: Farmax Dairy Pro, to determine the profitability of Canterbury dairy farms with various grazing management strategies on diverse pasture mixtures.

7.2 Materials and methods

7.2.1 Data collection and measurements

Briefly, herbage data for the model were collected from Chapter 3. Two years of herbage growth and nutritive value data were obtained from irrigated plots sown with a pasture mixture consisting of perennial ryegrass, white clover, red clover, chicory and plantain (diverse) or the same pasture mixture plus Italian ryegrass (diverse + Italian) in a 2 x 3 randomised block design. The two pasture types was grazed in three specific regimes: (1) conventional grazing, where cows grazed to a compressed pasture height of 3.5 cm year-round, (2) autumn lenient grazing, where cows grazed to a compressed pasture height of 5 cm during autumn before a switch to 3.5 cm for the remainder of the year and (3) spring lenient grazing, where cows grazed to a compressed pasture height of 5 cm during spring before a switch to 3.5 cm for the remainder of the year. All plots were subjected to a rotational grazing, and herbage growth rate (kg DM/ha/d) was calculated from the difference between pre-grazing herbage mass from the current grazing event and post-grazing herbage mass from the previous grazing event, divided by the number of days between pre-grazing herbage mass and post-grazing herbage mass. Pre- and post-grazing herbage mass was measured directly using quadrat cuts. Pre- and post-grazing herbage samples (n = 2043, where n=3 pre- and post-grazing cuts/plot at each harvest) were cut to the ground level and oven dried at 60°C for 48 hours for determination of DM herbage production. These samples were then ground through 1-mm sieve using a ZM200 rotor mill (Retsch Inc., Newtown, Pennsylvania, USA). The herbage digestible organic matter (DOM) content was determined using near infrared spectroscopy (NIRS; Foss Feed and Forage Analyser 5000, Maryland, USA). Metabolisable energy (ME) of pre- and post-grazing herbage samples was estimated based on the equation ME (MJ/kg DM) = 0.16 x DOM (% in DM). The ME of the diet was estimated based on the equation ME (MJ/kg DM) = [($ME_{pre\text{-}grazing\ herbage}$ *pre-grazing herbage mass) – ($ME_{post\text{-}grazing\ herbage}$*post-grazing herbage mass)]/ (pre-grazing herbage mass – post-grazing herbage mass) (Dalley *et al.* 1999).

7.2.2 Modelling sceanrios

The herbage growth (kg DM/ ha/d) and quality (ME of diet MJ/kg DM) data were then fitted to a base farm model using Farmax Dairy Pro. (Version 6.6.5.0, FARMAX, Waikato Innovation Park, Hamilton, New Zealand), resulting in six different farm scenarios:

(1) diverse pasture + conventional grazing (CG),

(2) diverse pasture + autumn lenient grazing (AL),

(3) diverse pasture + spring lenient grazing (SL),

(4) diverse pasture + Italian ryegrass + conventional grazing (CG + Ita),

(5) diverse pasture + Italian ryegrass + autumn lenient grazing (AL + Ita),

(6) diverse pasture + Italian ryegrass + spring lenient grazing (SL + Ita).

7.2.3 Base model and management assumptions

The base farm model was a representative of the average farm system in the North Canterbury region with an effective area of 229 ha (LIC 2015) and irrigated by a centre pivot irrigator. Physical assumptions used for this model included dairy breed (Holstein-Friesian × Jersey crossbred cows of mixed age), stocking rate (3.4 cows/ha), and milksolids (MS; milk fat + milk protein) production (416 kg MS/cow/year) and nitrogen fertiliser application rate (150 kg N/ha/year) (Table 7.1). Replacement stock were reared off farm and wintering cows (non-lactating cows during the winter period) were moved off the milking platform from late May and returned 5 to 10 days before calving. Planned calving date was to start on 1 August, with cows achieving peak milk production in spring, mid-October. The dry-off date was in autumn (May 28) resulting in an average lactation length of 261 days for the herd. All farm scenarios were subjected to the same physical assumptions and modelled to produce the same milksolids production (Table 7.1). Surplus pasture was managed to be cut for silage. Herbage growth and animal demand were matched, and feed deficits were filled by purchasing more feed (i.e. pasture silage). The body condition 4.8 before calving and 4.1 at drying off in May. Farm scenarios were ranked and compared by profit expressed as earnings before tax.

Table 7.1 Physical summary of all farm system scenarios in diverse pasture for a Canterbury dairy farm for the 2015-2016 season.

Grazing area	229	ha
Stocking rate	3.4	cows/ha
Nitrogen fertiliser	150	kg N/ha
Cow numbers 1st June	796	cows
Days in milk	261	days
Average body condition score at calving	4.8	BCS
Milksolids per cow	416	kg/cow

7.2.4 Operating costs and expenditures

Farm profitability, measured as farm operating profit, was calculated as: total revenue (from net milk sales, livestock sales and net capital value changes) - total farm working expenses, where total farm working expenses = sum of (labour/wages expenses, livestock expenses, feed expenses, cost incurred for grazing livestock replacements off farm, expenses such as fertilizer, nitrogen, irrigation, weed and pest control, vehicle expenses, overhead expenses including administration, insurance, rates and depreciation). Operating costs and dairy farm expenditure were sourced from Farmax for dairying in the Canterbury region in 2013-2014 (Table 7.2). The milk price was set at NZ $6.00 per kg MS, in accordance with the long-term average milk sale price across the main NZ dairy companies (NZ$6.11 MS; LIC 2015).

Table 7.2 Operating costs and dairy farm expenditures taken from the Farmax model of the Canterbury region

FARMAX YOUR ADVANTAGE

Canterbury 2013-14

Jun 15 - May 16

($/year)		Model (tick to use)		Timing	$ Total	$ / ha (229)	$ / Cow (785)	$ / kg MS (326,280)
Wages	Wages			Monthly	196,250	857	**250**	0.601
	Management Wage			Monthly	104,405	456	**133**	0.320
	Total Wages				**300,655**	**1,313**	**383**	**0.921**
Stock	Animal Health	**70,708**	☑	As Inc...	70,708	309	90	0.217
	Breeding	**19,036**	☑	As Inc...	19,036	83	24	0.058
	Farm Dairy	**12,322**	☑	As Inc...	12,322	54	16	0.038
	Electricity			Monthly	29,045	127	**37**	0.089
	Total Stock				**131,111**	**573**	**167**	**0.402**
Feed	Pasture Conserved	**4,840**	☑	As Inc...	4,840	21	6	0.015
	Cash Crop	**0**	☑	As Inc...	0	0	0	0.000
	Feed Crop	**27,600**	☑	As Inc...	27,600	121	35	0.085
	Bought Feed	**77,935**	☑	As Inc...	77,935	340	99	0.239
	Calf Feed	**4,574**	☑	As Inc...	4,574	20	6	0.014
	Total Feed				**114,949**	**502**	**146**	**0.352**
Grazing	Grazing	**331,727**	☑	As Inc...	331,727	1,449	423	1.017
	Run-Off Lease			Monthly	26,690	117	**34**	0.082
	Owned Run-Off Adjustment			Monthly	56,334	**246**	72	0.173
	Total Grazing & Run-Off				**414,751**	**1,811**	**528**	**1.271**
Other Working	Fertiliser (Excl. N)			Oct, Apr	161,216	**704**	205	0.494
	Nitrogen	**73,610**	☑	As Inc...	73,610	321	94	0.226
	Irrigation			Monthly	2,290	**10**	3	0.007
	Regrassing	**0**	☑	As Inc...	0	0	0	0.000
	Weed & Pest			Monthly	8,244	**36**	11	0.025
	Vehicles			Monthly	47,174	**206**	60	0.145
	Fuel			Monthly	0	**0**	0	0.000
	R&M Land & Buildings			Monthly	95,264	**416**	121	0.292
	R&M Plant & Equipment			Monthly	0	**0**	0	0.000
	Freight			Monthly	16,488	**72**	21	0.051
	Other Expenses			Monthly	**0**	0	0	0.000
	Total Other Farm Working				**404,286**	**1,765**	**515**	**1.239**
Overheads	Administration			Monthly	20,610	**90**	26	0.063
	Insurance			Jul, Jan	15,114	**66**	19	0.046
	ACC			Jul, Jan	8,931	**39**	11	0.027
	Rates			Jul, Oc...	16,946	**74**	22	0.052
	Total Overheads				**61,601**	**269**	**78**	**0.189**
Depreciation				Monthly	95,035	**415**	121	0.291
Total Operating Expenses					**1,522,388**	**6,648**	**1,939**	**4.666**
Other	Rent/Lease			Monthly	**0**	0	0	0.000
	Interest			Monthly	**0**	0	0	0.000
	Principal			Monthly	**0**	0	0	0.000
	Drawings			Monthly	**0**	0	0	0.000
	Taxation			Monthly	**0**	0	0	0.000
	Total Other Expenses				**0**	**0**	**0**	**0.000**
Total Expenses					**1,522,388**	**6,648**	**1,939**	**4.666**

7.2.5 Herbage growth rate and nutritive value

The monthly average growth rates (kg DM/ha/day) from 2015-2017 for all farm scenarios are shown in Figure 7.1.

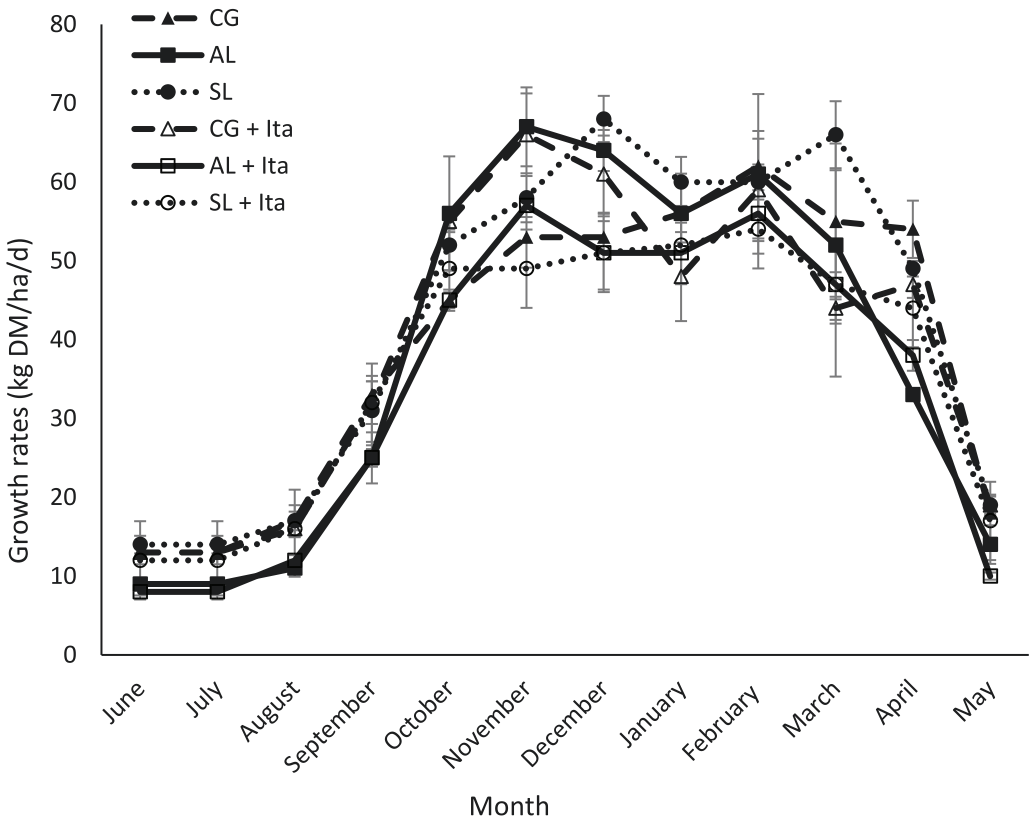


Figure 7.1 Monthly average growth rates (kg DM/ha/day) for two pasture mixtures and three grazing management regimes. CG, conventional grazing diverse pasture; AL, autumn lenient grazing diverse pasture; SL spring lenient grazing diverse pasture; CG + Ita, conventional grazing of diverse pasture with Italian ryegrass; AL + Ita, autumn lenient grazing of diverse pasture with Italian ryegrass; SL + Ita, spring lenient grazing of diverse pasture with Italian ryegrass. Bars indicated standard error of the means.

The monthly average ME (MJ ME/kg DM) for all farm scenarios from 2015-2017 are presented in Table 7.3. The average ME for all farm scenarios was 12.9 MJ ME/kg DM during spring (September to November), 11.8 MJ ME/kg DM during summer (December to February), 12.1 MJ ME/kg DM during autumn (March to May) and 12.8 MJ ME/kg DM during winter (June to August) (Table 7.3).

Table 7.3 Effects of grazing management and pasture mixture on monthly pasture metabolisable energy (MJ ME/kg DM).

	Farm Scenarios[1]					
Month	**CG**	**AL**	**SL**	**CG + Ita**	**AL + Ita**	**SL + Ita**
January	11.6 ± 0.64	11.1 ± 0.16	12.2 ± 0.05	11.1 ± 0.24	11.9 ± 0.66	12.3 ± 0.41
February	10.7 ± 0.31	11.6 ± 0.26	11.6 ± 0.27	11.4 ± 0.36	12.1 ± 0.40	12.2 ± 0.25
March	11.2 ± 0.25	11.4 ± 0.42	11.1 ± 0.54	11.1 ± 0.31	12.4 ± 0.13	12.0 ± 0.23
April	11.8 ± 0.51	12.3 ± 0.32	11.0 ± 0.18	12.9 ± 0.35	12.7 ± 0.28	10.9 ± 0.21
May	12.6 ± 0.40	12.4 ± 0.42	12.7 ± 0.02	12.9 ± 0.19	12.8 ± 0.15	12.8 ± 0.03
June	12.7 ± 0.34	12.5 ± 0.40	12.8 ± 0.02	13.0 ± 0.07	12.9 ± 0.13	12.7 ± 0.08
July	12.7 ± 0.34	12.5 ± 0.40	12.8 ± 0.02	13.0 ± 0.07	12.9 ± 0.13	12.7 ± 0.08
August	12.9 ± 0.30	12.6 ± 0.38	13.0 ± 0.05	13.2 ± 0.05	13.0 ± 0.11	12.7 ± 0.17
September	12.9 ± 0.16	12.8 ± 0.34	13.2 ± 0.11	12.6 ± 0.20	13.2 ± 0.07	12.4 ± 0.24
October	12.7 ± 0.06	12.8 ± 0.34	12.7 ± 0.31	12.6 ± 0.20	13.2 ± 0.07	12.4 ± 0.24
November	13.8 ± 0.59	12.6 ± 0.25	13.1 ± 0.34	13.2 ± 0.03	13.3 ± 0.05	13.1 ± 0.12
December	12.2 ± 0.45	11.9 ± 0.19	11.7 ± 0.20	12.3 ± 0.41	12.3 ± 0.58	12.5 ± 0.23

[1]CG, conventional grazing; AL, autumn lenient grazing; SL spring lenient grazing; CG + Ita, conventional grazing of diverse pasture with Italian ryegrass; AL + Ita, autumn lenient grazing of diverse pasture with Italian ryegrass; SL + Ita, spring lenient grazing of diverse pasture with Italian ryegrass. Values are treatment means within the month ± standard error of the means.

7.3 Results

7.3.1 Model outputs and financial performance

The Farmax model output for herbage DM production, supplement usage and production, and cost and production are presented in Table 7.4.

On average, pastures managed by lenient grazing in autumn resulted in the lowest annual DM production (12.7 t DM/ha) compared to pastures managed by conventional grazing (14.0 t DM/ha) and spring lenient grazing (14.1 t DM/ha; Table 7.4).

In the diverse pasture mixture, average annual herbage DM production increased by 1.0 t DM/ha when leniently grazed in spring compared to conventional grazing. In diverse pasture mixtures with Italian ryegrass, pastures managed by conventional grazing resulted in the greatest amount of herbage DM produced (13.9 t DM/ha) compared to spring lenient (13.2 t DM/ha) and autumn lenient management (12.0 t DM/ha) (Table 7.4).

Profit was numerically higher for diverse pastures managed leniently in spring (NZ$2658/ha) compared with other scenarios (average NZ$2261/ha). The greater profit in diverse pastures managed leniently in spring was driven by greater annual herbage DM production (15.0 vs 13.3 t DM/ha in other scenarios) and less purchased feed required to meet cow requirement (NZ$0/ha vs NZ$404/ha) compared to other scenarios, respectively. The lenient grazing of diverse pasture was the only scenario that resulted in a surplus feed supply (NZ$3145/year; Table 7.4)

The amount of supplement offered varied among the farm scenarios, ranging from 0.4 t DM/ha to 3.1 t DM/ha. Pastures managed by lenient grazing in autumn resulted in the greatest amount of supplement fed (average 2.9 t DM/ha) compared to pastures managed conventionally or leniently in spring (average 1.9 and 1.2 t DM/ha, respectively; Table 7.4).

Table 7.4 **Farmax model output from whole farm modelling using an average North Canterbury farm system with three grazing managements and two pasture mixtures on an irrigated 229 ha dairy farm. Operating profit is based on a milk price of NZ$6.00/kg milksolids at 3.4 cows/ha stocking rate and milksolids production of 416 kg MS/cow/yr.**

Farm	Conventional grazing diverse	Autumn lenient grazing diverse	Spring lenient grazing diverse	Conventional grazing diverse + Italian ryegrass	Autumn lenient grazing diverse + Italian ryegrass	Spring lenient grazing diverse + Italian ryegrass
Grazing area (ha)	229	229	229	229	229	229
Stocking rate (cows/ha)	3.4	3.4	3.4	3.4	3.4	3.4
Annual herbage production (t DM/ha)	14.0	13.4	15.0	13.9	12.0	13.2
Nitrogen fertiliser (kg N/ha/yr)	150	150	150	150	150	150
Herd						
Cow numbers 1st July (cows)	796	796	796	796	796	796
Days in milk (days)	261	261	261	261	261	261
Average body condition score at calving (BCS)	4.9	4.6	5.0	5.0	4.9	4.8
Milk production						
Milksolids per cow (kg/cow)	416	416	416	416	416	417
Feeding						
Pasture offered (t DM/cow)	3.8	3.7	4.1	3.8	3.4	3.8
Supplements offered (t DM/cow)	0.5	0.7	0	0.4	0.8	0.5
Pasture offered (t DM/ha)	13.2	12.9	14.2	13.5	11.9	12.8
Supplements offered (t DM/ha)	2.1	2.6	0.4	1.7	3.1	1.9
Cost of purchased feeds (NZ$/ha)	340	484	0	262	597	335
Pasture conserved (NZ$21/ha)	4840	0	4840	4840	0	0
Surplus feeds (NZ$40/ha)	0	0	3145	0	0	0
Operating profit (NZ$/ha)	2309	2194	2658	2400	2067	2337

7.4 Discussion

The previous chapters examined the effects of various defoliation management throughout the grazing season on DM production, nutritive value, and milk production. This chapter considered the effects on profitability at a farm systems level.

These diverse swards were able to maintain a greater nutritive value regardless of grazing management. The average ME for all farm scenarios was 12.9 MJ ME/kg DM during spring (September to November), 11.8 MJ ME/kg DM during summer (December to February), 12.1 MJ ME/kg DM during autumn (March to May) and 12.8 MJ ME/kg DM during winter (June to August). These values are comparable with the study of Nobilly *et al.* (2013) who reported ME of diverse pasture ranged from 11.5 to 12.9 MJ ME/kg DM depending on the season. Conventional grazing of diverse pastures had the lowest metabolisable energy (11.2 MJ ME/kg DM or 157 GJ ME/ha/year) than other management scenarios (12.2 MJ ME/kg DM or 174 GJ ME/ha/year). Diverse pastures with Italian ryegrass had greater metabolisable energy than diverse pasture mixtures without Italian ryegrass (11.9 vs 12.5 MJ ME/kg DM), although the total ME produced per year was greater in the mixture without Italian ryegrass (169 vs 163 GJ ME/ha/year).

The lowest operating cost/kg milksolids occurred with pastures managed leniently in spring (NZ$4.13) compared with average operating costs across all scenarios (NZ$4.40/kg MS produced). Annual herbage production for the diverse pasture mixtures were 14.0, 13.4, and 15.0 t DM/ha for conventional, autumn lenient and spring lenient grazing management, respectively. When pastures were leniently grazed in spring, this allowed for more feed to be conserved over spring and summer to be used in autumn or sold off as pasture silage under spring lenient grazing. With the spring lenient grazing scenario, 44 t DM of pasture silage was produced in late spring and 29 t DM was used to supplement the herd in autumn. This extra feed in autumn in the Canterbury region has an economic value of NZ$0.29/kg DM (Chapman *et al.* 2012) and equates to a worth of NZ$8410. An excess of 15 t DM of pasture silage was sold in May and less purchased feed required, decreasing the operating costs/MS to NZ$4.13.

Herbage mass at the start of calving averaged ~2700 kg DM/ha for conventional and spring lenient grazing of diverse pastures compared to 2300 kg DM/ha for autumn lenient management. The large deficit from the autumn lenient grazing in diverse pasture scenarios was due to low starting herbage mass in August at the start of calving. Chapman *et al.* (2016) showed a single event in autumn of under-grazing and overgrazing perennial ryegrass swards resulted in 240-465 kg DM/ha lower herbage accumulation compared to a target grazing treatment. Using the economic value of additional pasture grown in early spring in Canterbury (NZ$0.42/kg DM; Chapman *et al.* 2012), this equates to approximately NZ$168/ha potential profit lost when applying an autumn lenient management compared to conventional and spring lenient management. The low DM growth rates in early spring increased the requirement for supplement to be fed to maintain an average herbage mass above 2000 kg DM/ha and support animal feed demand during peak lactation.

Profit was numerically higher for SL (NZ$2658/ha) compared with other scenarios (average NZ$2261/ha). The greater profit was driven by greater annual herbage DM production (15.0 vs 13.3 t DM/ha) and hence, less purchased feed required to meet cow requirement (NZ$0/ha vs NZ$404/ha) for diverse pasture managed by spring lenient grazing compared with other scenarios, respectively. In addition, the lenient grazing of diverse pasture was the only scenario that resulted in a surplus feed of pasture silage to sell and therefore an increase in feed inventory (NZ$3145/year).

With the inclusion of Italian ryegrass in the diverse pasture mixture, conventional management was greatest by 0.7 t DM/ha and 1.9 t DM/ha in lenient management in early (spring) and late (autumn) lactation, respectively. With the Italian ryegrass included in the mixture, profitability began to decrease as more feed was required to fill the greater spring deficit. This resulted in a greater cost/kg MS of NZ$4.40 compared to diverse mixtures without Italian ryegrass (NZ$4.32). The low herbage DM production in diverse mixtures + Italian ryegrass from the spring and autumn lenient grazing management resulted in large feed deficits in summer and autumn. This required a large amount of supplementary feed to maintain herbage mass above 2000 kg DM/ha compared to conventional management of diverse pasture + Italian ryegrass. When diverse pasture + Italian ryegrass was managed by conventional grazing, no additional feed was purchased. This scenario resulted in the greatest operating profit (NZ$2400/ha) compared to the spring and autumn lenient grazing, (NZ$2337/ha) and (NZ$2067/ha), respectively, in the diverse pasture with Italian ryegrass.

It is important to note in this study, the results are related to the particular scenarios as previously described (e.g., milk production, lactation length and selling off extra feed). Alternative approaches may be possible and further discussed in the general discussion (Chapter 8).

7.5 Conclusion

When diverse pasture is considered, spring lenient grazing is a potential management option for irrigated Canterbury dairy farm systems. The greater profit from spring lenient grazing management was due to increased DM production, reduced purchased feed costs, and herbage surplus sold off as pasture silage. The inclusion of Italian ryegrass in the diverse mixture decreased herbage DM production when managed leniently in spring and autumn.

Chapter 8

General discussion

8.1 Introduction

The dairy sector makes a significant contribution to the New Zealand economy, contributing $13.9 billion NZD of dairy exports (Ballingall and Pambudi 2017). Proposed regulations in NZ are increasing the pressure on intensive pastoral dairy farming to adopt systems that reduce environmental footprints, including nitrogen (N) loading into the soil (Ministry for the Environment 2017). Studies have shown the inclusion of grasses, lucerne, chicory and plantain in a diverse mixed sward can reduce urinary N concentration, in lactating dairy cows without negatively affecting milk production (Woodward *et al.* 2013; Edwards *et al.* 2015; Bryant *et al.* 2017) and potentially mitigate the environmental N footprint (Beukes *et al.* 2014). The use of grazing management (i.e., frequency and intensity) has been well defined on pasture production of conventional perennial ryegrass white clover mixtures, however these diverse pastures may require different grazing management strategies (Lee *et al.* 2012).

A farmer is able to manage forage availability and quality by controlling the duration to manipulate the pasture eaten, so grazing management should focus on managing high-quality, low-cost feed to achieve better returns from a livestock production system. However, there has been a low adoption of diverse pastures as maintaining or enhancing the persistence of the pasture species sown has been difficult. And grazing management of diverse pastures will require compromises between the needs of each of the species present to be able to implement relatively simple practices. Various tactical grazing management strategies have been suggested throughout this thesis to aid farmers to optimise feed supply without hindering milk production. While these grazing management strategies do not solve all the problems within a farm system, farmers are able implement relatively simple practices and mitigate the impact to the environment. Grazing management regimes which increase herbage yield indicates improved soil nutrient uptake and a potential role in mitigating nutrient leaching.

8.2 Herbage DM production

Herbage DM production had been previously examined in alternative pasture mixture swards where alternative legumes (lucerne and red clover), herbs (chicory and plantain) and grasses (Italian ryegrass, timothy and prairie grass) were added to the conventional perennial ryegrass white clover mixtures and found a diverse pasture mixture can maintain available DM production and high quality feed for a greater part of the grazing year (Nobilly *et al.* 2013; Woodward *et al.* 2013) compared to a perennial ryegrass clover mixture in a New Zealand farm system. Grazing management requirements to optimise herbage DM production, persistence and nutritive value of many grasses, legumes and herbs (Sanderson *et al.* 2005; Labreveux *et al.* 2006; Lee *et al.* 2015) do not align with each other or with conventional mixtures.

The studies in this thesis were designed to examine different grazing management strategies on DM production from diverse pastures which included alternative legumes (lucerne and red clover) and herbs (chicory and plantain) in a perennial ryegrass white clover mixture. There were differences in seasonal herbage growth rates depending on the management and pasture mixture as shown in chapter 3. However, management options that improve feed supply as animal demand is at its highest in early spring has consistently high economic values in the Canterbury region. And extra feed produced in late spring has consistently low economic value (Chapman *et al.* 2012). Tactical spring grazing management, such as lenient grazing in spring followed by a switch to hard grazing at anthesis has been shown in perennial ryegrass-based mixtures to improve summer feed supply (Matthew 1991; Da Silva *et al.* 1994; Hernández Garay *et al.* 1997). Results from chapters 3, 5 and 6 confirms an increased feed supply in leniently grazed pastures in spring with diverse pastures with high proportions of perennial ryegrass. Interestingly, annual and seasonal herbage DM production was similar among conventional grazing and spring lenient grazing management. However, it is important to note that a spring lenient grazing increased the plantain composition in the sward compared to hard conventional grazing. Perennial ryegrass seedhead development usually occurs in late spring when pasture growth and feed supply exceed animal demand. If the grazing rotation is not quick enough, generally pasture quality will decrease. However, in this study, a spring lenient grazing to allow seedhead development, followed by a hard-conventional grazing did not affect the pasture quality of the sward offered. This would suggest a diverse pasture offers a greater flexibility in grazing management without affecting herbage DM production and pasture quality in spring.

The inclusion of Italian ryegrass into the mixture did not increase herbage DM production in winter/early spring. The inclusion of Italian ryegrass in the mixture decreased the proportions of herbs and legumes.

The use of a tactical winter grazing (lenient grazing in late autumn) to optimise pasture sward in early spring was tested in chapter 3 with grazing animals. Lenient grazing in late autumn resulted in greater pasture diversity compared to a hard grazing, but decreased pasture production over the winter and spring period of the first year and autumn and winter of the second year. In winter to early spring, the rapid establishment of perennial ryegrass is more likely to contributed to the growth rates in winter and spring compared to herbs and legumes (Goh and Bruce 2005). Therefore, the lower growth rates in autumn lenient grazing management could be attributed to a lower perennial ryegrass content relative to other species in the botanical composition compared to conventional and spring lenient grazing. However, in chapter 4, a one-off lenient grazing in autumn did not affect the early spring DM production. The lack of effect is most likely due to the pasture having sufficient WSC stores in the leaf after mowing to not significantly affect regrowth potential. Past research considered post- grazing herbage mass during winter and concluded a severe grazing (1260 kg DM/ha) and lax grazing (1868 kg DM/ha) provided similar regrowth potential, though there was a small transient reduction of WSC in severe grazing pasture (Lee *et al.* 2007). This would suggest the grazing severity in autumn will not affect the regrowth potential and quality over winter to early spring in the first 100 days if a one-off lenient management was used. However, if continuous lenient management was used, there would be an accumulation of dead material and ultimately result in a decrease of DM production in subsequent grazing rotations.

8.3 Milk production

Milk production is important for dairy farm profitability in New Zealand. Previous short-term production studies have shown that milk production is comparable from diverse pastures compared with the conventional pastures (Soder *et al.* 2006; Totty *et al.* 2013; Woodward *et al.* 2013). Two of the experiments (Chapters 5 and 6) were designed to examine difference in milk production of dairy based systems based on diverse pastures managed by conventional methods or lax management in spring and if a one-off pre-graze mowing would increase DM intake and thus increase MS production. DM intake and MS production results have been inconsistent with the three studies (Bryant 1982; Kolver *et al.* 1999; Irvine *et al.* 2010) that focused on a pre-graze mowing in perennial ryegrass white clover. In the spring trial (chapter 5), there was no difference in milksolids production between grazing management due to a similar herbage allowance and a similar consumed diet ME values, despite herbage quality often being lower in lax managed diverse pastures. The nutritional characteristics of the forage were within the ranges suitable for milk production (Waghorn *et al.* 2007) and despite herbage quality often being lower in lax managed pasture suggest at a similar herbage allowance and a similar consumed diet ME values, milk production would not be affected by grazing management in the short term. In the subsequent grazing rotation (Chapter 6), we compared the carry over effect of having mown the same pastures on pasture quality, apparent DM intake, and milk production. This would allow us to evaluate the net benefit of grazing intensity and mowing of diverse pastures in early spring. However, the combination of similar post- grazing from the previous grazing rotation and similar plant nutritive values in diverse pastures may not be of sufficient magnitude to affect spring management practices, offering greater flexibility in grazing management in the spring. A diverse pasture sward is able to maintain a high nutritive value (Ulyatt *et al.* 1976; Barry 1998) and possibly alleviate the magnitude of low energy levels relative to perennial ryegrass. And as previously mentioned by (Waghorn *et al.* 2007), the ME values in this experiment of greater than 11.3 MJ ME/kg DM were suitable for milk production. Though it is noted, due to the short term nature of these projects, it would be beneficial to confirm in a large farm study the effects over the entire grazing year.

8.4 Pasture persistence and N losses to the environment

The largest environmental pollutants from the New Zealand dairy industry is urinary N excreted by grazing livestock because nitrate derived from urinary N contributes to ground and surface water contamination (Di and Cameron 2002a). Plant growth in autumn and winter are limited due to low temperatures and excess rain is generally expected in these seasons and any nitrate N remaining in the soil in late autumn are liable to be lost by leaching. Diverse pastures consisting of mixtures of Italian ryegrass, herbs and alternative legumes offer the opportunity to lower nitrate leaching, either by increasing N uptake of urine from cows (Moir *et al.* 2013; Malcolm *et al.* 2014; Woods *et al.* 2016; Maxwell *et al.* 2018) or lowering N loading in urine patches (Woodward *et al.* 2012; Totty *et al.* 2013; Edwards *et al.* 2015; Box *et al.* 2017; Bryant *et al.* 2017) compared with the standard ryegrass white clover pastures. Compared to the standard ryegrass white clover pastures, Italian ryegrass significantly reduced N leaching due to the greater cool season growth and thus increasing N uptake (Moir *et al.* 2013; Malcolm *et al.* 2014; Woods *et al.* 2016; Maxwell *et al.* 2018). Also, grazing management regimes which increase herbage mass, raises the possibility of increased plant N uptake during the late autumn period and thereby reduce the risk of nitrate leaching. However, in chapters 3 and 4, there are no evidence during the autumn winter period to suggest grazing management could be used to increase pasture growth rates and whereby decrease the risk of nitrate leaching. The study by Malcolm *et al.* (2014) had greater proportions of Italian ryegrass (>50% of the botanical composition) in the swards than the studies found in Chapters 3 and 4 of 21% and 5% of Italian ryegrass in the botanical composition, respectively. Further work on management strategies to increase pasture growth rates and the minimum proportions of Italian ryegrass required in diverse pasture mixtures would be beneficial to reduce the risk of nitrate leaching.

Though not considered in this thesis, N loss from urinary excretion is an important environmental concern. The addition of Italian ryegrass, chicory or plantain in the mixtures decreased urinary N excretion (Woodward *et al.* 2012; Totty *et al.* 2013; Edwards *et al.* 2015; Box *et al.* 2017; Bryant *et al.* 2017), offering an opportunity to reduce the risk of nitrate leaching. Totty *et al.* (2013) showed 54% of herbs in the diet (18% plantain and 36% chicory) decreased urinary N output from 438 to 354 g N/d compared to a perennial ryegrass-based diet. Also, Box *et al.* (2017) reported a 1.8 g N/L of urine reduction with 50% of plantain in the diet compared to a perennial ryegrass diet. However, Bryant *et al.* (2018) reported pastures containing both 30-35% chicory and plantain of the diet was insufficient to reduce daily urinary N excretion. Though daily urinary N was not measured in these studies, the results from Chapters 3 and 4 suggest the similar herb proportions (15-30%) in the diet to those reported by Bryant *et al.* (2018), would be insufficient to reduce daily urinary N excretion. In chapter 4, the results showed a one off lenient grazing in autumn before the onset of winter was not able to increase nor decrease the herb proportions in the mixture, and hence alter urinary N excretion. However, in Chapter 3, lenient grazing in autumn better supported species diversity abundance (31.3% herbs and 18.8% legumes) compared to a hard-conventional grazing management (27.2% herbs and 13.3% legumes), at the expense of a lower DM production in the first year. Although lenient grazing in autumn can increase the proportion of herbs in the mixture, there is still considerable research needed to determine the minimum proportions of herbs required for urinary N reduction and how grazing management as a N mitigation strategy will affect DM production, species persistence and profit at the farm level.

One possible strategy to better support alternative species would be to sow the plants as a monoculture and grazing the pasture as spatially separate swards rather than in a mixed sward. This would allow the possibility of applying specific grazing management to the individual species to alter botanical composition and pasture persistence. There is limited data on cows grazing spatially separated herb monocultures, but Rutter *et al.* (2004) showed cows had a partial preference for 70% white clover in their diet, rather than pure swards of perennial ryegrass or white clover. The preference for clover from grazing dairy cows may affect the availability of the sward. More research is warranted in spatial separated grass, herbs and alternative legume monocultures to determine the animal response and the impact at a farm system level.

8.5 Farm system modelling

Computer models are used to stimulate the interactions between cows, grass, crops and management in farm systems to explore numerous alternatives in a cost-effective way. These models help us understand the effects of changes in climate, price and management on farm production, profit and environmental footprint. Seasonal growth rates from the pasture within a farm system will have a significant impact on the supplement required and daily milk production. There are numerous studies available that do not show statistically significant differences in DM yield, but when modelled, there may be a significant effect on profitability. For example, although the annual DM production was not significantly different between SL and CG grazing management in Chapter 3, there were seasonal increases in DM production in spring and summer when pastures were leniently grazed in the spring. Though DM production was not statistically different in Chapter 3, when modelled, the difference in profitability was evident. A spring lenient grazing is a potential management option to provide a feed surplus and no supplements needed for an irrigated

Canterbury dairy farm system when modelled over the entire grazing year (chapter 7). Other grazing management scenarios required purchased feed to fill the feed deficits throughout the year.

In a computer model such as Farmax, there will always be alternative approaches to simulate and optimise dairy farm productivity. Alternative approaches to simulate and optimise farm profitability from including diverse pasture in a farm may include, the reaction to variation in feed supply and demand on animal production in different regions, different proportions of a diverse sward or simulate the effects on persistence of the diverse sward on whole-farm profitability. Additional work is needed to optimise the farm systems. For example, setting pasture cover at calving, rather than setting a base farm to match a North Canterbury dairy farm, could have determined the reaction to variation in feed supply and demand of the diverse pasture managed by various grazing management.

Nevertheless, computer models are a strong and powerful tool to predict long term consequences of grazing management on farm productivity. Though more research to identify the risk for environmental impacts would be beneficial to model with farm profitability.

An important environmental consideration is N loss at the farm system level, though in this thesis, we only modelled profit from various grazing management strategies. Though modelling urinary N excretion was not considered here, Beukes *et al.* (2014) used a whole farm systems approach to model the environmental benefits (as determined by reduced UN excretion) of feeding diverse pastures to dairy cows and found 2-6% less UN excretion when cows were fed diverse pastures (20% and 50% diverse pastures sown) compared to the standard perennial ryegrass white clover pasture. This would suggest the potential for reduced N leaching (11-19%) risk from growing 20% or 50% of the farm with a diverse pasture (Beukes *et al.* 2014). Unconventional approaches or any significant changes to farm systems are major concerns to many farmers, as the economic response must be worthwhile and the ability to manage the risks must be simple to implement.

8.6 Pasture measurement

Measuring herbage mass by non-destructive methods (e.g., visual estimations, pasture meters and remote sensing) aids in pasture monitoring, planning and decision making, but are generally associated with a moderate to high error as reviewed by Lopez Diaz *et al.* (2011). However, herbage mass can be measured more accurately by destructive harvest (e.g. quadrat cuts). This would be expensive, labour intensive, time consuming and unrealistic on large areas (Brummer *et al.* 1994). Farmers are unlikely to cut pasture samples for regular herbage mass estimates, so a more convenient way to measure DM production on diverse swards would be valuable.

While the research aim was not to evaluate a rising plate meter on diverse pastures, the result of this study (Chapter 3) showed a poor correlation associated with RPM readings and estimation of herbage mass (R^2 ranged from 0.44 to 0.57, n=2043, Appendix A). Rising plate meters are widely used in the dairy industry in New Zealand to rapidly measure the herbage mass of the standing sward. Previous research has noted the RPM method to estimate herbage mass is quick and easy, though variable across livestock industries and across pasture mixtures. (Lile *et al.* 2001; Martin *et al.* 2005; Ramírez-Restrepo *et al.* 2006; Somasiri *et al.* 2014). The accuracy of the prediction of DM production (R^2) based on RPM has been reported to be highly variable, ranging from 0.31 in Northeastern US pastures (Sanderson et al. 2001) to 0.88 in permanent grasslands in Ireland (O'Donovan et al. 2002). The variability in the regression equations predicting herbage mass of pasture mixtures are most likely related to the morphological structure of the sward, climate, forage type, botanical composition, plant density or even soil surface (Lile *et al.* 2001; Thomson *et al.* 2001; Martin *et al.* 2005; Sanderson *et al.* 2006b). With large measurement errors and inconsistencies, there are likely to be economic consequences to farm profitability. For instance, Beukes *et al.* (2018) suggested that regular and accurate estimates of herbage mass can improve profitability by 11-15% compared with a low knowledge of herbage mass (i.e., estimated herbage mass error of 450 kg DM/ha). If diverse pasture swards are considered for a whole farm system, further information is required on practical management tools to quickly and accurately estimate forage production throughout the grazing season.

This study used calibrated plate meter readings and visual observations of ryegrass tillering (flowering) to give indication of timing of grazing. This gave pasture height profiles as indicated in Figure 3.2. In this study, significant effort was also made to calibrate pasture height and mass. Previous work has been placed on establishing calibration between height and mass for ryegrass-based pastures. There have been several attempts to provide calibrations for diverse pastures. For example, Nobilly *et al.* (2013) found good correlations (R^2=0.80) between height and mass over smaller numbers (n= 36 pre- and post-grazing quadrat cuts/season). In addition, Engelbrecht *et al.* (2014) found similar correlations with an R^2 of 0.85 between pasture height and mass and over a short term (n=20 pre- and post-grazing quadrat cuts). On the other hand, Somasiri *et al.* (2014) found a positive correlation (R^2=0.47 to 0.64) with a large number of samples (n=1152) between pasture height (i.e.. sward height or plate meter) and dry matter mass on herb-clover mixes during four seasons of the year. This variation indicates the regression equations are dependent on the number of readings recorded.

In this study, calibration achieved by an indirect method of rising plate meter readings and directly using quadrat cuts gave a poor correlation between pasture height and mass. This may have reflected the plant density. Calibration equations are shown in Appendix A Table 1. However, when the data was used to calculate the herbage mass and DM production, similar qualitative trends were found (lower annual yield with calibration equations compared with direct measurement of quadrat cuts). More work is required to establish calibrations and alternative methods to take account of different sward structure and calibrated visual assessments.

8.7 Future research

It would also be beneficial to test these grazing management strategies on larger, long term scales to determine if these simple management strategies are practical to adopt. Long term studies would also be beneficial for the manipulation of plant species sown and to continue to maximize long term economic return but also add information on whether grazing management can be used to mitigate the impacts of N leaching. In addition, while these experiments offer better information for grazing management of diverse pastures, there will always be a need to test and demonstrate any recommendations locally to ensure they are appropriate.

The combination of field experimentation with environmental modelling is a potentially powerful tool to predict long-term consequences of managing the impacts of seasonal conditions on the farm system. A software program that identifies the risk for environmental impacts through nutrient loss, such as Overseer, in combination with the whole farm systems model such as the one used in this study, Farmax, would have been beneficial to model the economic returns of a comprehensive farm system and determine the environmental trade-offs.

8.8 Overall conclusions

The research presented in this thesis has provided insight into the effects of grazing management on diverse pasture mixture production, pasture persistence and animal production from irrigated pastures in Canterbury, New Zealand. The main conclusion from each chapter can be summarised as followed:

A lenient grazing management in spring and conventional grazing of the sward showed similar DM production without hindering pasture growth and quality for irrigated Canterbury dairy farm systems. Although, an autumn lenient grazing decreased DM production, an autumn lenient grazing was beneficial to herbs and legume species abundance. The inclusion of Italian ryegrass in the mixture did not increase the DM production due to the low botanical content and from competition for resources of other species in the sward.

Diverse pasture mixtures can maintain high quality through winter followed by defoliation height had no significant effect on herbage DM growth, botanical composition or N uptake. Thus, no effect on N leaching would be expected. However, it is important to note, leaving a greater herbage mass in autumn increased the harvestable DM mass for early spring.

Results showed a lax spring grazing management significantly increased herbage mass, but had a tendency towards depressed milksolids production. This was not improved by pre-graze mowing. There is no evidence to support the hypothesis that pre-graze mowing herbage increases milk production for dairy cows offered a similar herbage DM allowance.

If grazing or mowing achieved similar post-grazing heights in the previous grazing event, the subsequent quality of regrowth of diverse pastures is unlikely to be affected by early spring grazing management. The similarity in herbage quality results in similar milk production when offered at the same allowance. Diverse pastures can be maintained to a greater herbage mass with reproductive development in spring without affecting milksolids production when grazed in the summer.

Grazing management may be more flexible in the spring to increase DM production without hindering pasture growth and quality for irrigated Canterbury dairy farm systems. The spring lenient grazing also saved on purchased feeds from a surplus of herbage and no supplementation was required.

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Appendix A

Best fit regression lines

Table 1. Best fit regression between RPM and DM production was used to derive calibrations for each grazing management treatment and pasture type

Pasture type + grazing management	Equation	R^2	s.e.m.	n
DP CG	kg DM/ha = 104.9*RPM + 712	0.44	5.49	342
DP AL	kg DM/ha = 106.5*RPM + 491	0.56	5.50	342
DP SL	kg DM/ha = 103.5*RPM + 628	0.55	5.11	342
DP+Ita CG	kg DM/ha = 101.4*RPM + 447	0.57	5.20	337
DP+Ita AL	kg DM/ha = 85.3*RPM + 790	0.46	5.08	339
DP+Ita SL	kg DM/ha = 98.8*RPM + 527	0.52	5.55	341

Note: RPM represents ‘click’ where each ‘click’ equals 0.5 cm, s.e.m. is the standard error of the mean. Treatment code: DP: diverse pasture, DP+Ita: diverse pasture plus Italian ryegrass, CG: conventional grazing, AL: lax grazing in autumn, SL: lax grazing in spring.

Appendix B

Publications during the course of the study

Cun GS, Edwards GR, Bryant RH. 2017. The effect of pre-graze mowing on milk production of dairy cows grazing grass-herb-legume pastures managed under contrasting spring defoliation regimes. Animal Production Science 57, 1414-1418. https://doi.org/10.1071/AN16458

Cun GS, Edwards GR, Bryant RH. 2017. Milk production does not benefit from mowing previously lax-grazed diverse pastures. New Zealand Journal of Agricultural Research. https://doi.org/10.1080/00288233.2017.1411954

Cun GS, Al-Marashdeh O, Edwards GR. 2018. Whole-farm modelling using different grazing-management strategies with diverse pastures within an irrigated dairy-farm system. New Zealand Journal of Animal Science and Production 78, 1-5. http://www.nzsap.org/proceedings/whole-farm-modelling-using-different-grazing-management-strategies-diverse-pastures