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Pasture production, nutritive value and water use efficiency of irrigated dairy pasture mixtures grazed by dairy cows

A thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy at Lincoln University by Frisco Nobilly

Lincoln University 2015
Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy

Pasture production, nutritive value and water use efficiency of irrigated dairy pasture mixtures grazed by dairy cows

by

Frisco Nobilly

The objective of this thesis was to compare herbage dry matter (DM) production, nutritive value and water use efficiency of simple perennial ryegrass/white clover and tall fescue-white clover pastures to diverse pastures where additional grasses, legumes and herbs were added to simple grass-clover mixture. Three experiments were conducted in Canterbury, New Zealand with all pastures irrigated and grazed by dairy cows.

The first study, conducted at a paddock scale, measured annual and seasonal herbage DM production, botanical composition and nutritive value of two species mixtures of perennial ryegrass (standard and high sugar) and tall fescue sown with white clover compared with more diverse mixtures where additional herbs (chicory and plantain), legumes (lucerne or red clover) and grasses (prairie grass) were added to the two species mixtures. Averaged over 2 years, annual herbage DM production was 1.6 t DM/ha greater in diverse (16.8 t DM/ha) than simple (15.2 t DM/ha) pastures, primarily reflecting greater DM production in summer. Diverse pastures had lower metabolisable energy (ME) (12.0 vs 12.2 MJ ME/kg DM) and neutral detergent fibre (301 vs 368 g/kg DM) content than simple pastures, although the total ME produced per year was greater in diverse than simple pastures (202 vs 185 GJ ME/ha). Ryegrass-based pastures had higher annual DM production (16.8 t DM/ha) than tall fescue-based pastures in the first (14.5 t DM/ha) but not second year.

The second study, conducted at a small plot scale, measured annual and seasonal herbage DM production, botanical composition and nutritive value of simple and diverse pasture mixtures grazed by dairy cows subjected to full and partial irrigation. Measurements were made over two years for a simple perennial ryegrass/white clover pasture (S) and pastures with additional legumes (red clover and lucerne, SL), herbs (chicory and plantain, SH), grasses (prairie grass and timothy, SG), herbs and legumes (SLH), or herbs, legumes and grasses (SLHG) added to the simple pasture. In the partial irrigation treatment, no irrigation was applied for a 2 month
period from 14 January 2011 to 10 March 2011 (Year 1) and from 7 January to 16 March 2012 (Year 2). Averaged over two years, annual herbage DM production was greater where additional legumes were added to mixtures than where additional herbs or grasses were added or in the simple mixture (16.5, 16.1, 15.1, 14.5, 14.1, 13.6 t DM/ha for SLHG, SLH, SL, SH, S and SG, respectively). The decline in DM yield associated with partial compared to full irrigation was lower in SL (10%) and SLH (14%) and SLHG (15%) than SG (19%) and S (26%) over the two year period. It was concluded that this reflected greater growth of the tap rooted legumes lucerne and red clover during the period of irrigation restriction. All pasture mixtures had similar ME content (11.1 to 11.5 MJ ME/kg DM) but mixtures containing additional legumes (SL, SLH and SLHG) had higher crude protein content (210 to 215g/kg DM) than mixtures containing additional grasses or the simple mixture (184 to 195 g/kg DM).

The third study measured water use in the small plot study outlined in study two in order to investigate the production differences between full and partially irrigated pastures. Neutron probe tubes were inserted to a depth of 2.5 m and water use measured. Water use was greater in mixtures containing additional legumes (SL, SLH and SLHG, 689 mm to 705 mm) than the mixture containing additional grasses (SG, 680 mm) or the simple mixture (S, 670 mm). However, the effect was relatively small (range 14 mm to 35 mm) and was tightly linked to the summer period. In mixtures containing additional legumes (SL, SLH and SLHG), water was extracted to greater depths (0-2m) than the mixtures containing additional grasses or the simple mixture (S, SG; 0-1m). Mixtures with additional herbs (SH) extracted water to 0-1.5m soil depth. Water use efficiency (WUE) was greater in the mixtures containing additional legumes and additional herbs (SH, SL, SLH and SLHG, 18.6 to 21.1 kg DM/ha/mm) than additional grasses (SG, 17.5 kg DM/ha/mm) or the simple mixtures (S, 18.3 kg DM/ha/mm).

In conclusion, the DM production and nutritive value of diverse pastures was similar or greater than that of standard perennial ryegrass/white clover pastures or tall fescue-white clover pastures. Under water restriction, DM production was less affected in mixtures containing the tap rooted legumes red clover and lucerne. Combined with the environmental benefits of diverse pastures (e.g. reduced urinary N excretion) demonstrated in other studies, it is concluded that diverse pastures are a promising alternative to perennial ryegrass-white clover pastures to deliver high production, with lower environmental implications, in dairy systems.
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Id Ngaan di Tama om di Tanak om di Spiritu Tobitura!

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### List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
<th>Units</th>
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<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
<td></td>
</tr>
<tr>
<td>ASWC</td>
<td>Available soil water content</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Base pasture</td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>Crude protein</td>
<td>g/kg DM</td>
</tr>
<tr>
<td>D</td>
<td>Diversity</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Drainage</td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>Dry matter yield</td>
<td>kg DM/ha</td>
</tr>
<tr>
<td>DOMD</td>
<td>Digestible organic matter</td>
<td>%</td>
</tr>
<tr>
<td>DUL</td>
<td>Drained upper limit</td>
<td></td>
</tr>
<tr>
<td>EP</td>
<td>Penman’s potential evapotranspiration</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>Gram</td>
<td>g</td>
</tr>
<tr>
<td>GJ</td>
<td>Gigajoule</td>
<td></td>
</tr>
<tr>
<td>ha</td>
<td>Hectare</td>
<td>ha</td>
</tr>
<tr>
<td>HS</td>
<td>High sugar ryegrass/white clover</td>
<td></td>
</tr>
<tr>
<td>HSD</td>
<td>High sugar ryegrass/white clover diverse</td>
<td></td>
</tr>
<tr>
<td>$I$</td>
<td>Irrigation</td>
<td>mm</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>LL</td>
<td>Lower limit</td>
<td></td>
</tr>
<tr>
<td>LSD</td>
<td>Least significant difference</td>
<td></td>
</tr>
<tr>
<td>LURDF</td>
<td>Lincoln University Research Dairy Farm</td>
<td></td>
</tr>
<tr>
<td>m$^2$</td>
<td>Metre square</td>
<td>m$^2$</td>
</tr>
<tr>
<td>ME</td>
<td>Metabolisable energy</td>
<td>MJ ME/kg DM</td>
</tr>
<tr>
<td>MJ</td>
<td>Megajoules</td>
<td></td>
</tr>
<tr>
<td>mm</td>
<td>Millimetre</td>
<td>mm</td>
</tr>
<tr>
<td>MSP</td>
<td>Multi-species pasture</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>Number</td>
<td>n</td>
</tr>
<tr>
<td>NDF</td>
<td>Neutral detergent fibre</td>
<td>g/kg DM</td>
</tr>
<tr>
<td>NIRD</td>
<td>Near-infrared spectroscopy</td>
<td></td>
</tr>
<tr>
<td>NO$_3$</td>
<td>Nitrate</td>
<td></td>
</tr>
<tr>
<td>NZ</td>
<td>New Zealand</td>
<td></td>
</tr>
<tr>
<td>PAWC</td>
<td>Plant available water capacity</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Rainfall</td>
<td>mm</td>
</tr>
<tr>
<td>RG</td>
<td>Standard perennial ryegrass/white clover</td>
<td></td>
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<tr>
<td>RGD</td>
<td>Standard perennial ryegrass/white clover diverse</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>Standard mixtures</td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td>Standard + grass</td>
<td></td>
</tr>
<tr>
<td>SH</td>
<td>Standard + herbs</td>
<td></td>
</tr>
<tr>
<td>SL</td>
<td>Standard + legumes</td>
<td></td>
</tr>
<tr>
<td>SLH</td>
<td>Standard + legumes + herbs</td>
<td></td>
</tr>
<tr>
<td>SLHG</td>
<td>Standard + legumes + herbs + grass</td>
<td></td>
</tr>
<tr>
<td>TDR</td>
<td>Time Domain Reflectometry</td>
<td></td>
</tr>
<tr>
<td>TF</td>
<td>Tall fescue/white clover</td>
<td></td>
</tr>
<tr>
<td>TFD</td>
<td>Tall fescue/white clover diverse</td>
<td></td>
</tr>
<tr>
<td>UN</td>
<td>Urinary nitrogen</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
<td></td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
<td>Unit</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>WSC</td>
<td>Water soluble carbohydrate</td>
<td>g/kg DM</td>
</tr>
<tr>
<td>WU</td>
<td>Water use</td>
<td>mm/ha</td>
</tr>
<tr>
<td>WUE</td>
<td>Water use efficiency</td>
<td>kg DM/ha/mm</td>
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Chapter 1
Introduction

1.1 Introduction

Milk solids production and dairy farm profitability in New Zealand is closely related to annual herbage dry matter (DM) yield, the seasonal pattern of pasture production, pasture nutritive value and utilisation of pasture (Moran et al. 2000). The most common pasture mixture grown in New Zealand for dairy pastures is a binary mixture of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). This reflects many desirable characteristics of these species including ease of establishment, high herbage DM production, complementary growth patterns of these species, and tolerance of a wide range of environments and grazing management (Kemp et al. 1999b). However, pastures based on perennial ryegrass-white clover mixtures do have limitations, including low nutritive value in summer (Burke et al. 2002) and shallow rooting systems (Brock et al. 2003), leading to herbage growth restrictions during summer and autumn dry periods or periods of restricted irrigation (Hoglund & White 1985). These limitations have resulted in greater interest in the use of alternative species (legume, herbs and grasses) to perennial ryegrass and white clover as components of pasture mixtures (Pembleton et al. 2014).

One of the important questions in the use of the alternative species is their performance when used in more diverse or complex mixtures with perennial ryegrass/white clover. Ecologists have long debated the importance of plant species diversity for ecosystem function (Tilman et al., 1996; Hector et al. 1999; Kennedy et al. 2002; Sanderson et al. 2007; Soder et al., 2007). Studies in extensive grasslands report increased primary production, greater stability of DM production, improved water use, reduced nitrate leaching and increased resistance to invasion of weeds in species rich than in species poor grassland. Various explanations have been proposed to explain these results, including complementary resource use and facilitation among species in ‘species-rich’ than ‘species-poor’ pastures (Pembleton et al. 2014). Thus, managing diverse mixtures of plants may be one ecological approach to improving the range of functions now being sought from our dairy pastures, such as improved DM production, water use, nutritive value and lower losses of nutrients to the environment (Sanderson et al. 2004).

The pasture species that may be considered in New Zealand as part of more diverse mixtures include legumes (lucerne, *Medicago sativa* L., red clover, *Trifolium pratense* L.), herbs (chicory, *Chicorium intybus* L., plantain, *Plantago lanceolata* L.) and grasses (prairie grass,
Bromus willdenowii Kunth., tall fescue, Schedonorus arundinaceus Roem. & Schult.). Lucerne is the most common pasture alternative used for dryland forage for either grazing or feed conservation (Wynn-Williams 1982). Lucerne is able to maintain its production under dryland conditions (Brown 2004). However, red clover and chicory are other tap-rooted perennial plants that have recently been advocated for dryland farming regions in New Zealand (Keoghan 1991; Paton & Fraser 1992; Brown 2004; Tonmukayakul 2009). A feature of chicory, lucerne and red clover is their high quality forage, which supports higher stock growth than perennial ryegrass/white clover during dry conditions (Burke et al., 2002). However, a negative aspect of these forages is their low cool-season production (Wynn-Williams 1982; Hay & Ryan 1989; Li et al. 1997). Grasses, such as prairie grass, may have improved cool season growth, but how they perform in mixtures with perennial ryegrass is unclear. Despite the potential advantages of these alternative species they are not widely adopted in dairy systems, and further work is needed to confirm their potential in combination with perennial ryegrass and white clover (Daly et al. 1996) to deliver pasture of high herbage DM yield and high nutritive value.

There are relatively few studies revise on intensive grazing management with irrigation, improved grasslands of the effect of pasture diversity on herbage DM yield and nutritive value, Daly et al. (1996) showed a multi-species pasture mixture of erect legumes (red clover and lucerne), herbs (chicory and plantain) and grasses (e.g. tall fescue, prairie grass, cocksfoot) out-yielded a perennial ryegrass-white clover pasture in a dryland pasture in Canterbury. In further New Zealand work, Goh and Bruce (2005) showed a multi-species mixture consisting of herbs, legumes and grasses had greater herbage DM production and legume content than a perennial ryegrass/white clover pasture under border dyke irrigation in Canterbury. In United States work, Skinner et al. (2006) reported greater herbage DM production and nutritive value of a five species mixture containing chicory, meadow fescue (Festuca pratensis Huds.), perennial ryegrass, cocksfoot (Dactylis glomerata), white clover than a simple perennial ryegrass/white clover pasture under three water regimes with the greatest difference when a summer water stress period was included treatment. The mixture not only extracted more water from deeper in the soil profile but also increased water remaining in the top 30 cm. Further work is needed to ascertain how pasture mixtures containing legumes and herbs can improve the herbage DM production and nutritive value in the moderate-high fertility, irrigated environments of dairy systems.

This thesis presents a series of experiments which measure treatment effects on herbage DM production, nutritive value, water extraction patterns, and water use of diverse pastures in
greater detail to allow the refinement of best management practices, hence, indications of a novel contributions to scientific knowledge.

1.2 Aims and research objectives

The purpose of this study was to evaluate herbage production, nutritive value and water use of alternative pasture species mixtures to perennial ryegrass-white clover in an irrigated dairy systems in Canterbury.

Specific objective are:

1. To determine the annual and seasonal herbage DM production, botanical composition and nutritive value of two species mixtures of perennial ryegrass (standard and high sugar) and tall fescue sown with white clover compared with more diverse mixtures where additional herbs, legumes and grasses were added;

2. To determine the annual and seasonal herbage DM production, botanical composition and nutritive value of simple perennial ryegrass and white clover mixtures compared with diverse mixtures where additional herbs, legumes and grasses were added under full and partial irrigation;

3. To determine the annual and seasonal water use and water use efficiency of simple perennial ryegrass with white clover mixtures compared with diverse mixtures where additional herbs, legumes and grasses were added under full and partial irrigation.

1.3 Hypothesis

Pastures planted in diverse mixture containing species of erect legumes, herbs and grasses would have greater herbage DM yield, higher nutritive value, and water use efficiency than pastures planted in simple perennial ryegrass/white clover mixtures on moderate high fertility soils under grazing.
1.4 Thesis structure

This thesis is presented in six chapters (Figure 1.1). In Chapter 2, literature concerning the effects of pasture diversity on DM production, nutritive value and water use efficiency is reviewed. Chapter 3 reports on a study conducted over two years of DM production productivity and nutritive value of irrigated simple and diverse mixtures under rotational grazing by dairy cows (Objective 1, Section 1.2). This is supported by an investigation of herbage DM production and nutritive value under cutting and full and partial irrigation of simple ryegrass-white clover based pastures where diversity is increased by adding additional herbs, legumes or grasses singly or in combination (Chapter 4, Objective 2, Section 1.2). In Chapter 5, water use of pasture mixtures in chapter 4 are measured (Objective 3, Section 1.2). Finally, in Chapter 6 the results are drawn together and compared with those previously reported in the literature to provide general guidelines for the successful inclusion of grasses, herbs and legumes into mixtures in New Zealand dairy pastures.
Figure 1.1  Diagrammatic representation of the relationship of each chapter to the general aim and main objectives of the research presented in this thesis.
2.1 Context of New Zealand dairy industry

The dairy industry in New Zealand is the largest contributor to agricultural exports, accounting for 27% of export earnings with a value of $11 billion in 2008-2009 (Statistic New Zealand 2010). As a consequence, dairying has a large impact on the New Zealand economy. The majority of dairy herds (76%) are located in the North Island, with the greatest concentration (30%) situated in the Waikato region. Taranaki, with 15% of dairy herds, is the next largest region on a herd basis. Although South Island dairy herds account for less than one-quarter of the national total (24%), they contain over one-third of all cows accounted for with more than 1.6 million cows in the South Island (DairyNZ 2011). Dairying in Canterbury region is growing rapidly, reflecting use of irrigation to support pasture growth.

2.1.1 Current situation on dairy pasture production in New Zealand

The milk solids production and profitability of NZ dairy farms is tightly linked to the amount of herbage harvested (Holmes et al. 2002; Savage & Lewis 2005; Chapman et al. 2008), with the supply of feed for dairy cows the single largest component of dairy farm operational costs (DairyNZ 2014). For NZ dairy farms, the primary source of home grown feed is grazed perennial pastures. The major pasture species used are perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), normally grown in a simple binary mixture. The dairy industry in New Zealand is pasture-based, with the dominant pasture sown being a mixture of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) (Charlton & Stewart 1999). Forage crops (e.g. maize and brassicas) have been introduced over the past 2-3 decades to fill gaps in pasture availability relative to animal demand in winter and summer (Bryant et al. 2010).

The widespread use of the perennial ryegrass-white clover pasture reflects desirable characteristics of these species including ease of establishment, high herbage dry matter (DM) production, complementary growth patterns and tolerance of a wide range of environments and grazing management (Kemp et al. 1999b). Production of perennial ryegrass-white clover pastures is highly dependent on nitrogen (N) fertiliser inputs and supplementary irrigation. This combined with an intensification in stocking rate supports profitability through increase forage consumption per ha (Mackinnon et al. 2010). However, this intensification has brought with it environmental challenges for dairy farming, particularly N and phosphorus losses from the farm.
(Monaghan et al. 2007). Furthermore, the high protein content of perennial ryegrass/white clover pastures means that N in the feed usually exceeds cow requirements for milk production, resulting in large losses of N in urine (Tamminga 1992).

Further, although perennial ryegrass-white clover based pastures in New Zealand are tolerant of a wide range of grazing and environmental conditions, they have some disadvantages. These pastures also have shallow rooting systems (Brock et al. 2003), leading to limited access to ground water and restrictions in herbage growth during summer and autumn dry periods or periods of restricted irrigation (Hoglund & White 1985). Pasture quality may also be low in perennial ryegrass in late spring and early summer (Burke et al. 2002). They are also susceptible to the attack by a range of insect pests including grass grub (Costelytra Zealandia) and Argentine stem weevil (Listronotus bonariensis syn Hyperodes bonariensis) (McFarlane 1990). These limitations can result in reduced feed supply leading to sub-optimal dietary intake and reduced milk production, accelerating the rate of decline in post peak milk yield (Exton et al. 1996). Combined with concerns about the poor persistence of perennial ryegrass (Parsons et al. 2011), and a growing awareness of the role that plant species may play in reducing the environmental impacts of dairy farming (Moir et al. 2012), there is increased interest in the role of alternative pasture species to overcome some of the limitations of perennial ryegrass and white clover and improve farm profitability (Keoghan 1991).

Of key interest, therefore, for dairy systems is whether alternative pasture species to perennial ryegrass and white clover can be used to improve the amount and quality of herbage produced. In the context of DM production, it is also important to consider effects of alternative species on water use. In expanding dairy areas such as the Canterbury Plains, rainfall is low (<650mm/year), and dairying is tightly linked to the capacity to irrigate to improve pasture growth (McBride 1994). However as the demand for irrigation water has increased, questions about water allocation have occurred with instances of water restrictions in Canterbury region (Environment Canterbury 2015) following lack of spring and summer rainfall. Thus, there is need to identify forage systems that use water more effectively.

### 2.1.2 Alternative species for dairy systems

Stewart et al. (2014) reviewed the range of forage plants that were available to be used on pastoral farms in New Zealand. These included alternative legumes such as red clover (Trifolium pratense L.) and lucerne (Medicago sativa L.), forage herbs such as chicory (Chicorium intybus L.) and plantain (Plantago lanceolata L.), and alternative grass species such as prairie grass (Bromus willdenowii Kunth.) and tall fescue (Schedonorus arundinaceus Roem.
These species show many appealing characteristics including greater tolerance to drought, improved herbage DM yield under low soil moisture and less decline in pasture quality in summer (Moloney 1991; Reed 1996; Skinner et al. 2004; Li & Kemp 2005; Moorhead & Piggot 2009). Several studies have noted that the quality of herbage of these species is as least as high than perennial ryegrass-white clover pastures (Barry 1998; Høgh-Jensen et al. 2006; Golding et al. 2008). Of these species, lucerne is the most common forage legume species sown in dryland pastures for either grazing or feed conservation (Wynn-Williams 1982) and is capable of maintaining its production under summer dry conditions (Brown 2004). Tall fescue, chicory and red clover have shown greater tolerance of drought conditions than perennial ryegrass leading to improved herbage DM production under low soil moisture (Keoghan 1991; Paton & Fraser 1992; Rollo et al. 1998; Brown 2004; Tonmukayakul 2009). Plantain has shown to be greater in DM production in the summer and autumn that leads to greater distribution of DM yield throughout the year (Moorhead & Piggot 2009), due to its high drought tolerance and considerable summer heat tolerance (Stewart 1996; Rumball et al. 1997). However, despite the desirable characteristics of these species, and numerous cultivars being made available through breeding programmes (Stewart et al. 2014), the use of these alternative species remains relatively low in dairy pastures.

### 2.2 Rationale for diverse pasture mixtures

Dairy farms are complex systems with interactions between paddocks within the grazing rotation. Management decisions for one paddock having consequences that flow through the entire system (Pembleton & Rawnsley 2011). To date the method promoted for the integration of new forage species within a dairy system has traditionally been the use of pure swards (paddocks) of the alternative species (Tharmaraj et al. 2014), within a background of perennial ryegrass paddocks. This method of integration requires the development and management of two or more grazing platforms. Although there are successful examples of this strategy (e.g. Woodward et al. 2008), this integration may require an increased level of grazing management skill, with grazing requirements of each platform periodically coming into conflict with each other. This may potentially result in poor overall performance of at least one of the monocultures, and limit the widespread adoption of such species. An alternative approach is to add alternative species as part of mixture to the simple grass-legume binary mixture, effectively increasing the diversity in the pasture. Historically, this was the common approach with grassland mixtures (e.g. Clifton Park and Cockle Park mixture) containing in excess of 10 species in mixture (Elliot 1943). In NZ in the 1970s, the sowing recommendation was for
complex mixtures (seven species mixtures), which aimed to cover the different ecological niches in a pasture (Harris 2001).

The concept of using mixtures to improve the performance of pastures has a sound base in the ecological literature. Set against a background of declining species globally, numerous studies since the early 1990s examined the impact of the plant species diversity on key ecosystem functions (for review see Tilman et al. 1996 and Sanderson et al. 2007). Some conclusions from these studies, generally conducted in extensive low input grasslands, are that increasing plant species diversity is associated with: greater DM production; greater tolerance of plant species to water stress; enhanced DM accumulation in response to N addition; reduced invasion by weed species; and greater sequestration of carbon dioxide under elevated atmospheric concentrations (Fridley 2001; Minns et al. 2001; Kennedy et al. 2002; Sanderson et al. 2004; Tracy & Sanderson 2004b; Sanderson et al. 2005). These effects on ecosystem function have been related to a range of factors (Sanderson et al. 2004) including: (1) the sampling effect whereby there is a greater chance of including a more productive species in the mixture at high diversity; (2) facilitation, whereby the presence of one species enhances the growth or survival of another species, (3) niche differentiation, whereby there is a greater coverage of spatial and temporal niches in more diverse pasture and (4) the insurance effect whereby more diverse pasture are able to buffer more effectively the pasture community against environmental stresses. Niches could be spatial (i.e. caused by soil variation) or temporal (i.e. caused by seasonal weather patterns). Niches can also occur through one species not fully utilising a particular resource (i.e. space, water), allowing another species to exploit those resources (Sanderson et al. 2004).

2.2.1 Dry matter production of diverse pastures

Over the same time period in pastoral systems, there has been increased interest in more diverse pastures (also termed herbal leys, or multi species pasture) as an alternative to the standard perennial ryegrass-white clover pastures (Ruz-Jerez et al. 1991; Daly et al. 1996; Goh & Bruce 2005). These diverse pastures were characterised by a combination of grasses, legumes and herb species, include functional erect-growing species and deep rooting and mineral rich species selected to improve species compatibility and diversity within pastures (Foster 1988). In the Canterbury and Manawatu-Wanganui regions, pasture seeded with a mixture of 18 to 26 species of cool-season grasses, legumes (including lucerne, red clover and white clover) and herbs (including chicory and plantain) yielded more herbage under sheep grazing than the simple perennial ryegrass-white clover pastures under dryland conditions (Ruz-Jerez et al. 1991; Daly et al. 1996). Ruz-Jerez et al. (1991) found that production was 25 to 30% higher for
the diverse pasture than the standard perennial ryegrass-white clover pasture, with late spring
and summer production in particular was higher. Daly et al. (1996) showed that annual DM
production of the diverse pasture was 10 to 41% greater than perennial ryegrass-white clover
pasture. In contrast, Goh and Bruce (2005) found no difference in total herbage yield between
a diverse and standard perennial ryegrass-white clover pasture without irrigation at the
Winchmore Irrigation Research Station, mid-Canterbury, New Zealand (dryland condition).
However, under full irrigation, the diverse pasture showed significantly higher total DM
production (26%) with higher legume content compared with that of perennial ryegrass-white
clover pasture (Goh & Bruce 2005).

Pembleton et al. (2014) reviewed more recent evidence for the effect of pasture diversity on
DM production under dairy grazing. They had identified a range of results which indicated from
no increase (Woodward et al. 2013) to 43% increase (Sanderson et al. 2005) in annual pasture
DM production. They concluded that results from Australian and New Zealand experiments
suggested that in situations where a benefit will occur with diverse pastures, it will be in the
order of a 9 to 15% improvement. There were no reports of a diverse pasture being less
productive than the simple pasture to which it was compared. However, an important point
noted was that in all experiments reported an environmental effect on yield, either as an inter-
year effect (wet versus dry years) or an intra-year effect (spring versus summer).

An interesting point is that the benefits in the productivity of diverse pastures in dairy systems
have been observed with as few as three species. For example, Sanderson et al. (2005) showed
that increasing the species diversity in cocksfoot (Dactylis glomerata L.) and white clover dairy
pastures from three to either six or nine species by sequentially adding chicory (Cichorium
intybus L.), tall fescue (Schedonorus arundinaceus Roem. & Schult.), Kentucky bluegrass (Poa
pratensis L.), red clover (Trifolium pratense L.), birdsfoot trefoil (Lotus corniculatus L.),
lucerne (Medicago sativa L.) and perennial ryegrass added little benefit in terms of annual
pasture DM production. These findings were similar to those found for beef cattle pastures with
a similar range of species (Tracy & Faulkner 2006). Further, it is noteworthy that the identity
of the plants contributing to the pasture may be more important factor contributing to the
increase in pasture DM yield rather than the number of species (Sanderson et al. 2004). In
grazed pastures, the observation is supported by the reports of New Zealand pastures containing
perennial ryegrass, white clover, red clover, prairie grass (Bromus willdenowii Kunth.), chicory,
plantain (Plantago lanceolata L.) and lucerne (Woodward et al. 2013), south west Victorian
pastures containing tall fescue, cocksfoot, white clover, red clover and chicory (Tharmaraj et
al. 2008, 2014). In these cases, the increase in summer DM production was associated with the presence of drought tolerant and heat tolerant species like chicory, lucerne and plantain.

2.2.2 Dry matter production and water use efficiency

Studies have generally displayed a linear relationship between yield and evapotranspiration (water use) for a given pasture species over a wide range of regions and years (Bauder et al. 1978; Smeal et al. 1992; Smeal et al. 2005; Mills 2007). Studies have shown that water use efficiency (WUE) decreased as water application decreased below optimum irrigation where losses from runoff and drainage were negligible (Smeal et al. 1992; Smeal et al. 2005). Moreover, Smeal et al. (1992) highlighted differences in WUE among pastures at low levels of water availability. Brown et al. (2005) showed lucerne yielded 17.5 to 21 t DM/ha/yr under dryland conditions, which was 30-50% greater than chicory or red clover. This was due in part due to differences in rooting depth and ability to extract water from deeper in the soil profile. Brown et al. (2003) showed that chicory and red clover extracted approximately 330 mm total water supply, which was lower than lucerne with 358 mm. In an extensive set of experiments in Australia (Neal et al. 2009), growth of perennial forages was recorded in response to optimal and deficit irrigation. The key findings were deficit irrigation reduces the yield of all the perennial forages, with lucerne the most tolerant species to water deficit with only a 22% decrease in mean yield; the least tolerant was white clover with more than a 70% decrease. The large difference in tolerance between lucerne and white clover to deficit irrigation is apparently related to root systems and ability to adapt to drought. Lolicato (2000) showed that lucerne was capable of extracting water from up to 2 m and this was highly correlated with yield.

While existence of variation among species in water use has been observed, these results arise largely for pure swards of the species, and there is less information where the species are grown as part of a mixture. In the United States, Skinner et al. (2006) reported greater DM production from a five species mixture containing chicory, meadow fescue, perennial ryegrass, cocksfoot and white clover than a simple perennial ryegrass/white clover mixture under three water regimes, with the greatest difference occurring the summer water stress period treatment. The mixture not only extracted more water from deeper in the soil profile but also increased the water remaining in the top 30 cm. Relative growth rates of chicory and white clover were greater in the 5 species mixture. Further work needed to evaluate the role of mixtures containing legumes and herbs in dairy systems in terms of their WUE.
2.2.3 Nutritive value of diverse pastures

Harvesting a diet of high nutritive value is a key factor affecting performance of dairy cows, with key forage composition factors being, metabolisable energy (ME), crude protein, neutral detergent fibre and acid detergent fibre. A reduction in the nutritive value of perennial ryegrass occurs due to reproductive stem development. Burke et al. (2002) showed that the ME content of perennial ryegrass declined from 11 MJ ME/kg DM in spring to between 7.6 and 9 MJ/kg DM in summer (Burke et al. 2002). Additionally, crude protein (CP) also declined from 21.5 to 14% over the same period (Litherland et al. 2002).

Inclusion of a legume in the pasture generally improves the quality of the ruminant’s diet and animal performance (Jefferson et al. 2002; McGraw & Nelson 2003). This is because the leaves of legumes tend to have higher CP levels and cell soluble carbohydrates than grasses at similar stages of maturity (Holechek et al. 2004). Legume are often noted to have high ME contents than grasses (Waghorn 2007). In a comparison of white clover and ryegrass, ME declined less in white clover than perennial ryegrass as the regrowth interval increased, and was less affected by an increase in temperature (Waghorn 2007). Less information is available on the nutritive value of red clover and lucerne. However, Brown et al. (2005) noted that lucerne, red clover and chicory had similar ME content, but red clover and lucerne had higher crude protein content (2%-29%) than chicory. Chicory has variable crude protein levels of 134–244 g/kg DM (Crush & Evans 1990) which is lower than legumes, but higher than perennial ryegrass (Li & Kemp 2005). The ME content in chicory is also 11% higher than the perennial ryegrass (Li & Kemp 2005). Plantain compared with perennial ryegrass, has similar physical breakdown characteristics, a lower proportion of cell wall, less cellulose, less neutral and acid detergent fibre but less crude protein, less water soluble carbohydrate and more lignin (Stewart 1996).

It is also possible that species diversity could improve nutrient supply to the animal and in turn nutrient synchrony within the digestive system (Hall & Huntington 2008; Hersom 2008; Yang et al. 2010). However, this likely to be mediated through the inclusion of species that have lower NDF contents and digestibility parameters (i.e. legumes and forbs), rather than an effect of the pasture diversity itself (Sanderson et al. 2006)

2.2.4 Milk production from diverse pastures

There has been limited research to date of the effect of pasture diversity on milk production. Results from American studies show that no increase in milk production from cows grazing a diverse pasture containing tall fescue, cocksfoot, Kentucky bluegrass, red clover, birdsfoot trefoil, lucerne, chicory and perennial ryegrass compared to cocksfoot/white clover pasture
Later, Soder et al. (2011) showed that cows grazing forage mixtures of 3 to 9 species mixtures containing cocksfoot, tall fescue, perennial ryegrass, Kentucky bluegrass, birdsfoot trefoil, red clover, white clover, lucerne and chicory compared to orchardgrass and white clover mixtures showed no increase in milk production. Although increasing pasture species and complexity of the forage mixtures did not improve milk productivity or intake of lactating dairy cows, the cows all maintained high levels of production (Soder et al. 2011).

In New Zealand based studies, greater milk production has been observed in some seasons from diverse pastures compared with simple pastures (Totty et al. 2013; Woodward et al. 2013). In these studies, improvements in milk production have been observed across a range of levels of diversity with pastures ranging from three up to seven species (perennial ryegrass, white clover, tall fescue, prairie grass, chicory, plantain and lucerne; Woodward et al. 2013). However, increases in milk production with greater sown species diversity are not consistently observed from season to season (Woodward et al. 2013). On the occasions where increased milk production has occurred, it has been associated with increasing proportions of legumes (red clover and lucerne) and forbs (chicory and plantain) in the diet (Chapman et al. 2008; Totty et al. 2013; Woodward et al. 2013). Diversity within a pasture may also potentially allow greater opportunities for selective grazing, however, this effect may be restricted to high forage allocations that allow selection to occur.

### 2.2.5 Nitrogen losses from diverse pastures

Perennial ryegrass-white clover pastures are high in crude protein, typically above 20% of DM (Litherland & Lambert 2007) with high solubility, resulting in a large proportion of dietary N being excreted in the urine (Tamminga 1992). Urinary nitrogen (UN) excreted by dairy cattle is a significant environmental concern for the New Zealand dairy industry because nitrate (NO$_3$) derived from UN contributes to ground and surface water contamination, and volatilised nitrous oxides contribute to the greenhouse gas problem (Di & Cameron 2002; Cameron et al. 2013).

Approaches to reduce UN excretion in grazing systems include utilisation of ryegrass cultivars with lower CP (Miller et al. 2001; Moorby et al. 2006; Totty et al. 2013) or using plant species with higher rumen undegradable protein (Totty et al. 2013) which divert the dietary N away from urine (Woodward et al. 2009). With a higher proportion of rumen undegradable protein, the amount of calculated blood urea will be reduced and therefore lower the amount of N excreted in urine (Tas 2006; Gregorini et al. 2010).

Recently, increased interest has emerged around the role of alternative plant species in altering protein intake of dairy cows and ultimately reducing the environmental impacts of dairy
farming in NZ. Studies have shown that the use of diverse pastures comprising grasses, legumes and herbs can reduce UN excretion in late lactating cows, without negatively impacting milk yield (Totty et al. 2013; Woodward et al. 2013). This offers the prospect of increasing milk production at a farm system level without increasing the N footprint. Results from Woodward et al. (2013) shows that mixed pasture containing prairie grass, chicory, plantain and lucerne added to standard perennial ryegrass-white clover based pasture can produce as much DM per year and produce at least as much milk as cows grazing standard pasture. Similarity, an indoor trial (Woodward et al. 2012) showed lactating dairy cows fed mixed pasture partitioned more feed nitrogen intake into milk than cows fed on standard pasture (23% versus 15%). Furthermore, cows fed on mixed pasture have less feed nitrogen wasted in the urine than cows fed on standard pasture (29% versus 43%), which halved the UN output of cows fed mixed pasture than the standard pasture (100 g N/cow/day versus 200 g N/cow/day) (Woodward et al. 2012). Another study (Totty et al. 2013) showed 30 to 34% reduction in urinary concentration with cows grazing diverse pastures containing chicory and/or plantain compared to standard ryegrass-white clover pastures. The exact reasons for the reduced concentration and amount of N excreted are unclear, however, it may not just reflect reduced N intake by cows (Totty et al. 2013). These results on mixed pastures shows great potential and could be used on dairy farms to help improve nitrogen use efficiency of cows and reduce nitrate leaching and nitrous oxide emission. This is likely, however to be dependent on sustaining a high proportion of herbs in pasture through time.
2.3 Conclusion

Perennial ryegrass and white clover pastures have been extremely successful as a production base in pastoral agriculture in NZ. However, both species have shallow roots, which limits their access to soil water and herbage production during dry periods. There are advantages of diverse pastures over simple pastures in terms of overall herbage DM production, seasonal distribution of forage supply, pasture stability, nutritive value, animal production and environmental outcomes. A combination of grasses, legumes and herb species, offer great possibilities to achieve farm profitability and stability. But there is limited data on production and nutritive value in irrigated systems grazed by dairy cows. Therefore, to validate the claim that alternative plant species in a diverse mixture perform better than simple perennial ryegrass-white clover mixture, a study on herbage DM production, nutritive value and water use of these alternative pasture species would be appropriate, specifically for irrigated dairy systems in Canterbury.
Chapter 3
Productivity of rotationally gazed simple and diverse pasture mixtures under irrigation in Canterbury

3.1 Introduction

The focus of dairy farming on simple and productive forage systems has led to a limited range of plants being used, predominantly perennial ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.) pastures, with some brassica and maize. There has been relatively low adoption of more diverse mixtures containing alternative legumes such as red clover (*Trifolium pratense* L.) and lucerne (*Medicago sativa* L.), or forage herbs such as chicory (*Chicorium intybus* L.) and plantain (*Plantago lanceolata* L.). With a growing awareness of the role that plant species may play in reducing the environmental impacts of dairy farming (Moir *et al.* 2012), concerns about the poor persistence of perennial ryegrass (Parsons *et al.* 2011), and the need for improved herbage quality in spring and both quality and quantity in dry summers (Clark *et al.* 1997), there has been increased interest in the use of alternative plant species in more diverse mixtures. Alternatively, drought resistant species could be successfully integrated into ryegrass-white clover mixtures to increase late spring, summer and autumn production in either irrigated or dryland farming systems, provided with a management practice that is beneficial to all sown species (Purves & Wynn-Williams 1989; Moloney & Milne 1993).

In studies in extensive low input grasslands, increased plant diversity has been linked to greater herbage DM production, more efficient use of available water, reduced nitrate leaching and greater resistance to weed invasion (Sanderson *et al.* 2004; Lee *et al.* 2013). However, there are limited data on the performance of intensively managed diverse pastures under grazing. Recent research has investigated the effect of pasture diversity on pasture production around the world. Major research carried out in northern part of USA (Deak *et al.* 2004; Skinner *et al.* 2004; Tracy & Sanderson 2004a; Sanderson *et al.* 2005; Skinner *et al.* 2006; Deak 2007) shows clearly that not only the number of pasture species is important but also species identity and significant species role in achieving increased pasture production (Deak *et al.* 2004; Sanderson *et al.* 2005; Skinner *et al.* 2006; Deak 2007). In New Zealand, research on diverse pasture mixtures has focused on comparing multi-species of pastures with perennial ryegrass-white clover pasture under both dryland and irrigated pastures grazed by sheep (Daly *et al.* 1996; Goh & Bruce 2005). Daly *et al.* (1996) suggests that multi-species pastures (MSP) can be considered as a serious option for dryland pastoral farming. Further, Goh and Bruce (2005) suggested that
alternative pasture mixtures under irrigated farming systems produce significantly higher DM production, higher legume content and higher nutritive value than simple perennial ryegrass/white clover pastures. However, the long-term performance and persistence of this alternative and multi-species pasture has yet to be determined under dairy grazing and further monitored to allowed better assessment of their value as permanent pastures.

In this chapter, herbage DM production and water use of irrigated rotationally grazed dairy pasture are examined. The objectives were to determine the annual and seasonal herbage DM production, botanical composition and nutritive value of two species mixtures of perennial ryegrass (standard and high sugar) and tall fescue (Schedonorus arundinaceus Roem. & Schult.) sown with white clover compared with more diverse mixtures where additional herbs (chicory and plantain), legumes (lucerne or red clover) and grasses (prairie grass; Bromus willdenowii Kunth.) were added to the two species mixtures. In this study, assessment on simple pastures and diverse pastures was carried out in a large scale paddocks reflecting the current situation of typical irrigated dairy farm in New Zealand.

3.2 Material and methods

3.2.1 Site and experimental design

This experiment was conducted at the Lincoln University Research Dairy Farm (LURDF), Canterbury, New Zealand (43° 38'S, 172° 27' E, 11 m a.s.l). The soil type was a Paparua sandy loam with 15-45 cm of fine sandy loam ranging from dark brown to yellowish brown colour (Gregg 1976). The experiment was a randomised block design consisting of three base pasture types and two levels of diversity. A 9 ha area was divided into three blocks each of 3 ha using permanent double wire fencing and each block was sown into six treatment paddocks each of 0.5 ha. The treatment paddocks were randomly allocated to six pasture treatments (Table 3.1). The treatments were based on three simple two species mixtures of perennial ryegrass-white clover (RG), high sugar ryegrass-white clover (HS), and tall fescue-white clover (TF) pastures, and three diverse pasture mixtures of more than four species where herbs (chicory and plantain), legumes (red clover or lucerne) and prairie grass were added to the simple pasture mixtures (RGD, HSD, TFD) (Table 3.1). Pastures were sown into a ploughed and cultivated seedbed on 4 February 2010 using a coulter drill with a 7.5 cm row spacing.
Table 3.1  Plant species, cultivar names and sowing rates (kg seed/ha) of simple and diverse pasture mixtures.

<table>
<thead>
<tr>
<th>Species</th>
<th>Common name</th>
<th>Cultivar</th>
<th>Simple</th>
<th>Diverse</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Lolium perenne</em> L.</td>
<td>Perennial ryegrass</td>
<td>One50-AR1</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td><em>Lolium perenne</em> L.</td>
<td>High sugar ryegrass</td>
<td>Abermagic</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td><em>Schedonorus arundinaceus</em> Roem. &amp; Schult.</td>
<td>Tall fescue</td>
<td>Advance</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td><em>Bromus wildenowii</em> Kunth.</td>
<td>Prairie grass</td>
<td>Ceres Atom</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td><em>Medicago sativa</em> L.</td>
<td>Lucerne</td>
<td>Torlesse</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td><em>Trifolium pratense</em> L.</td>
<td>Red clover</td>
<td>Colenso</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><em>Trifolium repens</em> L.</td>
<td>White clover</td>
<td>Kopu 2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><em>Plantago lanceolata</em> L.</td>
<td>Plantain</td>
<td>Tonic</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>Chicorium intybus</em> L.</td>
<td>Chicory</td>
<td>Choice</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

**Total number of species**  2  2  2  6  4  6

Note: RG: Perennial ryegrass/white clover, HS: High sugar ryegrass/white clover, TF: tall fescue/white clover, RGD: Perennial ryegrass/white clover +prairie grass +red clover + plantain + chicory, HSD: High sugar ryegrass/white clover + plantain + chicory, TFD: Tall fescue/white clover + prairie grass + lucerne + plantain + chicory.

### 3.2.2 Grazing management

From late-August to mid-May each year, all paddocks were rotationally grazed by Friesian–Jersey dairy cows. Grazing generally occurred when ryegrasses had reached approximately the 2.5- to 3-leaf stage. Cows were removed from the paddocks when the pasture height was approximately 3–4 cm. Paddocks were grazed nine times between June 2010 and May 2011 and 10 times between June 2011 and May 2012. All pasture mixtures were cut for silage in November 2011 and January 2012. The mixtures were fertilised with 200 kg N/ha/yr which was applied in four applications of 50 kg N/ha as urea each in early spring, mid spring, mid summer and mid autumn. Note that the rate of fertiliser was based on dairy farms practices in Canterbury, under irrigation rates are typically higher. In forage value index work on species interaction trial (which is grass-clover), low N is 150 kg N/ha and high N 400 kg N/ha for Canterbury irrigated based an industry estimates (Chapman et al. 2013). Study plots were irrigated using a travelling lateral irrigator between October and March 2010/11 (499 mm) and between November and March 2011/12 (368 mm) with approximately 20–30 mm of water applied per week.
3.2.3 Meteorological data

Rainfall and air temperatures for the measurement period are presented in Figure 3.1. Total rainfall during the first year of experiment (670 mm) was slightly higher than the average long-term rainfall of the last 30 years (599 mm). However, rainfall in the second year (548 mm) was slightly lower than the average long-term rainfall as depicted in Figure 3.1(a). The monthly air temperatures (Figure 3.1b) showed a similar trend to the long-term average air temperature.

![Figure 3.1](image-url)

**Figure 3.1** Mean monthly rainfall (a) and mean monthly air temperature (b) from June 2010 to May 2012 and comparison with 30 years (1981–2010) observation data at Lincoln, Canterbury, New Zealand. Data collected from Broadfields Meteorological Station, 1 km from the research site.
3.2.4 Data collection

3.2.4.1 Herbage dry matter production

Herbage mass was measured weekly with a calibrated rising plate meter (RPM, Jenquip, Filip's EC-09 Electronic Folding Plate Meter) (50 readings per paddock). Calibration measurements for each pasture mixture, pre (n = 18) and post-grazing (n = 18) were collected each season. Immediately prior to cutting two RPM measurements were recorded in the area to be harvested (quadrat = 0.2 m²). All live material were removed to ground level (0.5–1.0 cm stubble heights). Any soil contaminants in the samples were removed by hand and samples were oven-dried at 65°C for at least 48 hours, weighed, and DM determined. Calibration equations for each pasture mixture were determined by linear regression (Table 3.2).

<table>
<thead>
<tr>
<th>Pasture mixture</th>
<th>Equation</th>
<th>( R^2 )</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS</td>
<td>( \text{kg DM/ha} = 34.9 + 136.6 \text{RPM} )</td>
<td>0.84</td>
<td>4.16</td>
</tr>
<tr>
<td>RG</td>
<td>( \text{kg DM/ha} = 150.4 + 132.5 \text{RPM} )</td>
<td>0.76</td>
<td>5.23</td>
</tr>
<tr>
<td>TF</td>
<td>( \text{kg DM/ha} = 139.4 + 118.5 \text{RPM} )</td>
<td>0.81</td>
<td>3.95</td>
</tr>
<tr>
<td>HSD</td>
<td>( \text{kg DM/ha} = 450.5 + 105.3 \text{RPM} )</td>
<td>0.86</td>
<td>2.90</td>
</tr>
<tr>
<td>RGD</td>
<td>( \text{kg DM/ha} = 381.4 + 99.1 \text{RPM} )</td>
<td>0.80</td>
<td>3.41</td>
</tr>
<tr>
<td>HSD</td>
<td>( \text{kg DM/ha} = 610.6 + 83.5 \text{RPM} )</td>
<td>0.80</td>
<td>2.90</td>
</tr>
</tbody>
</table>

Note: RPM represent ‘click’ which is 0.5 cm per ‘click’, S.E. is the standard error of mean. Treatment code: RG: Perennial ryegrass/white clover, HS: High sugar ryegrass/white clover, TF: tall fescue/white clover, RGD: Perennial ryegrass/white clover +prairie grass +red clover + plantain + chicory, HSD: High sugar ryegrass/white clover + plantain + chicory, TFD: Tall fescue/white clover + prairie grass + lucerne + plantain + chicory.

Grazing records of each paddock were kept so herbage growth rate (kg DM/ha/day) could be estimated by comparing the previous RPM reading and the date of grazing. A new regrowth period was considered to commence following each grazing. Herbage DM production was then calculated on annual and seasonal basis (winter: June – August, spring: September–November, summer: December–February and autumn: March–May).

3.2.4.2 Botanical composition

Botanical composition was measured prior to each grazing by cutting four quadrats, each 0.2 m², in each paddock to 1 cm above ground level at four random locations throughout each paddock using electric hand shears. Fresh sub-samples of around 200 g were dissected into sown grass, herbs, legumes, weeds and dead material before dry weight of each component were determined. The dry botanical composition data were grouped according to season and were presented on seasonal basis. Later, all dried samples were bulked together according to pasture treatments for nutritive value analysis.
3.2.4.3 Plant population
The number of individual plants of each species was counted in all plots by digging up two drill each $2 \times 1$ m in each plot and counting number of plants of each species in diverse pastures only. Population counts were carried out in middle of autumn (April) and spring (October) in each year. Ryegrasses, tall fescue and prairie grass populations were omitted as they were difficult to count.

3.2.4.4 Nutritive value analysis
The oven dried sub-samples from botanical composition analysis were bulked for analysis following grinding to pass through a 1 mm stainless steel sieve. Samples were analysed using near infrared spectroscopy (NIRS) for crude protein (CP), digestible organic matter (DOMD), neutral detergent fibre (NDF) and water-soluble carbohydrate (WSC) by Lincoln University Analytical Laboratory. Calculation of metabolisable energy (ME) was derived from formula provided by McDonald et al. (2002), where $\text{ME (MJ/kg DM)} = 0.016 \text{ DOMD}$. ME for all pasture mixtures was based on these equations.

3.2.5 Statistical analysis
Total annual herbage DM production (kg DM/ha), pasture growth rate (kg DM/ha/day), botanical composition, nutritive value, water use and water use efficiency were analysed by two-way factorial ANOVA (3 base pastures $\times$ 2 level of diversity) using the statistical package GenStat, version 12.2 (VSN International Ltd 2010). The establishment phase for pasture growth was defined as Year 1 from June 2010 to May 2011 and Year 2 are from June 2011 to May 2012. The herbage DM production at each harvesting point were grouped into seasonal basis and accumulated into annual DM production before being analysed by ANOVA. Botanical composition data collected at each grazing were averaged across season prior to analysis. Means were separated using Fisher’s protected least significant difference test whenever the ANOVA indicated a significant treatment effect.
3.3 Results

3.3.1 Herbage DM production

Annual herbage DM production of treatment means for each mixture at time and diversity across the year was ranged from 14.5 to 17.6 t DM/ha and averaged across two years was higher (significant at $P=0.08$) in diverse (16.8 t DM/ha) than simple (15.2 t DM/ha) pastures (Table 3.3). In the first year, annual herbage DM production was similar in RG-based (17.6 t DM/ha) and HS-based (16.1 t DM/ha) pastures, and RG-based pastures had greater herbage DM production than TF-based pastures (14.5 t DM/ha) (Table 3.3). In the second year, total herbage DM production was unaffected by base pasture type. In the first year, winter and spring herbage DM production was lower ($P<0.05$) in TF-based pastures than RG-based and HS-based pastures (Table 3.3). Diverse pastures produced 0.87 t DM/ha more ($P<0.05$) herbage DM than simple pasture mixtures in summer of the first year (Table 3.3). Annual and seasonal herbage DM production were unaffected by the interaction of base pasture type and diversity.

3.3.2 Herbage growth rate

Herbage growth rate of treatment means for each mixture at time and diversity across the year was ranged from 7.7 to 92.1 kg DM/ha/day and averaged across two years was higher ($P=0.07$) in diverse (45.3 kg DM/ha/day) than simple (40.7 kg DM/ha/day) mixtures (Figure 3.2). The average pasture growth rate in RG-based (45.2 kg DM/ha/day) and HS-based (41.3 kg DM/ha/day) pastures was higher ($P<0.05$) than TF-based pastures (37.3 kg DM/ha/day) in the first year, while in the second year, herbage growth rate were unaffected by base pasture type.

During June and July at Year 1, pasture growth rates were greater ($P<0.001$) in RG-based pastures than HS-based and TF-based pastures (Figure 3.2). In the second year, a significant difference in herbage growth was only recorded in September, where HS-based (44.5 kg DM/ha/day) pastures had higher ($P<0.05$) growth rates than RG-based (30.4 kg DM/ha/day) and TF-based (34.2 kg DM/ha/day) pastures (Figure 3.2). The herbage growth rate for diverse pastures was 17.2 kg DM/ha/day more ($P<0.05$) than simple pastures in February (summer) of the first year (Figure 3.2). Herbage growth rate were unaffected by the interaction of base pasture type and diversity.
Table 3.3  Effect of base pasture and diversity on annual and seasonal DM production (t DM/ha) from June 2010 to May 2012 in Lincoln University Research Dairy Farm, Canterbury, New Zealand. P-values from ANOVA for main effects of base pasture and diversity are shown. Means followed by different letters within a row are significantly different (P<0.05), according to least significant difference test (LSD, α=0.05) following a significant ANOVA.

<table>
<thead>
<tr>
<th>Season</th>
<th>Base pasture treatment (B)</th>
<th>Diversity treatment (D)</th>
<th>B*D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HS</td>
<td>RG</td>
<td>TF</td>
</tr>
<tr>
<td>Winter 2010</td>
<td>2.03a</td>
<td>2.92b</td>
<td>1.99a</td>
</tr>
<tr>
<td>Spring 2010</td>
<td>5.30b</td>
<td>5.48b</td>
<td>4.22a</td>
</tr>
<tr>
<td>Summer 2011</td>
<td>6.26</td>
<td>6.11</td>
<td>5.89</td>
</tr>
<tr>
<td>Autumn 2011</td>
<td>2.52</td>
<td>3.03</td>
<td>2.43</td>
</tr>
<tr>
<td>Winter 2011</td>
<td>0.91</td>
<td>1.04</td>
<td>1.25</td>
</tr>
<tr>
<td>Spring 2011</td>
<td>6.43</td>
<td>5.42</td>
<td>5.36</td>
</tr>
<tr>
<td>Summer 2012</td>
<td>6.77</td>
<td>6.70</td>
<td>6.80</td>
</tr>
<tr>
<td>Autumn 2012</td>
<td>2.48</td>
<td>2.35</td>
<td>2.06</td>
</tr>
<tr>
<td>Year 1</td>
<td>16.10ab</td>
<td>17.55b</td>
<td>14.53a</td>
</tr>
<tr>
<td>Year 2</td>
<td>16.58</td>
<td>15.52</td>
<td>15.47</td>
</tr>
<tr>
<td>Mean</td>
<td>16.34</td>
<td>16.53</td>
<td>15.00</td>
</tr>
</tbody>
</table>

Note: Base pasture and diversity treatment followed by the same letter are not significantly different according to least significant difference test (LSD, α=0.05), ***P<0.001, *P<0.05, NS – not significant.
Figure 3.2 Herbage growth rate (kg DM/ha/day) of six pastures between June 2010 to May 2012 in Lincoln University Research Dairy Farm, Canterbury, New Zealand. Symbol represents treatment HS (●), HSD (○), RG (▼), RGD (△), TF (■), and TFD (□) pastures. Error equals LSD (α=0.05) for interaction at each time point, where significant effect of base pasture type and diversity incurred.
3.3.3 Botanical composition

The percentage of grass was higher ($P<0.05$), and percentage of legume was lower ($P<0.05$), in simple than diverse mixtures throughout the trial (Figure 3.3). The respective average percentage of grass and legume was 70.1% and 20.1% for simple mixtures and 41.3% and 13.2% for diverse mixtures over the two years of experiment. The percentage of legume was greater ($P<0.05$) in TF-based (20.4%) than RG-based (15.1%) and HS-based (14.6%) pastures throughout the trial. The percentage of herb (chicory plus plantain) in the diverse pastures was high, ranging from 25.4 to 64.8%, with little change between first ($\bar{x} = 39.9\%$) and second ($\bar{x} = 40.0\%$) years (Figure 3.3). The percentage of herb was greater ($P<0.05$) in HSD than RGD and TFD in all seasons except spring 2010 and 2011. The percentage of weed species, mostly grass such as annual poa (Poa annua) and broad-leafed weed such as yarrow (Achillea millefolium) and broad-leaved dock (Rumex obtusifolus) in the study never exceed 11 % of the total botanical composition. RG-based and TF-based pastures had a higher ($P<0.05$) percentage of weed across the measurement period than HS-based pastures.

3.3.4 Plant population

The number of plant/m$^2$ of lucerne, plantain, chicory, white clover and red clover for three diverse mixtures is given in Figure 3.4. Plant population of all species declined over time. The highest ($P<0.05$) mean annual plants/m$^2$ of chicory, plantain, and white clover were recorded in HSD (50.2 plants/m$^2$, 40.9 plants/m$^2$ and 38.5 plants/m$^2$, respectively). The lowest mean annual plants/m$^2$ for chicory, plantain and white clover was recorded in TFD (45.8 plants/m$^2$, 30.3 plants/m$^2$ and 21.2 plants/m$^2$, respectively). Lucerne plants/m$^2$ in TFD pastures declined at around 61%, with 47.5 plants/m$^2$ in Year 1 and 18.5 plants/m$^2$ in Year 2. Red clover plants/m$^2$ in RGD pastures declined from 38.8 plants/m$^2$ in Year 1 and to 20.8 plants/m$^2$ in Year 2.
Figure 3.3 Botanical composition (% of DM in pre-grazing mass) of (a) grasses, (b) herbs, (c) legumes, (d) weeds and (e) dead material for six pastures (Table 3.1) between June 2010 and May 2012. Symbol represents treatment HS (●), HSD (○), RG (▼), RGD (Δ), TF (■), and TFD (□) pastures. Error equals LSD (α=0.05) for interaction at each time point where significant effect of base pasture type and diversity incurred.
Figure 3.4 Mean plants/m² of (a) chicory, (b) plantain, (c) white clover, (d) lucerne and (e) red clover for diverse pastures between June 2010 and May 2012. Symbol represents treatment HSD (●), RGD (○), and TFD (▼) pastures. Error equals LSD (α=0.05) for interaction at each time point where significant effect of base pasture type and diversity incurred.
3.3.5 Nutritive analysis

3.3.5.1 Crude protein
Crude protein (CP) of treatment means for each species at two diversity level across the year was ranged from 185 g/kg DM to 265 g/kg DM, and was highest in autumn of each year (\(\bar{X} = 262\) g/kg DM and 265 g/kg DM in autumn 2011 and 2012, respectively) (Figure 3.5a). There were no differences in annual CP content between diverse (214 g/kg DM) mixtures and simple (217 g/kg DM) mixtures. CP was unaffected by base pasture or diversity mixture (Figure 3.5a).

3.3.5.2 Metabolisable energy
Metabolisable energy (ME) of treatment means for each species at two diversity level across the year was ranged from 11.5 to 12.9 MJ ME/kg DM with little seasonal variation (Figure 3.5b). ME was higher \( (P<0.001) \) in HS-based pastures \( (\bar{X} = 12.4\) MJ ME/kg DM) than RG-based pastures \( (\bar{X} = 12.1\) MJ ME/kg DM) and TF-based pastures \( (\bar{X} = 11.8\) MJ ME/kg DM) in each season (Figure 3.5b). ME was higher \( (P<0.05) \) in diverse mixtures than simple mixtures only in autumn 2011 and autumn 2012. Total ME ranged from 11.5 GJ ME/ha/yr to 82.0 GJ ME/ha/yr throughout the year. Mean annual total ME in Year 1 was higher \( (P<0.05) \) in RG-based (211.8 GJ ME/ha/yr) pastures and lowest was in TF-based (172.0 GJ ME/ha/yr) pastures. However, there were no differences in mean annual total ME in Year 2 between base pasture. Total annual ME was greater in diverse (201.8 GJ ME/ha/yr) mixtures than simple (184.6 GJ ME/ha/yr) mixtures. Mean annual total ME were unaffected by base pasture or diversity mixture interaction.

3.3.5.3 Neutral detergent fibre
Neutral detergent fibre (NDF) of treatment means for each species at two diversity level across the year was ranged from to 231 g/kg DM to 396 g/kg DM and averaged over the trial was greater \( (P<0.001) \) in simple \( (\bar{X} = 368\) g/kg DM) than diverse mixtures \( (\bar{X} = 301\) g/kg DM). In most seasons, NDF was lower \( (P<0.05) \) in HS-based pastures \( (\bar{X} = 313\) g/kg DM) than TF-based pastures \( (\bar{X} = 337\) g/kg DM) and RG-based pastures \( (\bar{X} = 353\) g/kg DM) (Figure 3.5c).

3.3.5.4 Water-soluble carbohydrate
The water soluble carbohydrate (WSC) content of treatment means for each species at two diversity level across the year was ranged from 153 g/kg DM to 302 g/kg DM, and at all dates was higher \( (P<0.05) \) in HS-based \( (\bar{X} = 226\) g/kg DM) than RG-based \( (\bar{X} = 189\) g/kg DM) or TF-based pastures \( (\bar{X} = 172\) g/kg DM) (Figure 3.5d). There was a trend for WSC to be lower in diverse \( (\bar{X} = 186\) g/kg DM) than simple \( (\bar{X} = 206\) g/kg DM) mixtures, with this effect significant in winter 2011 (Figure 3.5d).
Figure 3.5  Seasonal (a) crude protein (g/kg DM); (b) metabolisable energy (MJ ME/kg DM), (c) neutral detergent fibre (g/kg DM) and (d) water-soluble carbohydrate (g/kg DM) for six pasture mixtures from June 2010 to May 2012 in Lincoln. Symbol represents treatment HS (●), HSD (○), RG (▼), RGD (∆), TF (■), and TFD (□) pastures. Error equals LSD (α=0.05) for interaction at each time point where significant effect of base pasture type and diversity incurred.
3.4 Discussion

3.4.1 Effect of base pastures and diverse mixtures on pasture production

Annual DM herbage production averaged across both years for the three base pastures tended to be greater in the diverse than simple pastures. The high DM production of the diverse pasture supports previous results that diverse pastures are at least as good as conventional two species pastures (Ruz-Jerez et al. 1991; Daly et al. 1996; Goh & Bruce 2005; Sanderson et al. 2005). In the current study, the higher DM production primarily reflected increased growth during summer, with approximately 1 t DM/ha more grown over summer in diverse than simple pastures. In turn, the higher herbage growth is likely due to a high abundance of herbs (chicory and plantain) in diverse pastures in summer, which grow rapidly at this time of year given adequate water (Sanderson et al. 2005). Increased legume growth is unlikely to be an explanation as in most seasons the proportion of legume in pasture was lower in diverse than simple pastures.

Perennial ryegrass/white clover pastures are particularly suitable in summer moist or irrigated pastures, where under the appropriate fertiliser and grazing management regime, they form a productive pasture of high quality (Brock et al. 2003). In this experiment, the environment favoured the perennial ryegrass pastures which resulted in annual herbage DM production to be greater in the perennial ryegrass-based pastures (RG and HS) than TF-based pastures in the first but not second year. This supports results by Minnéé et al. (2010) where they found that tetraploid perennial ryegrass had a greater annual yield than tall fescue in the first year of establishment at Waikato and Canterbury. This was due to the rapid establishment of perennial ryegrass resulting in less time to first grazing of perennial ryegrass pastures and up to a 90 % increase in DM production during establishment phase compared with fescue pastures at the Waikato site (Minnéé et al. 2010). Compared to perennial ryegrass pastures, tall fescue pastures is more tolerance to heat (Reed 1996) and drought summer environment (Garwood et al. 1978) that may led to a higher growth rates (McCallum et al. 1992). The difference between year 1 and 2 may be explained by the slower establishment of tall fescue relative to perennial ryegrass (Milne et al. 1997), although the tall fescue was sown in summer, five months prior to measurements begin.

3.4.2 Effect on botanical composition and density

The pastures over the two years were dominated by perennial grasses (ryegrass and tall fescue). It is found that simple mixtures recorded higher grass percentage than diverse mixtures. Further,
over the two years of experiment, the grass percentage in both simple and diverse mixtures
decreased little.

The percentages of herbs in diverse mixtures maintained at about 40% throughout the two years
of the trial. This was despite plant population declining; for example, chicory decreased from
66 plants/m$^2$ to 31 plants/m$^2$ over two years of study. These population declines for chicory are
in line with study of Li and Kemp (2005), who found in Manawatu that chicory declined from
46 plants/m$^2$ in the establishment year to 15 plants/m$^2$ by year 4 in a mixed pasture study. The
difference between herb percentage and plant population data may reflect that plant size
increased and compensated for declining plant numbers (Hume et al. 1995; Li et al. 1997).

The percentages of legume in this study were between 14.6 to 20.4% throughout the trial. The
percentage of legume required to have any significant effect on animal performance is generally
considered to be much higher than the current low average of 10–20% found in many New
Zealand white clover/ryegrass pastures (Chapman et al. 1995; Caradus et al. 1996). Further
findings by Stewart (1984) and Thomson (1984) recommended that a mixed pasture should
contain at least 30% legume, while Harris et al. (1998a) showed summer pasture legume
contents of 50–65% are required to achieve near maximum, per cow, milk production. In this
experiment, total legume approached these targets in summer only when legume content
averaged 24.5% in simple mixtures but only 16.9% in diverse mixtures. There was no evidence
of more legume abundance in many diverse pastures where there was less grass competition. It
seems that herbs increased in abundance where grasses were less abundant and exerted a
competitive effect on the legumes or maybe the combined grass and herb out-competed
legumes.

3.4.3 **Effect on pasture quality**

The metabolisable energy content of all pasture mixtures was high (>11.5 MJ ME/kg DM), and
averaged over two years was marginally greater in simple than diverse pastures (12.18 versus
12.03 MJ ME/kg DM); autumn was the only season where diverse pastures had greater ME.
The greater ME in simple pastures most likely reflects the higher legume proportion in the
simple than diverse pastures, with legumes often noted to have high ME (Waghorn 2007).
Furthermore, pastures were consistently grazed to low pasture residuals preventing build-up of
stem and dead material, meaning grass ME is likely to have been maintained at a high level in
simple pastures. Despite the lower ME in diverse pastures, total ME produced per ha was
greater in diverse (202 GJ ME/ha/yr) than simple (185 GJ ME/ha/yr) pastures due to their higher
DM production.
There was negligible effect of pasture mixture on crude protein content, with values ranging from 185 to 265 g/kg DM. Similar CP content in simple and diverse pastures was also observed in related work using a subset of pastures from this study (Totty et al. 2013). These authors showed greater milksolids production per cow but reduced urine N concentration and urine N excretion per cow from the HSD than RG and HS pastures when offered at the same allowance, demonstrating potential environmental benefits. These findings may also be attributed to lower NDF in diverse (300 g/kg DM) than simple (368 g/kg DM) pastures, most likely due to high chicory and plantain content with lower NDF (Burke et al. 2002). Both CP and NDF values were within the range ranges suggested by Holmes et al. (2002) and Pacheco & Waghorn (2008) to be adequate for milk production in early lactation. The water soluble carbohydrate content was higher (+37 g/kg DM) in the high sugar perennial ryegrass than the standard ryegrass, supporting results obtained by Bryant et al. (2009) in Canterbury.

3.5 Conclusion

Based on these results, the following conclusion can be made:

- Rotationally grazed diverse pastures under irrigation in Canterbury were at least as productive as simple perennial ryegrass and tall fescue-white clover pastures. Ryegrass based pastures produced higher herbage DM production compared to tall fescue based pastures.

- Increased summer growth of diverse pastures could be attributed to a high herb content.

- The herbage and ME production data indicate that diverse pastures may play an important role in promoting greater milksolids production per cow and per ha.

- Together, with data indicating lower N excretion from cows grazing diverse pastures (Totty et al. 2013), the results indicate that diverse pastures containing additional herbs and legumes may play an important role maintaining or increasing milksolids production while reducing the environmental impact of dairy farming.
Chapter 4
Effects of irrigation and pasture diversity on pasture production, botanical composition and nutritive value of pasture under dairy grazing

4.1 Introduction

The most commonly sown pasture in New Zealand is a binary mixture of perennial ryegrass (Lolium perenne L.) and white clover (Trifolium repens L.). While this mixture is suitable for summer moist or irrigated dairy pastures supported by nitrogen (N) fertiliser, they may be less persistent and productive in farming systems subject to drought or periodic moisture stress associated with lack of irrigation (Mills & Moot 2010). Perennial ryegrass and white clover may be prone to water stress due to their shallow rooting system (Brock et al. 2003) and growing points that are exposed to high soil surface temperatures and severe grazing in summer (Watson et al. 1998). Thus, there is a need to consider and evaluate alternative mixtures, that are more persistence and productive where water is restricted. This question is relevant to both unirrigated sites subject to summer dry conditions and irrigated sites where irrigation restrictions occur in summer in response to water storage and availability constraint (Environment Canterbury 2015).

In grassland ecological studies, greater plant diversity has been linked to an ability to tolerate water stress. Study by Tilman and Downing (1994) in native grassland in Minnesota, United States, showed that more diverse pastures were more resistant to water stress, with herbage DM production declining less in diverse than simple grassland. Under dryland condition, Goh and Bruce (2005) reported that there was no significant difference in total DM yield between standard perennial ryegrass-white clover pasture and multi-species pasture (MSP) treatments (consisting more than 15 species grasses, herbs and legumes) although Daly et al. (1996) reported that the MSP treatments significantly produced higher DM yield than that of the standard pasture. However, under irrigation, the MSP treatments showed significantly higher total DM than the standard pasture (Goh & Bruce 2005). Skinner et al. (2006) reported greater herbage DM production of a five species mixture containing chicory (Chicorium intybus L.), meadow fescue (Festuca pratensis Huds.), perennial ryegrass, cocksfoot (Dactylis glomerata), and white clover than a simple perennial ryegrass/white clover pasture under three water regimes, with the greatest difference when a summer water stress period as was included treatment. Later, Deak et al. (2007) showed mixtures containing more than six species of either...
orchardgrass (*Dactylis glomerata* L.) tall fescue (*Schedonorus arundinaceus* Roem. & Schult.), perennial ryegrass, Kentucky bluegrass (*Poa pratensis* L.), red clover (*Trifolium pratense* L.), white clover, birdsfoot trefoil (*Lotus corniculatus* L.), chicory, and lucerne (*Medicago sativa* L.) produced more herbage DM than the two- or three-species mixtures in the spring and summer with a suggestion that herbage production was influenced the greater degree by species composition than species diversity (see Pembleton *et al.* 2014). Further explanation that plants identity contributing to the pasture appears to be more important factor contributing to the increase in pasture DM yield rather than diversity itself (Pembleton *et al.* 2014).

In New Zealand, Daly *et al.* (1996) showed that greater herbage DM production under sheep grazing was obtained from a MSP than a simple perennial ryegrass-white clover pasture in spring and summer. This reflecting inclusion of species with deeper tap roots (i.e. chicory, lucerne) in the mixtures as well as complementary resource use for water and N of the investigated species (Tilman 1999; Høgh-Jensen *et al.* 2006). However, less is known of the effect of pasture diversity on dairy pastures in New Zealand and how herbage DM production responds to a temporary restrict of irrigation.

When assessing the effect of pasture mixture of dairy systems it is not only important to consider DM production but also pasture nutritive value. Key forage attributes include the metabolisable energy, water soluble carbohydrate, crude protein and fibre content of the forage. Previous studies show that forage species vary in forage characteristics (Thom *et al.* 1998; Belesky *et al.* 1999; Skinner *et al.* 2004), and hence changes in botanical composition associated with pasture diversity and water stress may affect pasture nutritive value.

This chapter reports the effects of pasture species mixture and temporary restriction of irrigation on herbage DM production and nutritive value of dairy grazed pastures over two years study in Lincoln, Canterbury. The objective of this study was to determine the annual and seasonal herbage DM production, botanical composition and nutritive value of simple perennial ryegrass/white clover mixtures compared with more complex mixtures where additional herbs, legumes and grasses were added under full and partial irrigation. Pasture mixtures were examined by comparing a base perennial ryegrass/white clover pasture with a more diverse pastures where additional legumes (red clover, lucerne), herbs (chicory, plantain *Plantago lanceolate* L.), grasses (prairie grass *Bromus wildenowii* Kunth., timothy grass *Phleum pratense* L.), herbs + legumes and a multi species mixtures were compared. It was hypothesised that pasture mixtures containing deep root species such as chicory and lucerne, would be less affected by temporary restriction in irrigation in summer. The subsequent chapter (Chapter 5) measured water use by the mixtures.
4.2 Material and methods

4.2.1 Site and experimental area

This experiment was carried out under dairy cow grazing on the Lincoln University Research Dairy Farm (LURDF), Lincoln, Canterbury, New Zealand (43° 38’S, 172° 27’ E, 11 m a.s.l). The soil at this site is categorised as a Paparua sandy loam with 15–45 cm of fine sandy loam ranging from dark brown to yellowish brown colour (Gregg 1976). A soil test carried in May 2011 showed soil pH: 6.1, Olsen P: 26 mg/L, potassium: 0.2 me/100g, calcium: 8.1 me/100g, magnesium: 0.5 me/100g, sodium: 0.2 me/100g, CEC: 14.0 me/100g and sulphate-S: 5.0 mg/kg. The experimental design was four blocks of a 2 × 6 factorial arrangement laid out in a split-plot design with irrigation (full or partial) as the main factor, and pasture mixture (6 mixtures) as the sub-plot factor (Table 4.1). The main plots were 12.6 × 12.0 m, and the subplots were 4.2 × 6.0 m. The site was ploughed and cultivated prior to sowing with cone seeder width using a 7.5 cm row spacing on 15 February 2010.

Pasture treatments were based on a standard pasture of a diploid perennial ryegrass and white clover (S) to which functional groups of legumes (L; lucerne, red clover), grasses (G; prairie grass, timothy grass) and herbs (H; chicory, plantain) were added singly (SH, SL, SG) or in combination (SLH) or all species together (SLHG). This meant that the diversity of functional groups increased from 1 to 2 to 3. Two pasture species were added in each functional group so that pasture species richness increased from 2 to 4 to 6 to 8. Pasture treatments, cultivars and sowing rates used are presented in Table 4.1.

The study was carried out from 1 June 2010 to 31 May 2012. The study area was irrigated with a travelling overhead spray irrigator (Briggs model 15, Rainer Irrigation Ltd, Ashburton, New Zealand) between October 2010 and March 2011 and between November 2011 and March 2012, with approximately 25–30 mm of water applied per week. From October to March of each year, soil water content was monitored every week using a Time Domain Reflectometry (TDR) (0–0.2 m soil depth) (Trace Systems, Model 6050X1, Soil Moisture Equipment, Santa Barbara, California, USA) and a neutron access probe (Troxler Electronic Industries Inc., Model Troxler 4300, Triangle Research Park, North Carolina, USA) (0.2–2.25 m soil depth). The probe was permanently installed in one aluminium neutron probe access tube of 2.5 m in length in the centre of each plot in September 2010.

Pastures were subject to: (1) full irrigation to prevent soil water deficit of 100 mm in the top 1.5 m of soil or (2) partial irrigation corresponding to full irrigation until early to mid January (14 January 2011 and 7 January 2012), then no irrigation for at least 2 months started 14 January
2011 to 10 March 2011 and 7 January to 16 March 2012. After this, irrigation returned to the same irrigation schedule as the full irrigation treatment. Irrigation scheduling was based on the perennial ryegrass/white clover treatment with the same irrigation applied to all pasture treatments. The partial irrigation treatment was designed to simulate the practice of restricted water supply, for example irrigation shortfall and water storage or river supplied irrigation scheme that limits water supply during summer. Total irrigation applied from October 2010 to March 2011, and November 2011 to March 2012 was 562 and 504 mm under full irrigation, and 422 mm and 308 mm under partial irrigation, respectively.

Table 4.1 Species mixtures and component seeding rates (kg/ha) for pasture sown in 15 February 2010.

<table>
<thead>
<tr>
<th>Sown Species</th>
<th>Common name</th>
<th>Cultivar</th>
<th>Pasture mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lolium perenne L.</td>
<td>Perennial ryegrass</td>
<td>One50-AR1</td>
<td>S 10</td>
</tr>
<tr>
<td>Bromus wildenowii Kunth.</td>
<td>Prairie grass</td>
<td>Ceres Atom</td>
<td>SG 10</td>
</tr>
<tr>
<td>Phleum pratense L.</td>
<td>Timothy</td>
<td>Ceres Viking</td>
<td>SH 10</td>
</tr>
<tr>
<td>Medicago sativa L.</td>
<td>Lucerne</td>
<td>Torlesse</td>
<td>SL 10</td>
</tr>
<tr>
<td>Trifolium pratense L.</td>
<td>Red clover</td>
<td>Colenso</td>
<td>SLH 10</td>
</tr>
<tr>
<td>Trifolium repens L.</td>
<td>White clover</td>
<td>Kopu 2</td>
<td>SLHG 10</td>
</tr>
<tr>
<td>Plantago lanceolate L.</td>
<td>Plantain</td>
<td>Tonic</td>
<td></td>
</tr>
<tr>
<td>Chicorium intybus L.</td>
<td>Chicory</td>
<td>Choice</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No of species</th>
<th>Total seeding rate (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>25 21 16 25 28 41</td>
</tr>
</tbody>
</table>


4.2.2 Grazing management

From late-August to mid-May each year, all plots were grazed in common by about 50 Friesian × Jersey dairy cows over a period of 2–3 hours period. Grazing generally occurred when the grass had reached approximately the 2.5- to 3-leaf stage, which gave grazing intervals ranging from 21–28 days. Cows were removed from the plots when the pasture height was approximately 3–4 cm height (approximately 1500 kg DM/ha) as determined by rising plate meter (RPM, Jenquip, Filip's EC-09 Electronic Folding Plate Meter). Paddocks were grazed 9 times over the period of June 2010 to May 2011 and 10 times over the period of June 2011 to May 2012. All pastures were grazed at the same time with no differentiation based on pasture mixture or irrigation management. On occasion when grazing was uneven, paddocks were mown to the same pasture heights of 4 cm. The mixtures were fertilised with 100 kg N/ha/year, which was applied after grazing in 4 applications of 25 kg N/ha as urea each in early-spring, mid-spring, mid-summer and mid-autumn.
4.2.3 Measurements

4.2.3.1 Herbage dry matter production
Pasture height was measured weekly with a rising plate meter (RPM, Jenquip, Filip's EC-09 Electronic Folding Plate Meter) by 20 readings per plot. The RPM height measurements were calibrated to herbage mass for each pasture mixture by calibration cuts pre (n = 36) and post-grazing (n = 36) in each season in each mixture. Immediately prior to cutting, two RPM measurements were taken in the area to be harvested of the quadrat (0.2 m$^2$). All live material was removed to ground level (0.5–1.0 cm stubble height). Soil contaminants in the samples were removed by hand and samples were oven-dried at 65°C for at least 48 hours, weighed, and DM determined. Linear regression was performed to determine calibration equations for each mixtures. Calibrated equations for full irrigated and partial irrigation pasture mixtures were given in Table 4.2.

Grazing records of each paddock were kept so herbage growth rate (kg DM/ha/day) could be estimated between the previous RPM reading and the date of grazing. A new regrowth period was considered to commence following each grazing. Herbage DM production was then calculated on an annual and seasonal basis (winter: June–August, spring: September–November, summer: December–February and autumn: March–May). Mean growth rate (kg DM/ha/day) was calculated at end of rotation harvests by dividing total herbage DM production (kg DM/ha) by regrowth cycle duration (d).

### Table 4.2 Calibration equations of six pastures mixture under full and partial irrigation.

<table>
<thead>
<tr>
<th>Type of pasture mixture</th>
<th>Equation</th>
<th>$R^2$</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>S full-irrigated</td>
<td>kg DM/ha = 360 + 129RPM</td>
<td>0.75</td>
<td>5.61</td>
</tr>
<tr>
<td>S partial-irrigated</td>
<td>kg DM/ha = 522 + 119RPM</td>
<td>0.70</td>
<td>5.78</td>
</tr>
<tr>
<td>S+G full-irrigated</td>
<td>kg DM/ha = 625 + 108RPM</td>
<td>0.70</td>
<td>5.61</td>
</tr>
<tr>
<td>S+G partial-irrigated</td>
<td>kg DM/ha = 681 + 105RPM</td>
<td>0.70</td>
<td>5.06</td>
</tr>
<tr>
<td>S+H full-irrigated</td>
<td>kg DM/ha = 523 + 103RPM</td>
<td>0.83</td>
<td>3.49</td>
</tr>
<tr>
<td>S+H partial-irrigated</td>
<td>kg DM/ha = 662 + 91RPM</td>
<td>0.79</td>
<td>3.56</td>
</tr>
<tr>
<td>S+L full-irrigated</td>
<td>kg DM/ha = 356 + 122RPM</td>
<td>0.86</td>
<td>3.71</td>
</tr>
<tr>
<td>S+L partial-irrigated</td>
<td>kg DM/ha = 417 + 118RPM</td>
<td>0.82</td>
<td>4.08</td>
</tr>
<tr>
<td>S+L+H full-irrigated</td>
<td>kg DM/ha = 641 + 98RPM</td>
<td>0.80</td>
<td>3.78</td>
</tr>
<tr>
<td>S+L+H partial-irrigated</td>
<td>kg DM/ha = 662 + 93RPM</td>
<td>0.80</td>
<td>3.46</td>
</tr>
<tr>
<td>S+L+H+G full-irrigated</td>
<td>kg DM/ha = 721 + 92RPM</td>
<td>0.81</td>
<td>3.33</td>
</tr>
<tr>
<td>S+L+H+G partial-irrigated</td>
<td>kg DM/ha = 729 + 91RPM</td>
<td>0.78</td>
<td>3.67</td>
</tr>
</tbody>
</table>

Note: RPM represent ‘click’ which is 0.5 cm per ‘click’. Treatment code S: Standard perennial ryegrass/white clover, SG: Standard + grasses (prairie grass, timothy grass), SH: Standard + herbs (chicory, plantain), SL: Standard + legumes (lucerne, red clover), SLH: Standard + legumes + herbs, SLHG: Standard + legumes + herbs + grasses.
4.2.3.2 **Botanical composition**

Prior to each grazing, four quadrats, each 0.2 m², were cut in each plot to 1 cm height above ground level at four random locations using electric hand shears. A fresh sub-sample of approximately 200 g was dissected into sown grass, herbs, legumes, weeds and dead material before oven-dried at 65°C to a constant weight to determine DM%. Botanical composition on a DM basis was then determined. Later, the dried sub-samples were bulked and kept for nutritive value analysis.

4.2.3.3 **Plant population**

The number of individual plants of white clover, red clover, lucerne, chicory and plantain species was counted along two 1-m long drill rows in each plot in middle of autumn (April) and middle of spring (October) of each year. The total number of plant species on a m² basis was obtained by calculating total number of species × 7, based on based on a row spacing of 7.5 cm.

4.2.3.4 **Pasture nutritive value**

Oven-dried sub samples from the bulk sample from botanical composition were ground to pass through a 1 mm stainless steel sieve. Samples were analysed then using near infrared spectroscopy (NIRS) for crude protein (CP), nitrogen content, digestible organic matter (DOMD), water-soluble carbohydrate (WSC) and neutral detergent fibre (NDF) by Lincoln University Analytical Laboratory. Metabolisable energy (ME) was calculated according to the following equation: ME (MJ/kg DM) = Digestible organic matter content × 0.016 (g/kg DM) (McDonald *et al.* 2002).

4.2.4 **Statistical analysis**

Annual and seasonal herbage DM production (t DM/ha), botanical composition, plant population (plants/m²) and nutritive value were analysed by two-way factorial ANOVA of a split plot design (2 level of irrigation × 6 pasture mixtures) using the statistical package GenStat, version 13.0 (VSN International Ltd 2010). The establishment phase for pasture growth was defined as Year 1 from June 2010 to May 2011 and Year 2 are from June 2011 to May 2012. Botanical composition data collected at each grazing were averaged across season prior to analysis. For analysis of herb botanical composition, analysis was restricted to those treatment where herbs were sown (SH, SLH, SLHG). Means were separated using Fisher’s protected least significant difference test (LSD) whenever the ANOVA indicated a significant treatment effect.
4.3 Results

4.3.1 Climate

Rainfall and air temperatures for the measurement period are presented in Figure 3.2 (Chapter 3). Total rainfall during the first year of experiment (670 mm) was slightly higher than the average long-term rainfall of the last 30 years (599 mm). However, rainfall in the second year (548 mm) was slightly lower than the average long-term rainfall (Figure 3.2a). The monthly average air temperatures (Figure 3.2b) showed a similar trend to the long-term average air temperature. The first summer was warm, with average maximum temperatures above 20 °C in December 2010, January, February and March 2011, respectively. The second summer was cooler with only the month of January 2012 where the average maximum air temperature above 20 °C.

4.3.2 Annual and seasonal herbage DM production

Annual herbage DM production ranged from 13.8 to 16.7 t DM/ha in Year 1 and 12.5 to 16.2 t DM/ha in Year 2. Annual herbage DM production was 18–19% (c. 3.0 t DM/ha) greater in the full than partial irrigation over the two year period (Table 4.3).

There was a significant effect ($P<0.001$) of pasture mixture on herbage DM production over the two year period. Annual herbage DM production was 1.2 to 2.7 t DM/ha greater in SLHG and SL than other pastures in Year 1 (Table 4.3). The lowest ($P<0.001$) herbage DM production in Year 1 was recorded in S (13.8 t DM/ha). Annual herbage DM production was 1.2 to 2.7 t DM/ha greater in SLHG and SL than other pastures in Year 2 (15.9 and 16.2 t DM/ha, respectively) (Table 4.3). The lowest herbage DM production in Year 2 was recorded in SG (12.5 t DM/ha). While herbage DM production in most of all pasture mixtures increased from Year 1 and Year 2, there was a slight decline in herbage DM production in SG and SLHG (Table 4.3).

Seasonal herbage DM production ranged from 1.5 t DM/ha (winter 2011) to 6.0 t DM/ha (summer 2012) for full irrigation and from 1.4 t DM/ha (winter 2011) to 4.7 t DM/ha (spring 2011, summer 2012) for partial irrigation (Table 4.3). Full irrigation produced 1.3 t DM/ha greater ($P<0.001$) herbage DM production in summer than partial irrigation (Table 4.3). The greatest decrease ($P<0.001$) in herbage DM production between full and partial irrigation pastures occurred in autumn 2011 (-32%) and autumn 2012 (-35%).
There was a significant effect of the pasture mixture × irrigation interaction \( (P<0.05) \) on herbage DM production averaged across Year 1 and Year 2. The reduction in average herbage DM production between full and partial irrigation was greater in S and SH \( (4.0 \text{ t DM/ha}) \), intermediate in SG, SLH and SLHG \( (2.8 \text{ t DM/ha}) \) and lowest in SL \( (1.7 \text{ t DM/ha}) \) (Figure 4.1). There was a significant pasture mixture × irrigation interaction \( (P<0.05) \) for seasonal herbage DM production in autumn 2011 and summer 2012 (Table 4.3). The interaction between pasture mixture and irrigation treatment in autumn 2011 showed that the reduction in herbage DM production with partial irrigation was greater in S \( (1.5 \text{ t DM/ha}) \), intermediate in SG, SH, SLH, SLHG \( (1 \text{ t DM/ha}) \) and lowest in SL \( (0.6 \text{ t DM/ha}) \). This was similar in summer 2012, with the reduction in the herbage DM production greatest in S \( (2 \text{ t DM/ha}) \), intermediate in SG, SH, SLHG \( (1 \text{ t DM/ha}) \) and lowest in SL \( (0.7 \text{ t DM/ha}) \) and SLH \( (0.6 \text{ t DM/ha}) \).
Table 4.3  The effect of pasture mixture and irrigation on annual and seasonal herbage DM production (t DM/ha) from June 2010 to May 2012 in Lincoln University, Canterbury, New Zealand. P values from ANOVA for main effects and interaction are shown. LSD = least significant difference (α=0.05).

<table>
<thead>
<tr>
<th>Season growth</th>
<th>Pasture mixture (P)</th>
<th>Irrigation treatment (I)</th>
<th>P*I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>SG</td>
<td>SH</td>
</tr>
<tr>
<td>Winter 2010</td>
<td>2.7b</td>
<td>2.7b</td>
<td>2.1c</td>
</tr>
<tr>
<td>Spring 2010</td>
<td>3.8</td>
<td>4.8</td>
<td>4.4</td>
</tr>
<tr>
<td>Summer 2011</td>
<td>4.6bc</td>
<td>4.6bc</td>
<td>4.6c</td>
</tr>
<tr>
<td>Autumn 2011</td>
<td>2.7b</td>
<td>2.6b</td>
<td>2.9b</td>
</tr>
<tr>
<td>Winter 2011</td>
<td>1.7a</td>
<td>1.4bc</td>
<td>1.2c</td>
</tr>
<tr>
<td>Spring 2011</td>
<td>5.3</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Summer 2012</td>
<td>4.6c</td>
<td>3.9d</td>
<td>5.7b</td>
</tr>
<tr>
<td>Autumn 2012</td>
<td>2.6b</td>
<td>2.6b</td>
<td>3.4a</td>
</tr>
<tr>
<td>Year 1</td>
<td>13.8b</td>
<td>14.7b</td>
<td>13.9b</td>
</tr>
<tr>
<td>Year 2</td>
<td>14.3c</td>
<td>12.5d</td>
<td>14.7bc</td>
</tr>
<tr>
<td>Mean</td>
<td>14.1cd</td>
<td>13.6d</td>
<td>14.3c</td>
</tr>
</tbody>
</table>

Means within a row for pasture mixture and irrigation same letter are not significantly different. *** P<0.001, * P<0.05, NS - not significant.

Figure 4.1 Interaction effects of irrigation (full or partial) and pasture mixture on mean annual herbage DM production (t DM/ha/yr) from June 2010 to May 2012 in Lincoln University, Canterbury, New Zealand. Error bar represent standard error of mean. Data are means averaged across 2 years. Treatment code: S: Standard perennial ryegrass + white clover, SG: Standard + grasses (prairie grass, timothy grass), SH: Standard + herbs (chicory, plantain), SL: Standard + legumes (lucerne, red clover), SLH: Standard + legumes + herbs, SLHG: Standard + legumes + herbs + grasses.
4.3.3 Botanical composition

The botanical composition of pastures as a percentage of DM of grasses (perennial ryegrass, prairie grass, timothy grass), herbs (chicory, plantain), legumes (white clover, lucerne, red clover), weeds (i.e. poa *Poa annua*), yarrow *Achillea millefolium*, dock *Rumex obtusifolius*) and dead matter are presented in Figure 4.2 (main effect of irrigation) and Figure 4.3 (main effect of pasture mixture). Over the two years of the study, there was little effect of irrigation on botanical composition. Pasture mixture had a larger effect on botanical composition.

**Grasses (all mixtures)**

The percentage of grass in autumn 2011 and 2012 was higher (*P*<0.01) in full (49 and 48%) than partial (46 and 43%) irrigation (Figure 4.2a). Pasture mixture had a larger effect on grass composition over the two years of study (Figure 4.3a). The percentage of grass over the two year period ranged from 16% (summer 2012) to 95% (winter 2010) with the highest (*P*<0.001) mean annual percentage of grass of 81% in SG and the lowest of 30.4% in SLH. The largest decrease in the percentage of grass from the first to second year of the study was in SLHG (25%) and the lowest decrease was observed in SH (3%). There were no pasture mixture × irrigation interaction for the percentage of grass.

**Herbs**

The percentage of herbs in the pasture on a DM basis ranged from 20.1% (spring 2010) to 54.9% (winter 2010), and changed little from Year 1 (\(\bar{x}=36.9\%\)) to Year 2 (\(\bar{x}=36.7\%\)) (Figure 4.2b). Irrigation did not significantly affect (*P*>0.05) herb botanical composition. Pasture mixture significantly (*P*<0.01) affected the herb botanical composition in all seasons except winter 2011 (Figure 4.3b). The mean herb percentage averaged over 2 years was highest (*P*<0.01) in SH (48.0%) and the lowest of in SLHG (28.0%) (Figure 4.3b). Averaged over the 2 years of study, the percentage of herbs was greater in SH (47.6%) than SLH (35.1%) and SLHG (27.7%). This pattern were similar in all seasons except summer and autumn of each year when SLH and SLHG had a similar percentage of herbs.

**Legumes (all mixtures)**

The percentage of legumes in the pasture on a DM basis ranged from 1.4% to 64.9%, showing a tendency to increase from Year 1 to Year 2 in S, SG, SH and SLHG but not in SL and SLH (Figure 4.3c). Averaged over the 2 years, the percentage of legume was greater (*P*<0.001) in SL (42%), intermediate in SLH (32.6%), SLHG (26.7%), and lower in S (19.8%), SG (13.6%)
and SH (14.2%). The effect of irrigation on percentage of legumes was small, with a significant effect detected in summer 2011 only (31 vs 34 %, $P<0.01$).

*Weeds (all mixtures)*

The percentage of weed was low (<1.2%) and not affected by irrigation and pasture mixture or the interaction (Figure 4.2d and Figure 4.3d).

*Dead material (all mixtures)*

The percentage of dead material ranged from 2.5% to 9.5%, with the peak occurring in summer and autumn (Figure 4.2e). The percentage of dead material was lower in full than partial irrigation in autumn 2011 (5% versus 6%), autumn 2012 (4% versus 6%), and averaged across 2 years (4 versus 6%, $P=0.01$) (Figure 4.2e). The percentage of dead material was highest ($P<0.001$) in S (7.2%), followed by SG (5.7%), SH (4.4%), SL (4.2%), SLHG (3.9%) and SLH (3.1%) over the two years study (Figure 4.3e).
Figure 4.2  Effects of full versus partial irrigation on (a) grass, (b) herbs, (c) legumes, (d) weeds and (e) dead matter percentage (% of DM) from June 2010 to May 2012. Error bar represents LSD (a=0.05) at each time point.
Figure 4.3  Effects of pasture mixture on (a) grass, (b) herbs, (c) legumes, (d) weeds and (e) dead matter percentage (% of DM) from June 2010 to May 2012. Error bars represent LSD ($\alpha=0.05$) at each time point. Treatment code S: Standard perennial ryegrass + white clover, SG: Standard + grasses (prairie grass, timothy grass), SH: Standard + herbs (chicory, plantain), SL: Standard + legumes (lucerne, red clover), SLH: Standard + legumes + herbs, SLHG: Standard + legumes + herbs + grasses.
4.3.4 Plant population

Plant population averaged across full and partial irrigation treatments for white clover, chicory, plantain, lucerne and red clover over the two year experiment shown in Figure 4.4. There was no significant ($P>0.05$) effect of irrigation treatment on plant population of any species. Plant population of all species declined over time. Mean annual plants/m$^2$ of white clover was higher in S (78 plants/m$^2$), while SLH and SLHG the lowest of 32 plants/m$^2$. Mean annual plants/m$^2$ of lucerne was consistently higher in SL (94 plants/m$^2$), while SLH and SLHG the lowest (62 and 57 plants/m$^2$). Population of plantain increase in mixtures with additional herbs (SH, SLH and SLHG) from spring 2010 (20 to 46 plants/m$^2$) to spring 2011 (53 to 68 plants/m$^2$) before dropped to about 11 to 18 plants/m$^2$ in autumn 2012. Seasonal chicory population were maintained to more than 40 plants/m$^2$ in all mixture with additional herbs (SH, SLH and SLHG). Mean annual plants/m$^2$ for red clover increased for SL from 65 plants/m$^2$ in Year 1 to 74 plants/m$^2$ in Year 2, while red clover in SLH and SLHG maintained to about 40 plants/m$^2$. 
Figure 4.4 Seasonal plant population (plant/m²) of (a) white clover, (b) lucerne, (c) plantain, (d) chicory and (e) red clover between all six pasture mixtures from June 2010 to May 2012. Error bars represent standard error of mean. Treatment code S: Standard perennial ryegrass + white clover, SG: Standard + grasses (prairie grass, timothy grass), SH: Standard + herbs (chicory, plantain), SL: Standard + legumes (lucerne, red clover), SLH: Standard + legumes + herbs, SLHG: Standard + legumes + herbs + grasses.
4.3.5 Pasture nutritive value

4.3.5.1 Crude protein
Crude protein (CP) content between full and partial irrigation ranged from 119 to 235 g/kg DM, with the lowest values recorded in spring 2010 (119 g/kg DM) and summer 2011 (163 g/kg DM), and the highest values in winter 2010 (215 g/kg DM) and spring 2011 (235 g/kg DM) (Table 4.4). Irrigation had little effect on CP content, with the effect only significant in summer 2011, with lower CP content in full irrigation than partial irrigation (163 versus 170 g/kg DM). Pasture mixture had a larger effect on annual and seasonal CP content (Table 4.4). Averaged over 2 years, CP content was highest in SL (215 g/kg DM), SLH (210 g/kg DM) and SLHG (210 g/kg DM), intermediate in SH (195 g/kg DM), and lowest in S (195 g/kg DM) and SG (184 g/kg DM).

On a seasonal basis, CP content was significantly different (P<0.01) among mixtures in all seasons except winter 2010, winter 2011 and spring 2011 (Table 4.4). Where significant effects occurred, the general pattern was higher CP content in SL, SLH and SLHG than S, SG and SH. There was a significant interaction between irrigation and pasture mixture (P=0.012, LSD=8.93) for CP content in the summer 2012. CP content increased in SLH, SH, SL and S with irrigation but declined in CP content in SG and SLHG.

4.3.5.2 Metabolisable energy
The metabolisable energy (ME) content between full and partial irrigation ranged from 10.6 to 12.0 MJ ME/kg DM, with the lowest value in summer 2011 (10.6 MJ ME/kg DM) and summer 2012 (10.6 MJ ME/kg DM) and highest in the winter 2010 (11.9 MJ ME/kg DM) and winter 2011 (12.0 MJ ME/kg DM) (Table 4.5). Irrigation had a little effect on ME content. The ME value averaged over 2 years was lower (P<0.05) in irrigated pasture, although the effect was small (11.2 versus 11.3 MJ ME/kg DM) (Table 4.5). Averaged over 2 years, ME content was highest in S (11.5 MJ ME/kg DM) and SH (11.4 MJ ME/kg DM), intermediate in SG (11.3 MJ ME/kg DM), SL (11.3 MJ ME/kg DM), SLH (11.2 MJ ME/kg DM) and lowest in SLHG (11.1 MJ ME/kg DM), but again the differences were small (0.3 MJ ME/kg DM). Seasonal ME content was significantly different (P<0.01) among pasture mixture in all seasons except winter 2010, autumn 2011 and winter 2011 (Table 4.5), with patterns similar to annual patterns. There was a significant interaction between irrigation and pasture mixture (P<0.05) for annual mean averaged over 2 years of study and ME content in winter 2010 and spring 2010. The annual mean ME content was 0.1 MJ ME/kg DM lower (P=0.040, LSD=0.12) in full than partial irrigation plots in S, SG, SLH and SLHG, respectively, while SH and SL found no difference was found (Table 4.5).
4.3.5.3 Neutral-detergent fibre

The neutral detergent fibre (NDF) content between full and partial irrigation ranged from 337 to 421 g/kg DM, with the highest value in summer 2011 (415 g/kg DM) and summer 2012 (421 g/kg DM) and lowest in winter 2010 (337 g/kg DM) and winter 2011 (337 g/kg DM) (Table 4.6). Irrigation treatment had a significant effect on annual and seasonal NDF (Table 4.7). Irrigation increased NDF content consistently in summer (415 versus 393 g/kg DM, \( P=0.001 \)) and autumn (393 versus 381 g/kg DM, \( P=0.001 \)) in Year 1 and also summer (421 versus 408 g/kg DM, \( P=0.002 \)) and autumn (399 versus 380 g/kg DM, \( P=0.003 \)) of Year 2, respectively.

The effect of pasture mixture on NDF content was highly significant (\( P<0.001 \)) on an annual and seasonal basis over the 2 years of study (Table 4.6). Averaged over 2 years of study, NDF content was highest (\( P<0.001 \)) in SG (458 g/kg DM) and S (430 g/kg DM), intermediate in SL (384 g/kg DM) and SLHG (372 g/kg DM) and lowest at SH (327 g/kg DM) and SLH (332 g/kg DM). These patterns were broadly consistent in all season of study. There was a significant effect (\( P<0.001 \)) of the interaction between irrigation and pasture mixture in spring 2010. In SG, SH and SLH, NDF content was greater with full irrigation than partial irrigation (+30, +20, +17.2 g/kg DM, respectively), but for S, SL and SLHG, NDF content was less (22.8, 6.9, 13.2 g/kg DM, respectively) for full irrigation than partial irrigation.

4.3.5.4 Water-soluble carbohydrate

The water-soluble carbohydrate (WSC) content between full and partial irrigation ranged from 107 to 194 g/kg DM, and was lowest in autumn 2011 (108 g/kg DM) and spring 2011 (107 g/kg DM) and highest in winter 2010 (194 g/kg DM) and winter 2011 (194 g/kg DM) (Table 4.7). Averaged over the 2 years of the study, WSC content was greater in full than partial irrigation although the effect was small (139 vs 146 g/kg DM, \( P=0.010 \)) (Table 4.7). Averaged over 2 years of study, WSC content was highest (\( P<0.001 \)) in S (165 g/kg DM) and SG (153 g/kg DM), intermediate in SH (147 g/kg DM) and SL (136 g/kg DM), and lowest in SLH (132 g/kg DM) and SLHG (124 g/kg DM) (Table 4.7). There was a significant (\( P<0.05 \)) effect of pasture mixture on WSC content in all seasons except winter 2010 and winter 2011 (Table 4.7). The general pattern in each season recorded highest WSC in S and SG, and lowest WSC in SLH and SLHG. The exception was spring 2011, when SG had low WSC content similar to SLH.
Table 4.4 The effect of pasture mixture and irrigation on annual and seasonal crude protein (g/kg DM) from June 2010 to May 2012 at Lincoln University, Canterbury, New Zealand. P values from ANOVA for main effects and interaction are shown. LSD = least significant difference (α=0.05).

<table>
<thead>
<tr>
<th>Season growth</th>
<th>Pasture mixture (P)</th>
<th>Irrigation treatment (I)</th>
<th>P*I</th>
</tr>
</thead>
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<td>SG</td>
<td>SH</td>
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</tr>
</tbody>
</table>

Means pasture mixture and irrigation followed by the same letter are not significantly different according to least significant difference test (LSD, α=0.05), *** P<0.001, * P<0.05, NS - not significant.

### Table 4.5  
Annual and seasonal metabolisable energy (MJ ME/kg DM) content between pasture mixture, irrigation treatment and treatment interaction from June 2010 to May 2012 in Lincoln University, Canterbury, New Zealand. P values from ANOVA for main effects and interaction are shown. LSD = least significant difference (α=0.05).

<table>
<thead>
<tr>
<th>Season growth</th>
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<th>Irrigation treatment (I)</th>
<th>P*1</th>
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Means pasture mixture and irrigation followed by the same letter are not significantly different according to least significant difference test (LSD, α=0.05), *** P<0.001, * P<0.05, NS - not significant.

Table 4.6  Annual and seasonal neutral detergent fibre (g/kg DM) content between pasture mixture, irrigation treatment and treatment interaction from June 2010 to May 2012 in Lincoln University, Canterbury, New Zealand. P values from ANOVA for main effects and interaction are shown. LSD = least significant difference (α=0.05).

<table>
<thead>
<tr>
<th>Season growth</th>
<th>Pasture mixtures (P)</th>
<th>Irrigation treatment (I)</th>
<th>P*I</th>
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Means pasture mixture and irrigation followed by the same letter are not significantly different according to least significant difference test (LSD, α=0.05), *** P<0.001, * P<0.05, NS - not significant.

Table 4.7 Annual and seasonal water-soluble carbohydrate (g/kg DM) content between pasture mixture, irrigation treatment and treatment interaction from June 2010 to May 2012 in Lincoln University, Canterbury, New Zealand. P values from ANOVA for main effects and interaction are shown. LSD = least significant difference (α=0.05).

<table>
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<tr>
<th>Season growth</th>
<th>Pasture mixtures (P)</th>
<th>Irrigation treatment (I)</th>
<th>P*I</th>
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Means pasture mixture and irrigation followed by the same letter are not significantly different according to least significant difference test (LSD, α=0.05), *** P<0.001, * P<0.05, NS - not significant.

4.4 Discussion

4.4.1 Herbage dry matter production

The results show a marked effect of restricting summer irrigation on herbage DM production. Averaged across pasture mixtures, full irrigation yielded 2.9 t DM/ha and 3.1 t DM/ha more than partial irrigation in Year 1 and Year 2, respectively. This was primarily due to both lower summer and autumn herbage DM production in partial irrigation. Although, irrigation in the partial irrigation treatment was restored to the same level as the full irrigation treatment at the start of autumn, herbage DM yield was 1.1 and 1.3 t DM/ha lower in autumn with partial irrigation in Year 1 and 2, respectively. The effect of summer irrigation is consistent with previous studies. Thom et al. (1998) showed irrigation improved summer herbage DM production by 1.1 to 1.5 t DM/ha in a two year study of pastures in the Waikato. A study of drought impacts on past productivity at four sites (Waikato, Northland, Canterbury and Manawatu) (Barker et al. 1998) showed summer water deficit reduced annual herbage DM production by an average of 24%; in this study the decline was 21 to 23% in annual herbage DM production.

The results indicate a strong effect of pasture mixture on herbage DM production. Averaged over two years, herbage production was 1 to 2 t DM/ha/yr higher in pastures containing additional legumes (red clover and lucerne; SL, SLH and SLHG) than the standard pasture. Further, the decline in production from Year 1 to Year 2 was lower in SL (0%), SLH (0 %) and SLGH (5 %) than in S. The greater herbage DM production appeared to reflect greater summer and autumn herbage growth, with smaller differences in DM production between pasture mixtures in other seasons. The most likely explanation for the increased growth of the pasture containing legumes is the ability of tap rooted legumes red clover and lucerne to extract water from deeper in the soil profile (Brown et al. 2003) and good heat tolerance of legume, which allows it to keep producing high quality forage during periods of water stress (McGuickin 1983). Also, the experiment was conducted at a relatively low N fertiliser input of 100 kg N/ha/year; under these condition, additional legumes in SL, SLH and SLHG compared to S are likely to have provided inputs of N via N fixation which enhanced growth.

The experiment was designed to also examine whether the effect of partial irrigation was dependent on pasture mixture. In this context, the data indicate strongly that pasture containing additional legumes (SL, SLH, SLHG) were less affected by partial irrigation; restricting irrigation in summer reduced herbage DM production by 1.7 to 2.7 t DM/ha/yr in these mixtures but by 2.9 to 4.1 t DM/ha/yr in S, SG and SH (Figure 4.1). These results suggest that the
presence of the tap rooted legumes lucerne and red clover, by extracting water from deeper in the soil profile (Brown et al. 2003), were important for reducing the impact of partial irrigation in summer; however, this would need to confirmed by soil water measurements. The effect of the legumes is in agreement with previous studies. Neal et al. (2011) showed deficit irrigation led to a significant decline in annual herbage yield and annual WUE for all perennial species (perennial ryegrass, chicory, cocksfoot, kikuyu, paspalum, phalaris, plantain, prairie grass, red clover, tall fescue and white clover) except lucerne. A further feature of the interaction between pasture mixture and irrigation was the large decline in herbage DM production with partial irrigation (-24 %) in the SH treatment. Although this pasture contained the tap rooted herb chicory, it is evident that this species was not able to mitigate the effects of restricted water to the same extent as legume (lucerne and red clover). These findings are consistent with Swan et al. (2014). Deep rooted legumes such as lucerne is a comparatively drought-hardy species capable of withstanding a moderate degree of moisture stress (Swan et al. 2014). By comparison, chicory, through possessing a summer growth habit, is not as drought-hardy as lucerne (Li et al. 2008). Furthermore, lower application of N fertiliser (100 kg N/yr) in this experiment may have influenced the productivity of herbs in the mixtures.

A concern raised over the use of pastures containing additional legumes and herbs is reduced seasoned growth of the mixture, particularly in the cool season. Several studies have recorded lower growth in pure swards in winter from lucerne, red clover, chicory and plantain than perennial ryegrass (White & Lucas 1990). In the current study there was some evidence of lower winter growth where legumes and herbs were dominant in mixture. In Year 1, herbage DM yield in winter was greater in S, or where additional grasses were added (SG and SLHG) than in SL, SH and SLH. These data suggest a role of cool season active species such as prairie grass (Charlton & Stewart 1999) in promoting additional cool season growth in mixtures. However, this seasonal effect appeared to be short-lived as the effect was not evident for spring herbage DM production.

4.4.2 Effects of irrigation and pasture mixtures on botanical

Inclusion of additional legumes in the pasture mixture had a marked effect on legume abundance in the pasture. Compared to S, the percentage of legume was 32.6 % to 42 % higher where lucerne and red clover were sown in the mixture. Further, these effects persisted throughout the two years of the trial; in the last autumn, there were 50 %, 35 % and 34 % legume in SL, SLH and SLHG, respectively. Previous studies have shown that increasing the proportion of legume in diet leads to greater milk production (Nuthall et al. 2000; Marotti et al. 2001; Cosgrove et al. 2006) with the percentage of legume required to have any significant effect on
animal performance is generally considered to be much higher than the current low average of 10–20% found in many New Zealand perennial ryegrass/white clover pastures (Chapman et al. 1995; Caradus et al. 1996). According to Stewart (1984) and Thomson (1984), a mixed pasture should contain at least 30% legume, while Harris et al. (1998a) showed summer pasture legume contents of 50–65% are required to achieve near maximum, per cow, milk production. However, using white clover it has been difficult to achieve high levels of legume in mixed pasture and alternative approaches such as use of spatially separated monocultures have been suggested (Chapman et al. 1996). The current study indicates that within a low N fertiliser regime and rotational grazing management that a better approach to achieve the levels of legume desired may be to use alternative legume species mixed with white clover such as lucerne and red clover.

The proportion of herbs remained high throughout the study (>20%), with similar amounts of chicory and plantain. In the last autumn of the study, chicory and plantain made up 32% and 51% of the herbage DM, respectively. An analysis of the plant populations of chicory and plantain, showed relatively little decline in population through time. Indeed, the plantain population increased perhaps reflecting fragmentation of plants or recruitment of new plants from seeds (Edwards et al. 2005). Previous studies (Li et al. 1997; Kemp et al. 1999a;) have noted a decline in the population of chicory in experiment designed to investigate the impact of different sheep grazing practices on a mixed pastures, with the greatest decline in year 3. Whether populations will decline in current study in third year is not clear. However, it is noteworthy that grazing management of pastures in this trial (graze rotationally to 3–4 cm, at 21 to 28 day intervals) is consistent management to enhance production of herbs (Parker & Kemp 1998).

### 4.4.3 Effects of irrigation and pasture mixtures on pasture nutritive value

The metabolisable energy (ME) content of all pasture mixtures was high (>11.0 MJ ME/kg DM; Table 4.5). Averaged over 2 years, ME was greater in partial irrigation pastures than full irrigated pastures, although the difference was small (11.31 versus 11.26 MJ ME/kg DM). Further, there were small differences in ME among pasture mixtures; averaged across 2 years there was a 0.4 MJ ME/kg DM difference between the mixture with the highest ME (S) and that with the lowest (SLHG). The small differences probably reflect that management of the trial with grazing to a low height (3–4 cm) relatively short intervals all year keeping all pastures in green leafy state and prevented the build-up of dead material. Previous studies note relatively little difference among plant species in the ME of leafy material (Densley et al. 2005; Millner et al. 2011; Westwood & Mulcock 2012). In farming systems ME produced per ha is a key
driver of dairy farm productivity and profitability. In this context, the lower ME observed in some treatments was offset by greater herbage DM production, so that total ME produced per ha was higher. The averaged ME over the two years was marginally greater in S (11.5 MJ ME/kg DM) than diverse pastures SL, SLH and SLHG (11.3, 11.2 and 11.1 MJ ME/kg DM, respectively). Despite the lower ME/kg DM in these diverse pastures (SL, SLH and SLHG), total ME produced per ha was greater in diverse (181, 169 and 181 GJ ME/ha/yr, or SL, SLH and SLHG) than in simple (162 GJ ME/ha/yr, S) pasture due to their higher DM production. This confirms the dominant role of herbage DM production in determining ME production in well managed irrigated pastoral systems, where overall ME is high.

Neutral detergent fibre (NDF) content of herbage is viewed as an important factor in feeding guidelines, in particular through effects on DM intake; according to Jung (1997), as the NDF values increase, the dry matter intake will generally decrease. In current study, fully irrigation pastures had higher NDF (415 g/kg DM) than partially irrigation pastures, although this effect was small (+22 g/kg DM). There was a larger effect of pasture mixture, with NDF consistently lower in SL, SLH and SLHG than S and SG (Table 4.6). The lower NDF probably reflects high chicory and plantain content of pasture containing herbs, which have been shown in previous studies to have low NDF (Burke et al. 2002). However, similar to Chapter 3, the NDF values are within the ranges suggested by Holmes et al. (2002) and Pacheco and Waghorn (2008) to be adequate for milk production. Further, in studies where diverse pastures containing chicory and plantain have been offered to dairy cows at the same herbage allowance to perennial ryegrass-white clover pastures (Totty et al. 2013; Bryant unpublished data), milk production was similar, indicating that the low NDF of mixtures containing herbs was not negatively impacting on milk production.

Throughout the study, the water-soluble carbohydrate (WSC) content of the S and SG pastures was higher than the SL, SH, SLH and SLHG pastures (Table 4.7). The WSC content of pastures has been linked to animal performance and their potential environmental impact. It is proposed that pastures species or mixtures with higher WSC content would have improved capture of N in the rumen due to an improvement in the supply and synchrony of energy relative to protein (Edwards et al. (2007). This is particularly the case if the ratio of WSC to CP exceeded 0.70. However, in the current study, adding additional species to the grass dominant pastures S and SG resulted in lower WSC content; further the ratio of WSC:CP was lower in SL (0.63), SH (0.75), SLH (0.63) and SLHG (0.59) pastures than S (0.90) and SG (0.83) pastures. These results suggest the using alternative legumes and herbs in mixtures with perennial ryegrass is unlikely to increase N capture in milk or reduce urinary N mechanism through a mechanism of
increased WSC content. Indeed, as urinary N excretion is tightly linked to N intake, the high CP of the SL, SHL and SHLG pastures is likely to promote greater urinary intake through enhanced N intake. Elsewhere studies (Khaembah et al. 2014) have shown reduced N excretion in urine where herbs such as chicory and plantain have been included in the diet. Based on the results of this study, where SH, had lower WSC content than S and SG, it would seem that this may be due to a range of other mechanisms including diuretic and secondary plant compounds associated with chicory and plantain (Totty et al. 2013).

4.5 Conclusion

This chapter presented the results necessary to meet objective 2 (Chapter 1.2). Based on these results, the following conclusion can be made:

- Partial irrigation had a large effect on herbage DM production, but little effect on botanical composition and nutritive value.

- The use of more diverse mixtures containing additional legumes resulted in greater DM production relatively to standard grass-clover mixtures and greater tolerance of irrigation restrictions.

- Adding additional legumes (red clover + lucerne) was a successful approach to increasing legume content to levels more appropriate for high dairy production.
Chapter 5
Effects of irrigation and pasture diversity on water use and water use efficiency of pasture under dairy grazing

5.1 Introduction

The potential milk production in dairy systems in New Zealand is strongly dependent on herbage DM yield, nutritive value of pasture and the utilisation of the pasture (Macdonald 1999; Fulkerson & Doyle 2001). The most common pasture mixture is binary mixture containing perennial ryegrass and white clover, as these species are tolerant of a range of soil and climatic environments and management. However, both these species have shallow roots (Hoglund & White 1985), which may limit water extraction, hence leading to water stress, and reduced herbage growth during dry periods in summer and autumn. Irrigation may be used to mitigate some of potential impacts of water stress in perennial ryegrass-white clover pastures. However, due to irrigation availability issues (e.g. those associated with water storage, allocation and consenting), it is not always possible to irrigate fully and restricted irrigation may occur during summer and autumn (McBride 1994; Thorrold et al. 2004). In this context, alternative pasture options to perennial ryegrass and white clover are needed to mitigate the impacts of restricted water supply on herbage DM production and nutritive value.

The perennial forage species chicory, lucerne and red clover are deep tap rooted perennials that have been shown to have greater DM production than perennial ryegrass and white clover under dryland conditions (Langer 1967; Paton 1992; Hunter et al. 1994). These species are also summer active and high quality, and so capable of supporting animal performance and high levels of milk production (Waghorn & Barry 1987; Burke et al. 2002; Chapman et al. 2012). In the previous chapter the potential of these species to increase herbage production when grown in mixtures under restricted water supply in summer was examined. Under restricted irrigation in summer, pastures where additional legumes (lucerne and red clover) and herbs (chicory and plantain) were sown into a perennial ryegrass-white clover pasture had greater herbage DM production than a standard ryegrass-white clover pasture. It was suggested this advantage may be attributed to greater water use and water use efficiency in the more diverse pasture mixtures associated with presence of species with deep tap roots (Skinner 2008).

The objective of this study was to determine the annual and seasonal water use and water use efficiency of simple perennial ryegrass and white clover mixtures compared with more diverse mixtures where additional herbs, legumes and grasses were added under full and partial
irrigation. This approach was based on the concept that herbage DM production is proportional to water used (Monteith 1988). This leads to two possible mechanisms promoting more herbage under restricted irrigation: either more water was extracted from soil, or water use efficiency was higher. These mechanisms were examined in study of water use, water use efficiency and water extraction patterns in the pastures were herbage DM production and nutritive value was measured in Chapter 4.

5.2 Material and methods

5.2.1 Experimental design and site

Water use and extraction measurements were conducted within the experiment described in Chapter 4 (Section 4.2). In brief, 6 pasture mixtures were grown in 4.2 × 6.0 m plots under full and partial irrigation using a split-plot design with three replicates. The experimental design and species sown detail are given in Table 4.1 and the meteorological data for the experimental site is presented in Chapter 3 (Figure 3.1).

5.2.2 Herbage dry matter production

Herbage DM production data in Chapter 4 were further investigated in this chapter in order to obtain pasture water use efficiency (WUE) data. In Chapter 4, herbage DM production data were presented in seasonal basis; however in this chapter, results on herbage DM production were calculated on a monthly basis to align with neutron probes measurement data collected from 15 October 2010 to 25 April 2011 for Year 1 and from 1 September 2011 to 31 March 2012 for Year 2. Herbage DM production data collected from rising plate meter (RPM) of each plot over a total of 7 regrowth periods in each year in 2010/11 and 2011/12, respectively, in order to determine relationship between herbage DM production and water use, and to calculate WUE. Herbage DM production was calculated on a monthly basis for each mixture data to align with the water extraction data. This was done by calculating the mean daily herbage DM production of appropriate pastures over each regrowth period, and adjusting monthly values based on time of regrowth period in each month.
5.2.3 Soil water

5.2.3.1 Neutron probe access tube installation

One aluminium neutron probe access tube of 2.5 m length was installed in the centre of each plot in September 2010. Soil moisture was measured by Time Domain Reflectometry (TDR) in the 0–0.2 m soil depth (Trace Systems, Model 6050X1, Soil Moisture Equipment, Santa Barbara, California, USA) with stainless steel rod of 0.2 m length inserted within the neutron probe access tube. A neutron access probe (Troxler Electronic Industries Inc., Model Troxler 4300, Triangle Research Park, North Carolina, USA) was used from 0.2 m to 2.25 m soil depth. Volumetric soil water content ($\theta$, mm$^3$/mm$^3$) was measured at 7–14 day (Black 2004; Mills 2007) intervals from 15 October 2010 to 25 April 2011 (2010/2011) and from 15 September 2011 to 16 March 2012 (2011/2012). The neutron probe was calibrated for a Paparua sandy loam which has the same parent material as the Templeton sandy loam and Wakanui silt loam series, and only differs in the depth to gravels (Cox 1978). During the different irrigation periods from 14 January 2011 to 10 March 2011 (Year 1) and from 7 January 2012 to 16 March 2012 (Year 2), soil water were measured every 3 days. Details on irrigation management were explained in Section 4.2.5 (Chapter 4).

5.2.3.2 Water use

Water use (WU) was calculated for each period between soil water measurements using a soil water balance:

Equation 5.1 \[ WU = \Delta \text{SWC} + R + I \]

where $\Delta \text{SWC}$ is change in soil water contents at the start and end of each measurement period. $R$ is the sum of rainfall and $I$ is the sum of irrigation for each measurement period. This equation assumes that soil water movement (e.g. drainage, up-flow) and runoff are zero. Daily WU within each measurement period were calculated as:

Equation 5.2 \[ WU_{\text{daily}} = \left( \frac{WU}{EP} \right) \times EP_{\text{daily}} \]

where $WU$ is the calculated water use (Equation 5.1) and $EP$ is Penman’s potential evapotranspiration for the corresponding measurement period. $EP_{\text{daily}}$ is $EP$ on the day of calculation.

5.2.3.3 Water use efficiency

Water use efficiency (WUE; kg DM/ha/mm) was calculated on a monthly basis from 15 October 2010 to 25 April 2011 for Year 1 and from 1 September 2011 to 31 March 2012 for Year 2, when all pasture mixtures had developed complete canopies.

WUE were calculated as:
Equation 5.3  \[ WUE = \frac{Y}{(R + I + ASWC – D)} \]

where corresponding \( Y \) is total herbage DM/ha, \( R \) is rainfall, \( I \) is irrigation, \( ASWC \) is available soil water content, \( D \) is drainage which can be calculated from water lost from the deepest soil layers in the absence of herbage growth.

5.2.3.4 **Plant available water capacity**

The plant available water capacity (PAWC) of the soil is the difference the drained upper limit (DUL) and the lower limit (LL) of water extraction by a mature crop which has fully explored all soil moisture (McLaren & Cameron, 1990). DUL was defined as the maximum stable volumetric water content which was measured 5 days after complete soil recharge.

5.2.3.5 **Soil water extraction pattern**

Soil water extraction was calculated as the difference between the upper and lower limits of extraction for each soil layer and the total soil profile. The soil water extractions were carried out only for the partial irrigated pastures during drydown period from 26 January 2011 to 2 March 2011 (Year 1) and 25 January 2012 to 29 February 2012 (Year 2). The full irrigated pastures were omitted since the aim was to find out how much water was extracted by those pastures during dry summer condition, where water was scarce.

5.2.4 **Statistical analysis**

Water use and water use efficiency measurements were analysed by split-plot design ANOVA with 2 levels of irrigation and 6 pasture mixtures using statistical package GenStat 13.0 (VSN International Ltd 2010). Means were separated using Fisher’s protected least significant difference (LSD) (P=0.05) test whenever the ANOVA indicated that significant treatment effect.
5.3 Results

5.3.1 Water use

Annual WU ranged from 616 to 755 mm/ha/yr, and averaged across 2 years was significantly higher ($P<0.001$) in full than partial irrigation (696 versus 678 mm/ha/yr). On a yearly basis, the annual WU was greater in full than partial irrigation in both 2010/11 and 2011/12, although the effect was small (10 mm/ha and 22 mm/ha, respectively). The WU per month ranged from 38 mm/ha in early spring (October) to 136 mm/ha in summer (January). On a monthly basis, WU was greater in fully irrigated plots in October and March 2010/11, October, November, December and January 2011/12 but did not differ between treatments at other times periods (Table 5.1).

Averaged over the 2 years of study, WU was highest ($P<0.05$) in SLH, intermediate in SLHG, SH and SL and the lowest in S and SG, although differences of WU among 6 pastures were small (4 mm/ha). Monthly WU was only significant different among pasture mixture during the dry summer period (December 2011, January 2012 and February 2012) and when the water restrict for partial irrigated pastures was taking place (January to February 2012). No significant interactions were found between irrigation and pasture mixtures for WU over the 2 year period of trial (Table 5.1)

5.3.2 Water use efficiency

The WUE per month ranged from 11.7 to 34.2 kg DM/ha/mm, and averaged across 2 years was 5.0 kg DM/ha/mm/yr higher ($P<0.05$) in full than partial irrigation (Table 5.2). On a monthly basis WUE was significantly higher ($P<0.05$) in full than partial irrigation in all months except late spring 2010/11 (November) and mid-summer 2010/11 (January).

Averaged over the 2 years of study, WUE was highest ($P<0.001$) in SL, followed by SLHG, intermediate in SLH, S and SH and lowest in SG (Table 5.2). On a monthly basis, there were significant differences ($P<0.05$) in WUE among pasture mixtures in all months except spring 2011 (October and November) (Table 5.2). The pattern in each month was consistent with annual WUE, with the highest WUE in SL and lowest in S and SG.

There was a significant interaction ($P<0.05$) between irrigation and pasture mixtures for WUE in 2010/11 and the average of the 2 years study (Table 5.2). The WUE was greater in full than partial irrigation in all mixtures (Figure 5.1 and Figure 5.2); however, the WUE was higher in SL, SLH and SLHG than S, SG and SH under partial irrigation. The difference in WUE between full and partial irrigation was lowest in SL and SLH (Figure 5.1 and Figure 5.2).
Table 5.1 Effects of mixtures and irrigation treatments on water use (mm/ha) from 15 October 2010 to 25 April 2011 and 15 September 2011 to 16 March 2012 in Lincoln University Research Dairy Farm, Canterbury, New Zealand. Means followed by different letters within a row are significantly different according to least significant difference test (LSD, $\alpha=0.05$) following a significant ANOVA.

<table>
<thead>
<tr>
<th>Pasture Mixtures (P)</th>
<th>Irrigation Treatment (I)</th>
<th>P*I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month</td>
<td>S</td>
<td>SG</td>
</tr>
<tr>
<td>Oct-10</td>
<td>105$_c$</td>
<td>113$_b$</td>
</tr>
<tr>
<td>Nov-10</td>
<td>112</td>
<td>114</td>
</tr>
<tr>
<td>Dec-10</td>
<td>113</td>
<td>115</td>
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<tr>
<td>Jan-11</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Mar-11</td>
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</tr>
<tr>
<td>Apr-11</td>
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<td>77</td>
</tr>
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</tr>
<tr>
<td>Nov-11</td>
<td>100</td>
<td>102</td>
</tr>
<tr>
<td>Dec-11</td>
<td>113$_b$</td>
<td>114$_b$</td>
</tr>
<tr>
<td>Jan-12</td>
<td>124$_b$</td>
<td>125$_b$</td>
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<td>116$_d$</td>
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</tr>
<tr>
<td>Mar-12</td>
<td>66</td>
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</tr>
<tr>
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<tr>
<td>Mean</td>
<td>670$_d$</td>
<td>680$_{cd}$</td>
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</tbody>
</table>

Means pasture mixture and irrigation followed by the same letter are not significantly different, *** $P<0.001$, * $P<0.05$, NS - not significant.

Table 5.2  
Effects of mixtures and irrigation treatments on water use efficiency (kg DM/ha/mm) from 15 October 2010 to 25 April 2011 and 15 September 2011 to 16 March 2012 in Lincoln University Research Dairy Farm, Canterbury, New Zealand. Means followed by different letters within a row are significantly different, according to least significant difference test (LSD, α=0.05) following a significant ANOVA.

<table>
<thead>
<tr>
<th>Month</th>
<th>Pasture Mixtures (P)</th>
<th>Irrigation Treatment (I)*</th>
<th>P*I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>SG</td>
<td>SH</td>
</tr>
<tr>
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<td>Feb-12</td>
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<td>11.7b</td>
<td>17.3a</td>
</tr>
<tr>
<td>Mar-12</td>
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<td>15.0c</td>
<td>19.2b</td>
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<tr>
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<td>16.3cd</td>
</tr>
<tr>
<td>Year 2</td>
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<td>18.6c</td>
<td>20.8b</td>
</tr>
<tr>
<td>Mean</td>
<td>18.3cd</td>
<td>17.5d</td>
<td>18.6c</td>
</tr>
</tbody>
</table>

Means pasture mixture and irrigation followed by the same letter are not significantly different. *** P<0.001, * P<0.05, NS - not significant.

Treatment code  
Figure 5.1 Interaction effect of full and partial irrigation × pasture mixtures on water use efficiency (kg DM/ha/mm/yr) in Year 1 (15 October 2010 to 25 April 2011) at Lincoln University Research Dairy Farm, Canterbury, New Zealand. Error bar represent standard error of mean for each treatment.


Figure 5.2 Interaction effect of full and partial irrigation × pasture mixtures on mean annual water use efficiency (kg DM/ha/mm/yr) from 15 October 2010 to 25 April 2011 and 15 September 2011 to 16 March 2012 at Lincoln University Research Dairy Farm, Canterbury, New Zealand. Error bar represent standard error of mean for each treatment.
5.3.3 Plant available water capacity and extracted water

The plant available water capacity (PAWC) of each mixture under partial irrigation is presented in Figure 5.1. Complete recharge was known to occur in the study plots which were flooded in the second season (early spring 2011/12), incurring ~670 mm of rainfall and no plant water extraction. The PAWC to 2.3 m soil depth was 177 mm, 239 mm, 283 mm, 285 mm, 283 mm and 299 mm for S, SG, SH, SL, SLH and SLHG, respectively (Figure 5.3). Distribution of soil water down the soil profile differed between mixtures with most extraction occurring (50% of total extractable water) in the top 0.75 m for all mixtures (Figure 5.3).

The plant water extraction pattern of soil water during the restricted irrigation period for all six pasture mixtures at Year 1 establishment and subsequent growth at Year 2 are displayed in Figure 5.4. All six mixtures had similar initial available soil water content between 27 mm to 29 mm in the top 0.2 m and between 29 mm to 31 mm at 0.2 m to 0.25 m soil depth in Year 1 (Figure 5.4). A similar trend was observed in all mixtures in Year 2 with 26 mm to 29 mm in the top 0.2 m and between 28 mm to 32 mm at below 0.2 m to 0.25 m soil depth (Figure 5.5). All mixtures showed lower (11 mm to 28 mm) soil water content in 0.5 m to 1 m of the soil profile. The final soil water content was highly variable between mixtures treatments and at different depths. After about 36 days of the drydown period, the result shows that a soil depth between 0.2 m to 0.75 m was where most water extraction occurred in both Year 1 and Year 2.

Water extraction was generally uneven at further depths and there was considerable variation in extraction patterns below 1.25 m (Figure 5.4 and Figure 5.5). No water extraction was observed below 1 m soil depth for S and SG. The SH shows significant extraction at 1.05 m to 1.25 m soil depth, while SL show soil water was extracted exceeding 1.30 m in the soil profile in both years. The SLH and SLHG showed further extraction below 1.45 m (Figure 5.4 and Figure 5.5). At the end of the restricted irrigation period in Year 2, the maximum extraction depth can be estimated to have exceeding 2 m soil depth for SL, SLH and SLHG, respectively, while the standard perennial ryegrass/white clover extracted less water than any other mixtures from 0.2 to 1.0 m depth (Figure 5.4 and Figure 5.5).
Figure 5.3 Upper (●) and lower (○) limits of six pasture mixtures water extraction (mm) to 2.3 metres depth measured from 15 October 2010 to 15 March 2012 at Lincoln University Research Dairy Farm, Canterbury, New Zealand. Note: Shaded areas and numbers represent plant available water content (mm). Treatment code: S: Standard perennial ryegrass + white clover, SG: Standard + grasses (prairie grass, timothy grass), SH: Standard + herbs (chicory, plantain), SL: Standard + legumes (lucerne, red clover), SLH: Standard + legumes + herbs, SLHG: Standard + legumes + herbs + grasses.
Figure 5.4 Changes in volumetric soil water content under six pasture mixtures during the intensive restricted irrigation period from 26/1/2011 to 11/3/2011 in Year 1. Days after end of irrigation (25/1/2011): ● 1, ○ 10, ▼ 18, △ 25, ■ 36. Data are means of three replicates down to 2.3m soil depth.

Figure 5.5 Changes in volumetric soil water content under six pasture mixtures during the intensive drydown period from 25/1/2012 to 5/3/2012 in Year 2. Days after end of irrigation (25/1/2012): ● 1, ○ 10, ▼ 18, Δ 27, ■ 38. Data are means of three replicates down to 2.3m soil depth. Treatment code: S: Standard perennial ryegrass + white clover, SG: Standard + grasses (prairie grass, timothy grass), SH: Standard + herbs (chicory, plantain), SL: Standard + legumes (lucerne, red clover), SLH: Standard + legumes + herbs, SLHG: Standard + legumes + herbs + grasses
5.4 Discussion

Diverse pasture containing additional legumes and herbs to a perennial ryegrass and white clover mixture were shown to have greater herbage DM in Chapter 4. Further, it was found herbage DM production in diverse pastures was less affected by a temporary restriction of water supply in summer. This study was designed to ascertain the main reasons from water use and water use efficiency point of view, as to why herbage production was greater in diverse pastures and less affected by irrigation restriction.

5.4.1 Water use

Water use in this study for the Paparua silt loam soil ranged to 616 mm to 755 mm. These results are generally consistent with previous studies. Brown et al. (2005) working on a Wakanui silt loam soil for three perennial forages grown under dryland conditions at a closely located site to the current study reported average annual WU of 714 mm, 698 mm, and 691 mm for lucerne, chicory, and red clover, respectively. However, under full irrigation, WU of these forages averaged 900 mm (Brown et al. 2005). In Australian grassland studies Neal et al. (2011), WU for a set of herb, legume and grass species ranged from 667 mm to 751 mm. The lower value in this study may reflect that WU was measured only over a 7 months period in this study rather than full year.

Water use was higher in full than partial irrigation (Table 5.1), although the effect was small (+18 mm/ha averaged across the 2 years of study). This reflected, in particular, greater WU in full irrigation during summer of the second year. There were also small differences in WU due to pasture mixture, with a general pattern of higher WU where additional legumes were added singly (SL) or in combination with herbs (SLH) and grasses (SLHG) than in the grass dominated mixtures (S and SG). However, again the effect was relatively small (range 14 mm to 35 mm) and was tightly linked to the summer period during the second year (Table 5.1). As herbage DM yield was highest in SL, SLH, and SLHG (Table 4.3), it is probably that greater water use contributed to the higher herbage DM production.

Previous studies in temperate pastures have shown no significant differences in WU between pasture grass-legume mixtures in any time period of measurement and in total WU (Snaydon 1972; McKenzie et al. 1990; Parry 1994). This study however shows small effects of irrigation on total WU (Table 5.1) but larger effect on WUE (Table 5.2) for all pasture mixtures.

A detailed analysis of water relations in the restricted irrigation period highlighted that greater water extraction in SL, SLH and SLHG, may be related to water extraction from deeper part of the soil profile by tap rooted plants. Brown et al. (2005) showed that lucerne was able to extract
water from up to 420 mm, with a total extraction from 0.2 to 2.3 m depth of 331, 358 and 330 for chicory, lucerne and red clover, respectively. In the current study, no water extraction was observed below 1 m soil depth for S and SG, two mixtures that lacked tap rooted species (Figure 5.4). For SH, which contained the tap rooted species chicory, there was extraction at 1.05 to 1.25 m soil depth. However, for SL, SLH and SLHG, mixtures containing the tap rooted i.e. red clover, lucerne and chicory, soil water was extracted below 1.3 m in both years. The SLH and SLHG showed further extraction below 1.45 m (Figure 5.4 and Figure 5.5). Further at the end of the restricted irrigation period, the maximum extraction depth exceeding 2 m soil depth for SL, SLH and SLHG. These data highlight the important role of lucerne and red clover in extracted soil from deeper in the soil profile, even when growing as part of mixtures with grasses and herbs. As no root excavations were done, it is not possible to ascertain which species lucerne or red clover was mainly responsible for the greater extraction. However, based on the water extraction data of Brown et al. (2005) it would seem that a significant contribution to water extraction at depths <1.6 m, would have come from lucerne. Further, in the mixtures, lucerne was more abundant than red clover on an individual species basis (71 versus 52 plant/m²), and made up a greater proportion of DM.

### 5.4.2 Water use efficiency

Water use efficiency (WUE) in this study ranged from 11.7 to 34.2 kg DM/ha/mm. These results are generally consistent with previous studies (Tonmukayakul et al. 2009; Neal et al. 2011). In Australian grassland studies (Neal et al. 2011), WU for a set of herb, legume and grass species ranged from 8.3 to 30.6 kg DM/ha/mm. A further feature of the results was the higher WUE in the second spring of the study. Higher values in this period have been noted previously, and this most likely reflects differences in their botanical composition specifically legume which contributed to differences in total N yield (Tonmukayakul et al. 2009).

Irrigation had a larger effect (>30%) on WUE reflecting the extra 1.1 t DM/ha obtained from fully irrigated pasture and the amount of soil water extracted by the plants led to a higher average value of WUE of 17.3 versus 13.5 kg DM/ha/mm. The highest WUE was obtained from the diverse mixtures (SL, SLH and SLHG) containing extra legumes (lucerne and red clover) (Table 5.2) with a strong interaction between irrigation and pasture mixtures on annual herbage DM yield (Figure 4.1; Chapter 4), whereby DM yield of these mixtures was less affected by partial irrigation. SL recorded the highest WUE under both under full (22.9 kg DM/ha/mm/yr) and partial irrigation (19.3 kg DM/ha/mm/yr) due to additional legumes (lucerne and red clover) that extract water from deeper in soil profile. Lucerne and red clover
are known to be flexible and more tolerant to drought and summer dry condition (Brown et al. 2003).

The herbage DM production results indicate that the yield difference between the mixtures, rather than water use was the main determinant of these differences in WUE. The mixtures with highest annual yield (SL, SLH and SLHG), exhibited the highest WUE (Tables 5.2). Conversely, those pastures which were the lowest yielding (S, SG and SH) were among the pastures with lowest WUE (Tables 5.2). Although there are decline in herbage DM yield was observed from Year 1 to Year 2 (Table 4.3), the WUE amongst pastures increased. This contradicts the results of Neal et al. 2011. As yield declined, due to poor yield stability and persistence (Neal et al. 2009), WUE also declined (Neal et al. 2011). However, the results of Neal et al. (2011) were based on a three year period, whereas this study was a two years period. Perhaps, if this study was carried out for three or four years, we would expect similar findings to Neal et al. (2011).

Partial irrigation led to a decline in WUE for all mixtures, with this effect significant in almost all months. This decline in WUE indicates that pasture mixtures are unable to utilise water at the same level of efficiency as under full irrigation. These WUE results are in line with number of other studies which have shown a decline in WUE as water input declines (Neal et al. 2011). The reduced WUE observed may reflect a range of factors including changes in plant numbers or ground cover (Neal et al. 2011), incomplete stomatal closure (Begg & Turner 1976; Sheaffer et al. 1988; Durand et al. 1995), decrease in respiration (Begg & Turner 1976; Sheaffer et al. 1988) and increased allocation to root at the expense of shoot in response to water stress (Gales 1979; Malik et al. 1979; Kramer & Boyer 1995).

It is noteworthy that WUE efficiency was reduced by partial irrigation beyond the period of restricted irrigation. For example, this occurred in in January 2011, February 2011, January 2012 and February 2012. Presumably, this reflects carryover effects on persistence and plant growth that prevent plants responding when irrigation resumes. Of note, in the current study is that irrigation in partial treatment was only returned to the same schedule as the full irrigation treatment and no attempt was made to restore soil water to the same level as the full treatment.

A further feature of the WUE data was the interaction between pasture mixture and irrigation (Table 5.2), emphasizing the importance of pasture mixture choice under restricted irrigation. This in line with the findings of Smeal et al. (2005) in cool seasons perennial grasses. In both years, S, SG and SH, showed a larger reduction in WUE with partial irrigation (-4.6 to 6.4 kg DM/ha/mm/yr) than SL, SLH and SLHG. These data are supported by the results of Neal et al.
(2011), which showed there was significant decline in WUE for all species with deficit irrigation except lucerne. The highest decline in WUE occurred S and SG, most likely due to poor growth of perennial ryegrass/white clover in response to partial irrigated conditions which contributed to up to a 50% declined in herbage yield (Table 5.2).

5.5 Conclusion

This chapter presented the results necessary to meet objective 3 (Chapter 1.2). Based on these results, the following conclusion can be made:

- Irrigation treatments had a small effect on WU but a larger effect on WUE amongst pasture mixtures. The annual water WUE ranged from 15.6 to 22.8 kg DM/ha/mm/yr and averaged across two years was significantly higher in full irrigated pastures (21.5 kg DM/ha/mm/yr) than partial irrigated pastures (16.5 kg DM/ha/mm/yr).

- Total water extraction was >60 mm greater in SLHG than S, SG, SH and SL and all mixtures containing legumes lucerne and red clover (SL, SLH and SLHG) had the highest water extraction of more than 35 mm at 1.65 m depth compared to S, SG and SH.

- The maximum extraction depth was estimated to exceeding 2.3 m depth for SL, SLH and SLHG.
Chapter 6
General discussion

6.1 Introduction

In New Zealand, the supply of feed for cows is the single largest component of dairy farm operational costs (DairyNZ 2014). Thus, high consumption per ha by dairy cows of forage produced on farm is a key determining factor for dairy business success (Van Bysterveldt 2005), with the efficient conversion of forage into milk providing New Zealand with a competitive advantage on the world dairy market (Dillon et al. 2005). To remain competitive, dairy farmers must continue to make efficiency gains in the production of feed and the conversion into milk.

A perennial ryegrass-white clover pasture mixture is the major forage source in the dairy regions of New Zealand (Holmes et al. 2002), reflecting tolerance of a wide range of environments and managements and responsive to inputs of N fertilisers and irrigation. A high reliance on N and irrigation has enabled the increases in stocking rate to occur that have helped to underpin profitability (Macdonald 1999). This intensification has brought a number of concerns including N and P losses to the environment (Ledgard 2001; Di & Cameron 2002); combined with issues related to increased incidence of drought or water restrictions on farm (Baskaran et al. 2009; Moot et al. 2010), alternative forage approaches to a perennial ryegrass-white clover pasture need consideration.

Alternative forage approaches were considered in this study by examining herbage DM production, botanical composition and water use efficiency of standard perennial ryegrass pastures and diverse pastures where additional legumes (lucerne, red clover), herbs (chicory, plantain) and grasses (timothy and prairie grass) were added. Pastures were evaluated under dairy grazing, with irrigation and a relatively low N fertiliser input (<150 kg N/ha/year). Data from two studies in this thesis showed that annual herbage DM yield of diverse pasture was similar or greater to that of standard pasture.

In the paddock scale experiment in Chapter 3, annual herbage DM yield was 7 to 8 % greater in the more diverse pasture. In the small plot study in Chapter 4, perennial ryegrass/white clover based pastures containing additional legumes or herbs, either singly or in combination, had a greater annual herbage DM yield of 1 to 1.2 t DM/ha/yr compared standard ryegrass white clover pastures or pastures where additional herbs had been added. These findings are in line with a recent review of herbage DM production in simple and diverse pastures (Pembleton et al. 2014), where herbage DM production has been measured under grazing and at a scale and a
level of inputs reflective of paddocks on dairy farms with difference between simple and diverse has ranged from no increase (Woodward et al. 2013) to a 43% increase (Sanderson et al. 2005).

The increase in herbage DM production with the addition of herbs and legumes in this study was often associated with an increase in summer herbage DM production. This was particularly noticeable under restricted irrigation where summer herbage DM yield was 22 to 63 % higher under restricted irrigation where additional herbs and legumes had been added to the pasture compared to a standard ryegrass white clover pasture. In all cases, the increase in summer herbage DM production was associated with the presence of drought tolerant species like chicory, red clover and lucerne that are capable of producing more DM of high nutritive value in the higher temperatures during summer (Waghorn & Barry 1987; Burke et al. 2002; Brown et al. 2005). These species were better adapted to the summer water deficit that occurred when irrigation was restricted, and in the case of lucerne, able to extract water from far deeper (<2.3 m) in the soil profile than standard perennial ryegrass-white clover pastures (<1.3 m), so leading to greater water use efficiency.

In NZ dairy systems, there is a high demand for feed in early spring to coincide with the start of calving. This high demand for feed in spring has resulted in concerns over the potentially lower cool season growth of herbs and perennial legumes (Clark et al. 1997) when included in pasture mixtures. However, across this study, there was a relatively small effect of including herbs and legumes in the pasture mixture on winter growth. Winter DM production was greater in standard pastures to those diverse pasture where herbs were added on two occasions only (Table 4.3). This result may reflect that pastures were dominated with grasses, with grasses making up greater than >80% of DM during winter. This may have compensated for the lower growth of the legume species.

6.2 Livestock production

The effect of diverse pasture on milk production was not measured in this study due to the small nature of the plots. Previous short term milk production studies have shown that milk production from diverse compared with standard pastures is at least as high from the diverse pastures (Totty et al. 2013; Woodward et al. 2013). Soder et al. (2006) showed no increase in milk production from cows grazing a diverse pasture containing cocksfoot, chicory, tall fescue, Kentucky bluegrass, red clover, birdsfoot trefoil, lucerne and perennial ryegrass compared to cocksfoot/white clover pasture. Woodward et al. (2013) and Totty et al. (2013) showed milk production from cows grazing diverse pastures containing perennial ryegrass, white clover, red
clover, plantain, prairie grass, chicory, plantain and lucerne was 11 to 19% higher than cows grazing standard ryegrass-white clover pastures (Toty et al. 2013; Woodward et al. 2013).

These data combined with data from the current study showing that DM and ME production on annual and seasonal basis is similar or higher in diverse than standard pastures, and that nutritional characteristics of the forage were within the ranges suitable for milk production (Waghorn 2007), leads to the expectation that including diverse pastures within dairy farm may indeed increase milk production at the farm scale. The higher herbage DM production under partial irrigation of diverse mixtures indicates that they may be particularly useful in farming systems subject to summer drought or irrigation restrictions. This would need to be confirmed by farm systems studies or modelling.

A consistent result that has been observed in studies is that increasing the proportion of legumes in pasture and diet increases milk production from dairy cows (Dewhurst 2006). However, the proportion of legume in perennial ryegrass-white clover pastures is often low (<20%) (Chapman et al. 1995; Caradus et al. 1996). Various approaches have been taken to increase the proportion of legume, including plant breeding and altered management (McKenzie et al. 1990; Harris et al. 1998b; Woodward et al. 2008), but these have showed limited success. In this study, we showed an effective method for increasing the proportion of legume was to use alternative legumes (red clover and lucerne) in diverse pastures. On an annual basis, the percentage of legume in perennial ryegrass based pasture was 0.3 to 1.2 times higher in diverse pastures when legumes had been added, with legume abundance reaching >27% in the SL, SLH and SLHG mixtures. The SL, SLH and SLHG (Figure 4.3) in this study shows possibilities of approaching summer pasture legume contents of 50-65% in order to achieve near maximum, per cow, milk solids production (Harris et al. 1998a).

6.3 Nitrogen losses to environment

An emerging issue for dairy production systems in New Zealand is the negative environmental impact of dairy farming, in particular, that associated with nitrate leaching from urine patches (Moir et al. 2012; Beukes et al. 2014; Malcolm et al. 2014). This issue is related to the high protein content of the forage relative to cow protein demand (de Klein 2010) and can be exacerbated by high N fertiliser use on perennial ryegrass-white clover pastures. Recent work points to diverse pastures playing a role in reducing this environmental impact, primarily through a pathway of reduced N excretion in urine.
Modelling has suggested that diverse pastures containing deeper rooted species have a greater potential to limit nitrate leaching (Snow et al. 2013), although the highlight was the individual species identity rather than the diversity of the pasture that was responsible for this. Malcolm et al. (2014) in a lysimeter study compared nitrate leaching losses following urine application from perennial ryegrass/white clover pastures and tall fescue/white clover pastures with those from a diverse pasture containing perennial ryegrass, white clover, red clover, chicory and plantain, and from Italian ryegrass (Lolium multiflorum Lam.)/white clover pastures. This showed that nitrate-N leaching losses beneath Italian ryegrass/white clover pastures were 24-33% less than beneath the diverse and perennial ryegrass/white clover pastures, and 50% less than beneath tall fescue pastures; but, no effect of the diverse pasture was detected.

In indoor work on N excretion in urine, milk yield and N partitioning to milk, urine and faeces were compared in dairy cows fed either a perennial ryegrass/white clover pasture or a diverse pasture which also contained chicory, plantain and lucerne (Woodward et al. 2012). Lower dietary CP content was recorded for diverse pastures than perennial ryegrass/white clover pasture (15.0 vs 18.6% DM), along with higher milk solids (1.16 vs 1.03 kg MS/cow/day) and a greater percentage of daily N dietary intake allocated to milk (23 vs. 15%). Urine N concentration was lower in diverse pastures (2.6 vs. 6.9) and because urine volume did not change, the urinary N excretion from cows fed the diverse pasture was half that of cows fed the standard pasture (100 vs. 200g N/cow/day). A reduction in urinary concentration of 30 to 34% was observed by Totty et al. (2013) with cows grazing diverse pastures containing chicory and/or plantain compared to standard perennial ryegrass/white clover pastures. As the urinary N concentration and total urine excretion are important factors leading to nitrogen loading in the urine patch, and subsequent nitrate-N leaching, the results demonstrate a role for diverse pastures in reducing nitrogen losses without negative impacts on milk production. Using data of herbage DM production from Chapter 3, Beukes et al. (2014) modelled the effect on nitrogen losses at the farm scale. The modelling results suggest that diverse pastures consisting of perennial ryegrass/white clover plus prairie grass, chicory, plantain and lucerne have the potential to reduce N leaching from Waikato dairy farms by 11% or 19%, depending on the proportion of the farm sown, 20% or 50% respectively. This potential to substantially reduce N leaching needs to be further evaluated in the context of farm profitability, when other aspects of diverse pastures like yield, persistency, drought resistance and ability to extract soil-N becomes part of the farm system analysis (Beukes et al. 2014).
6.4 Management of diverse pastures

Using greater species diversity in pasture involves the challenge of maintaining each additional component’s presence within the pasture. Although there was limited evidence of lack of persistence of diverse pastures in this study, they can revert to simple grass dominant pastures over a period of three to four years (Sanderson et al. 2007). Repeated applications of N fertiliser has been associated with a reduction in the legume components of pasture (Bolland & Guthridge 2007). However, other reports have identified that when stocking rates were at levels that minimise the competitive advantage of grasses over legumes and limited selective grazing, the application of N fertiliser had a minimal effect on the content of legumes in pastures (Harris & Clark 1996; McKenzie et al. 2003). It is clear that reducing N applications favours the legume component of pastures (Turner et al. 2013). However, there is little comparative data on the performance of diverse and standard pastures in response to N fertiliser. Van Rossum et al. (2013) compared herbage DM production of simple grass-clover pastures and diverse pastures to N fertiliser and gibberellic acid application in autumn. The herbage DM yield response to N fertiliser was similar for diverse and standard pastures; however, the effect of gibberellic acid application was lower in diverse pastures that contained a high proportion of chicory and plantain.

Grazing management specifically, defoliation interval and intensity, become more critical to maintain legume composition in the sward. Shorter defoliation intervals and lower post-defoliation residuals can eventually reduce legume composition of dairy pastures (Turner et al. 2013; Rawnsley et al. 2014). In this study, rotational grazing was based on standard perennial ryegrass/white clover pasture which required at about 20 to 25 days growing interval before the next grazing. Unfortunately, the grazing management requirements to optimise herbage DM production, persistence and nutritive value of many grasses, legumes and forbs (Sanderson et al. 2003; Labreveux et al. 2006; Lee et al. 2012; Turner et al. 2013) do not align with each other or align with perennial ryegrass/white clover. For example, our study included herbs and legumes species i.e. chicory, plantain, red clover and lucerne which are slower to establish than perennial ryegrass, requiring greater thermal time for emergence. Thus, in the period of early spring to early autumn sowing would be necessary. However, there are examples of some species combinations with aligning grazing management which could be components of diverse pastures, for example, cocksfoot and lucerne (Casler 1988), cocksfoot and chicory (Parker & Kemp 1998) and tall fescue and chicory (Tharmaraj et al. 2008). To ensure their productivity and persistence, the grazing management of diverse pastures will require compromises between the needs of each of the species present. However, it has been confirmed that some pasture
species may only have specific defoliation requirements at certain times of the year to ensure their persistence, for example lucerne (Teixeira et al. 2007). This means that grazing management could be tailored to the needs of each species during critical times of the year, but requires an in-depth understanding of each individual species’ physiology and skilled grazing management when implementing it.

In the context of grazing management, it is also important to consider how to measure and allocate diverse pastures. In this study, the rising plate meter was used as one tool to estimate herbage mass. Due to the different morphological structure of the various mixtures, separate calibration curves were developed for each pasture type (Table 3.2, Table 4.2). These showed differences in slope and intercept of the equations, so giving different predictions for a particular height. Recalibration of rising plate meter of sward height sticks to diverse pasture will be required to deliver accurate allocation of feed.

Elsewhere, studies in New Zealand have shown that diverse pastures for beef and sheep grazing had considerable resilience to weed incursion than the standard binary mixtures but not for the more intensively managed dairy pastures (Tozer et al. 2010). A study in North America also showed diverse pastures in beef grazing systems have considerable resilience to weed incursion than the standard binary pasture mixtures (Tracy & Faulkner 2006). Similarly to herbage DM production, resilience to weed incursion appears to be related to individual species identity ‘rather than diversity itself (Sanderson et al. 2007; Soder et al. 2007). This is due to individual species occupying the same ecological niche as the weeds (Gitay & Noble 1997). Consequently weed incursion can still occur if such a species is absent or not able to fully compete critically during establishment. Weed incursion can potentially be a challenge to the maintenance of species diversity, especially in pasture that contains the herbs plantain and chicory. Weed control management, especially herbicides for broadleaved weeds (e.g. thistles) used in this study can harm chicory and plantain. Therefore, chicory and plantain may not be an option where thistles are an expected problem. Alternatively, the use of non-herbicide control methods, such as mowing or grubbing might need to be implemented. While there is evidence of specific herbicides being safe for these species (Lockley & Wu 2008), few of these herbicides are registered for this purpose for dairy farms in New Zealand. Conversely, herbicides that are safe to use on these herbs are damaging to other species likely to be present in a diverse pasture, particularly legumes.
6.5 Recommendation for future work

In order to have a better understanding of the nature and mechanisms of competition between pasture grass-legume-herbs species and to allow the transfer of this knowledge to the farming situation, further research needs to be carried out in the following areas:

- The variable response of the DM production of diverse pastures in summer and under irrigation, indicates that further research of a longer (at least 3–5 years) term in Canterbury would assist the clarification of diverse pastures production and persistence.

- This current study will be more meaningful when combined with the findings of milk solids production comparison between simple and diverse pasture mixtures. It is known that perennial ryegrass/white clover pasture has been successfully gaining popularity for increasing milk solids production; however the extent to which diverse mixtures can produce more milk solids than the standard perennial ryegrass/white clover will need a better understanding between diverse pastures.

- A logical extension of this study would be to examine the voluntary intake of dairy cows grazing these pasture species (varying in digestibility), when grazed at the optimum stage of growth, in order to determine the potential ME intake by dairy cows under these condition.
6.6 Conclusion

The research presented in this thesis has provided a comprehensive assessment on the use of alternative plant species in diverse pasture mixtures in comparison to simple perennial ryegrass/white clover mixtures. Specific conclusions were:

- The herbage DM production and nutritive value (i.e. metabolisable energy; ME) of diverse pastures was similar or greater than that of standard perennial ryegrass/white clover pastures or tall fescue-white clover pastures.

- The reduction in DM production associated with water restriction in summer was less in mixtures containing the tap rooted legumes red clover and lucerne than perennial ryegrass/white clover pastures. Diverse mixtures with additional herbs and legumes (SL, SLH and SLHG) to the simple perennial ryegrass/white clover produced 7% to 15% greater annual herbage DM production, improved pasture nutritive value and maintained plant population, specifically in summer.

- Full irrigation versus water restriction in summer had a small effect on WU but larger effect on WUE amongst pasture mixtures. The annual WUE was 5.0 kg DM/ha/mm/yr greater in full (21.5 kg DM/ha/yr) than partial irrigation (16.5 kg DM/ha/yr). The annual WUE was 8% to 15% greater in SL (21.1 kg DM/ha/yr) and SLHG (19.8 kg DM/ha/yr) than the simple perennial ryegrass/white clover pastures (18.3 kg DM/ha/yr). These results suggested that pastures containing deep tap rooted species had greater WUE than pasture of perennial ryegrass and white clover.

- The greater herbage DM yield and nutritive value, specifically the higher total ME production, indicated that diverse pastures may play an important role in promoting greater milk solids production per cow and per ha. Combined with the environmental benefits of diverse pastures (e.g. reduced urinary N excretion) demonstrated in other studies, it is concluded that diverse pastures are a promising alternative to perennial ryegrass-white clover pastures to deliver high production, with lower environmental implications, in dairy systems.
References


Rawnsley, R.P.; Langworthy, A.D.; Pembleton, K.G.; Turner, L.R.; Corkrey, R.; Donaghy, D. 2014. Quantifying the interactions between grazing interval, grazing intensity, and


Refereed Publications during the course of study


Productivity of rotationally grazed simple and diverse pasture mixtures under irrigation in Canterbury

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Abstract
Herbage dry matter (DM) production, botanical composition and nutritive value were compared over 2 years under irrigation and dairy cow grazing for simple two-species grass (perennial ryegrass or tall fescue)-white clover pastures and diverse pastures where herbs (chicory and plantain), legumes (red clover and lucerne) and prairie grass were added to the simple mixtures. Averaged over 2 years, annual herbage DM production was 1.62 t DM/ha greater in diverse (16.77 t DM/ha) than simple (15.15 t DM/ha) pastures, primarily reflecting greater DM production in summer. Diverse pastures had lower metabolisable energy (ME) (12.0 vs 12.2 MJ ME/kg DM) and neutral detergent fibre (301 vs 368 g/kg DM) content than simple pastures, although the total ME produced per year was greater in diverse than simple pastures (202 vs 185 GJ ME/ha). Ryegrass-based pastures had higher annual DM production than tall fescue-based pastures in the first but not second year. The results indicate that including additional legumes and herbs with simple grass-white clover pastures may increase total DM and ME production of dairy pastures under irrigation.

Keywords: Lolium perenne L., Festuca arundinacea, herbs, legumes, pasture mixtures, diversity, nutritive value

Introduction
The focus of dairy farming on simple and productive forage systems has led to a limited range of plants being used, predominantly perennial ryegrass-white clover pastures, with some brassica and maize. There has been relatively low adoption of more diverse mixtures containing alternative legumes such as red clover and lucerne, or forage herbs such as chicory and plantain. With a growing awareness of the role that plant species may play in reducing the environmental impacts of dairy farming (Moir et al. 2012), concerns about the poor persistence of perennial ryegrass (Parsons et al. 2011), and the need for improved herbage quality in spring and both quality and quantity in dry summers (Clark et al. 1997), there has been increased interest in the use of alternative plant species in more diverse mixtures.

In studies in extensive low input grasslands, increased plant diversity has been linked to greater herbage dry matter (DM) production, more efficient use of available water, reduced nitrate leaching and greater resistance to weed invasion (Lee et al. 2013; Sanderson et al. 2004). However, there is limited data on the performance of intensively managed diverse pastures under grazing. Dryland pasture studies in New Zealand (Daly et al. 1996; Goh & Bruce 2005) show that diverse pastures containing more than 10 species had greater herbage DM production than simple ryegrass-white clover mixtures, and sustained a higher legume content. Under full irrigation, Goh & Bruce (2005) showed multi-species pastures had greater total DM production and higher legume content than simple ryegrass-white clover pastures.

This experiment was carried out to determine the herbage DM production, botanical composition and nutritive value under irrigation of two-species mixtures of perennial ryegrass (standard and high sugar) and tall fescue sown with white clover compared with more diverse mixtures where additional herbs (chicory and plantain), legumes (lucerne or red clover) and grasses (prairie grass) were added to two-species mixtures.

Materials and methods
Site
This experiment was conducted between June 2010 and May 2012 at the Lincoln University Research Dairy Farm in Canterbury, New Zealand. The experiment was a randomised block design consisting of three base pasture types and two levels of diversity. A 9 ha area was divided into three blocks each of 3 ha using permanent double wire fencing, and each block was sown into six treatment paddocks each of 0.5 ha. The treatment paddocks were randomly allocated to six pasture treatments (Table 1). The treatments were based on three simple two-species mixtures of perennial ryegrass-white clover (RG), high sugar ryegrass-white clover (HS), and tall fescue-white clover (TF) pastures, and three diverse pasture mixtures of more than four species where herbs (chicory and plantain), legumes (red clover or lucerne) and prairie grass were added to the simple pasture mixtures (RGD, HSD, TFD) (Table 1).
Grazing management
From late August to mid May each year, all paddocks were rotationally grazed by Friesian-Jersey dairy cows. Grazing usually occurred when the grass had reached approximately the 2.5- to 3-leaf stage. Cows were removed from the paddocks when the pasture height was approximately 3-4 cm. Paddocks were grazed nine times between June 2010 and May 2011 and 10 times between June 2011 and May 2012. All pasture mixtures were cut for silage in November 2011 and January 2012. The mixtures were fertilised with 200 kg N/ha/yr which was applied in four applications of 50 kg N/ha as urea each in early spring, mid spring, mid summer and mid autumn. The area was irrigated by travelling lateral irrigator between October and March.

Table 1  Plant species, cultivar names and sowing rates (kg seed/ha) of simple and diverse pasture mixtures.

| Species                | Common name     | Cultivar  | Simple  |  |  |  |  |  |
|------------------------|-----------------|-----------|---------|  |  |  |  |  |
| *Lolium perenne* L.    | Perennial ryegrass | One50-AR1 | RG      | HS | TF | RGD | HSD | TFD |
| *Lolium perenne* L.    | High sugar ryegrass | Abermagic | 20      | 20 | 10 | 10  | 20  | 10  |
| *Festuca arundinacea* | Tall fescue     | Advance   |         | 20 | 15 | 15  | 10  | 10  |
| *Bromus wildenowii*   | Prairie grass   | Atom      |         | 15 | 4  | 4   | 2   | 2   |
| *Medicago sativa*     | Lucerne         | Torlesse  |         | 8  | 2  | 2   | 1   | 1   |
| *Trifolium pratense*  | Red cloth       | Colenso   |         | 2  | 1  | 1   | 2   | 2   |
| *Trifolium repens*    | White clover    | Kopu 2    | 5       | 5  | 2  | 2   | 2   | 2   |
| *Plantago lanceolata* | Plantain        | Tonic     |         | 2  | 2  | 2   | 2   | 2   |
| *Chicorium intybus*   | Chicory         | Choice    |         | 2  | 2  | 2   | 2   | 2   |
| Total number of species | 2 | 2 | 2 | 6 | 4 | 6 |  |  |
2010/11 (499 mm) and between November and March 2011/12 (368 mm) with approximately 20–30 mm of water applied per week.

**Measurement**

Herbage mass was measured weekly with a calibrated rising plate meter (RPM; Jenquip, Filip’s EC-09 Electronic Folding Plate Meter, 50 readings per paddock). Calibration measurements for each pasture mixture, pre- (n = 18) and post-grazing (n = 18) were collected each season. Immediately prior to cutting two RPM measurements were recorded in the area to be harvested (quadrat = 0.2 m²). All live material was removed to ground level (0.5–1.0 cm stubble heights). Any soil contaminants in the samples were removed by hand and samples were oven-dried at 65°C for at least 48 hours, weighed, and DM determined. Calibration equations for each pasture mixture were determined by linear regression. Calibrated equations for each pasture mixture were:

- **HS (kg DM/ha)**: \(34.9 + 316.6 \times \text{RPM}, R^2=0.84, \text{S.E.}=4.16\)
- **RG (kg DM/ha)**: \(50.4 + 132.5 \times \text{RPM}, R^2=0.76, \text{S.E.}=5.23\)
- **TF (kg DM/ha)**: \(139.4 + 118.5 \times \text{RPM}, R^2=0.81, \text{S.E.}=3.95\)
- **HSD (kg DM/ha)**: \(450.5 + 105.3 \times \text{RPM}, R^2=0.86, \text{S.E.}=2.90\)
- **RGD (kg DM/ha)**: \(381.4 + 99.1 \times \text{RPM}, R^2=0.80, \text{S.E.}=3.41\)
- **HSD (kg DM/ha)**: \(610.6 + 83.5 \times \text{RPM}, R^2=0.80, \text{S.E.}=2.90\)

Grazing records of each paddock were kept so herbage growth rate (kg DM/ha/day) could be estimated by comparing the previous RPM reading and the date of grazing. A new regrowth period was considered to commence following each grazing. Herbage DM production was then calculated on annual and seasonal bases (winter: June–August, spring: September–November, summer: December–February, and autumn: March–May).

Botanical composition was measured prior to each grazing by cutting four quadrats, each 0.2 m², in each paddock to 1 cm above ground level at four random locations throughout each paddock using electric hand shears. Fresh sub-samples of around 200 g were dissected into sown grass, herbs, legumes, weeds and dead material before dry weight of each component was determined. The oven dried sub-samples were bulked for nutritive analysis following grinding to pass through a 1 mm stainless steel sieve. Samples were analysed using near infrared spectroscopy for nitrogen content, digestible organic matter (DOMD), water-soluble carbohydrate (WSC) and neutral detergent fibre (NDF) by Lincoln University Analytical Laboratory. Calculation of metabolisable energy (ME) was derived from formula provided by McDonald et al. (2002), where ME (MJ/kg DM) = 0.016 DOMD. ME for all pasture mixtures were calculated based from this equation.

**Meteorological data**

Rainfall and temperatures for the measurement period are presented in Figure 1. Total rainfall during the first year of experiment (670 mm) was slightly higher than the average long-term rainfall of the last 20 years (579 mm). However, rainfall in the second year (564 mm) was slightly lower than the average long-term rainfall as depicted in Figure 1(b). The monthly air temperatures showed a similar trend to the long-term average air temperature.

**Statistical analysis**

Herbage DM production, botanical composition, and nutritive value were analysed by two-way factorial ANOVA (3 base pastures × 2 level of diversity) using the statistical package GenStat (Release version 12.2, 2010). Botanical composition data collected at each

### Table 2

Effect of base pasture and diversity on annual and seasonal DM production (t DM/ha). P-values from ANOVA for main effects of base pasture and diversity are shown. Means followed by different letters within a row are significantly different (P<0.05), according to least significant difference test (LSD, α=0.05) following a significant ANOVA.

<table>
<thead>
<tr>
<th></th>
<th>Base Pasture</th>
<th></th>
<th></th>
<th>Diverse Pasture</th>
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<tr>
<td></td>
<td>HS</td>
<td>RG</td>
<td>TF</td>
<td>P-value</td>
<td>LSD</td>
<td>Simple</td>
</tr>
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<td>Winter 2010</td>
<td>2.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.92&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.99&lt;sup&gt;a&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.35</td>
<td>2.19</td>
</tr>
<tr>
<td>Spring 2010</td>
<td>5.30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.48&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>&lt;0.05</td>
<td>1.05</td>
<td>4.97</td>
</tr>
<tr>
<td>Summer 2011</td>
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<td>6.11</td>
<td>5.89</td>
<td>0.74</td>
<td>1.06</td>
<td>5.65&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Autumn 2011</td>
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<td>3.03</td>
<td>2.43</td>
<td>0.26</td>
<td>0.83</td>
<td>2.60</td>
</tr>
<tr>
<td>Winter 2011</td>
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<td>1.04</td>
<td>1.25</td>
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<td>1.09</td>
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<td>Spring 2011</td>
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<td>0.38</td>
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<td>Summer 2012</td>
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<td>6.80</td>
<td>0.99</td>
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<tr>
<td>Autumn 2012</td>
<td>2.48</td>
<td>2.35</td>
<td>2.06</td>
<td>0.65</td>
<td>1.00</td>
<td>2.22</td>
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<tr>
<td>Year 1</td>
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<td>17.55&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.53&lt;sup&gt;b&lt;/sup&gt;</td>
<td>&lt;0.05</td>
<td>2.33</td>
<td>15.41</td>
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<tr>
<td>Year 2</td>
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<td>15.47</td>
<td>0.77</td>
<td>3.89</td>
<td>14.89</td>
</tr>
<tr>
<td>Mean</td>
<td>16.34</td>
<td>16.53</td>
<td>15.00</td>
<td>0.31</td>
<td>2.27</td>
<td>15.15</td>
</tr>
</tbody>
</table>
grazing were averaged across season prior to analysis. Means were separated using Fisher’s protected least significant difference test whenever the ANOVA indicated a significant treatment effect.

Results
Annual and seasonal dry matter production
Annual DM herbage production ranged from 14.53 to 17.55 t DM/ha, and averaged over two years, was 1.62 t DM/ha higher in diverse (16.77 t DM/ha) than simple (15.15 t DM/ha) pastures (Significant at $P<0.08$) (Table 2). In the first year, annual DM herbage production was similar in RG-based (17.55 t DM/ha) and HS-based (16.10 t DM/ha) pastures, and RG-based pastures had greater herbage DM production than TF-based pastures (14.53 t DM/ha) (Table 2). In the second year, total DM herbage production was unaffected by base pasture type. In the first year, winter and spring herbage DM production was lower ($P<0.05$) in TF-based pastures than RG-based and HS-based pastures (Table 2). Diverse pastures produced 0.87 t DM/ha more ($P<0.05$) herbage DM than simple pasture mixtures in summer of the first year (Table 2). Annual and seasonal herbage DM production were unaffected by the interaction on base pasture type and diversity.

Botanical composition
The percentage of grass was higher ($P<0.001$), and percentage of legume was lower ($P<0.001$), in simple than diverse pastures throughout the trial (Figure 2). Averaged over the 2 years of trial, the respective average percentage of grass and legume was 70.1% and 20.1% for simple and 41.3% and 13.2% for diverse pastures. The percentage of legume was greater in TF-based than

Figure 3  Seasonal (a) crude protein (g/kg DM); (b) metabolisable energy (MJ ME/kg DM), (c) neutral detergent fibre (g/kg DM) and (d) water-soluble carbohydrate (g/kg DM) for all pasture mixtures from June 2010 to May 2012 in Lincoln. Error bar equals LSD ($a=0.05$) for interaction at each time point.
RG-based and HS-based pastures throughout the trial. The percentage of herb (chicory plus plantain) in the diverse pastures was high, ranging from 25.4 to 64.8%, with little change between first (\(\bar{x} = 39.9\%\)) and second (\(\bar{x} = 40.0\%\)) years (Figure 2b). The mean percentage of herb was greater (P<0.05) in HSD (\(\bar{x} = 50.6\%\)) than RGD (\(\bar{x} = 33.3\%\)) and TFD (\(\bar{x} = 36.0\%\)) in all seasons except spring 2010.

**Nutritive value**
Crude protein ranged from 196 g/kg DM to 261 g/kg DM throughout the year, and was highest in autumn of each year (\(\bar{x} = 259\) g/kg DM and 261 g/kg DM in autumn 2011 and 2012, respectively) (Figure 3a). Crude protein was unaffected by base pasture or diversity (Figure 3a). Metabolisable energy ranged from 11.6 to 12.7 MJ ME/kg DM with little seasonal variation (Figure 3b). ME was higher (P<0.001) in HS-based pastures (\(\bar{x} = 12.4\) MJ ME/kg DM) than RG-based pastures (\(\bar{x} = 12.1\) MJ ME/kg DM) and TF-based pastures (\(\bar{x} = 11.8\) MJ ME/kg DM) in each season (Figure 3b). In all seasons except autumn 2011 and autumn 2012, ME was higher (P<0.01) in simple pastures (\(\bar{x} = 12.2\) ME MJ/kg DM) than diverse pastures (\(\bar{x} = 12.0\) ME MJ/kg DM). Neutral detergent fibre ranged from to 275 g/kg DM to 363 g/kg DM and averaged over the trial was greater (P<0.001) in simple (\(\bar{x} = 368\) g/kg DM) than diverse pastures (\(\bar{x} = 301\) g/kg DM). In most seasons, NDF was lower (P<0.001) in HS-based pastures (\(\bar{x} = 313\) g/kg DM) than TF-based pastures (\(\bar{x} = 337\) g/kg DM) and RG-based pastures (\(\bar{x} = 353\) g/kg DM) (Figure 3c). The water soluble carbohydrate (WSC) concentration ranged from 157 g/kg DM to 275 g/kg DM, and at all dates was higher (P<0.01) in HS-based (\(\bar{x} = 226\) g/kg DM) than RG-based (\(\bar{x} = 189\) g/kg DM) or TF-based pastures (\(\bar{x} = 172\) g/kg DM) (Figure 3d). There was a trend for WSC to be lower in diverse (\(\bar{x} = 186\) g/kg DM) than simple (\(\bar{x} = 206\) g/kg DM) pastures, with this effect was significant (P<0.001) in winter 2011.

**Discussion**

**DM herbage production**
Annual DM herbage production calculated from weekly rising plate meter and averaged across both years for the three base pastures was 1.62 t DM/ha greater in the diverse than simple pastures. The high DM yield of the diverse pasture supports previous results that diverse pastures are at least as good as conventional two-species pastures (Daly et al. 1996; Goh & Bruce 2005; Ruiz-Jerez et al. 1991; Sanderson et al. 2005). In the current study, the higher DM production primarily reflected increased growth during summer, with approximately 1 t DM/ha more grown over summer in diverse than simple pastures. In turn, the higher herbage growth is probably due to a high abundance of herbs (chicory and plantain) in diverse pastures in summer, which grow rapidly at this time of year given adequate water (Sanderson et al. 2005). Increased legume growth is unlikely to be an explanation as in most seasons the proportion of legume in pasture was lower in diverse than simple pastures.

Ryegrass and white clover are particular suitable in summer moist or irrigated pastures, where under the appropriate fertiliser and grazing management regime, they form a productive pasture of a high quality. In this experiment, annual herbage DM production was greater in the perennial ryegrass-based pastures (RG and HS) than TF-based pastures in the first but not second year, supporting similar results by Minné et al. (2010). Compared to perennial ryegrass, tall fescue pastures are more suitable and tolerant to hot, dry summer environments and may have higher growth rates (McCallum et al. 1992). The difference between Year 1 and Year 2 may be explained by the slower establishment of tall fescue relative to perennial ryegrass (Milne et al. 1997), although the tall fescue was sown in summer, five months before measurements began.

**Nutritive value**
The metabolisable energy content of all pasture mixtures was high (>11.5 MJ ME/kg DM). Averaged over 2 years, ME was greater in simple than diverse pastures, although the difference was small (12.2 versus 12.0 MJ ME/kg DM). The greater ME in simple pastures most likely reflects the higher legume proportion in the simple than diverse pastures, with legumes often noted to have high ME (Waghorn 2007). Furthermore, pastures were consistently grazed to low pasture residuals preventing build-up of stem and dead material, meaning grass ME is likely to have been maintained at a high level in simple pastures. Despite the lower ME in diverse pastures, total ME produced per ha was greater in diverse (202 GJ ME/ha/yr) than simple (185 GJ ME/ha/yr) pastures due to their higher DM production.

There was negligible effect of pasture mixture on crude protein content, with values ranging from 195 to 261 g/kg DM. Similar CP content in simple and diverse pastures was also observed in related work using a subset of pastures from this study (Totty et al. 2013). These authors showed greater milk solids production per cow but reduced urine N concentration and urine N excretion per cow from the HSD than RG and HS pastures when offered at the same allowance, demonstrating potential environmental benefits. These findings may also be attributed to lower NDF in diverse (300 g/kg DM) than simple (368 g/kg DM) pastures,
most likely due to high chicory and plantain content with lower NDF (Burke et al. 2002). Both CP and NDF values were within the range ranges suggested by Holmes et al. (2002) and Pacheco & Waghorn (2008) to be adequate for milk production in early lactation. The water soluble carbohydrate concentration was higher (+37 g/kg DM) in the high sugar perennial ryegrass than the standard ryegrass, supporting results obtained by Bryant et al. (2009) in Canterbury.

Conclusion
Rotationaly grazed diverse pastures under irrigation in Canterbury were at least as productive as simple perennial ryegrass and tall fescue-white clover pastures. Increased summer growth of diverse pastures could be attributed to a high herb content. The herbage and ME production data indicate that diverse pastures may play an important role in promoting greater milksolids production per cow and per ha. Together, with data indicating lower N excretion from cows grazing diverse pastures, the results indicate that diverse pastures containing additional herbs and legumes may play an important role maintaining or increasing milksolids production while reducing the environmental impact of dairy farming.

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REFERENCES


Lee, J.M.; Clark, A.J.; Roche, J.R. 2013. Climate change effect and adaptation options for temperate pasture-based dairy farming systems: a review. Grass and Forage Science DOI: 10.1111/gfs.12039


The potential of diverse pastures to reduce nitrogen leaching on New Zealand dairy farms

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Abstract. The largest contributor to nitrogen (N) leaching from ryegrass-clover pasture based dairy farms is the surplus feed N excreted as urinary N (UN) onto pastures. Pastures consisting of mixtures of ryegrass, herbs and legumes (diverse pastures) have shown potential to yield similar DM, but with a lower N content and a higher water soluble carbohydrate : crude protein ratio compared with standard ryegrass-clover pastures. These diverse pastures have shown the potential to lower the UN excreted by dairy cows in short-term, late-lactation studies. This modelling study was designed to scale the results from component studies up to farm and over a full season to evaluate the potential of diverse pastures to become a suitable strategy for reducing N leaching on New Zealand dairy farms. The Molly cow model was tested against observed data from one indoor and one outdoor study where feeding diverse pasture resulted in UN (N excreted in urine g/day) reductions of 50% and 17%, respectively. The model predicted UN reductions of 23% and 17% Farm-scale model scenarios, where 20% or 50% of the farm was sown with diverse pastures, resulted in 2% and 6% reductions in UN deposited onto paddocks. This reduction was smaller than expected with some system interactions related to seasonal feed supply, diet composition and total N intake being likely to play a role. The reduction in UN onto paddocks, together with a dilution effect from larger urine volumes per cow per day as a result of lower DM% of diverse pastures, resulted in N leaching reductions of 11% and 19% for the two scenarios, respectively. This potential to reduce N leaching needs to be evaluated further in the context of farm profitability when other aspects of diverse pastures such as yield, persistence, drought resistance and ability to extract N from the soil becomes part of the farm-system analysis.

Additional keywords: farming systems, mixed pastures, modelling, multi-species pastures, urinary nitrogen, urine dilution.

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Introduction

The focus of dairy farming in New Zealand (NZ) on simple but productive systems has led to a limited range of plants being used – predominantly perennial ryegrass-white clover (Lolium perenne-Trifolium repens) pastures with some cropping of brassicas and maize (Woodward et al. 2013). These ryegrass-white clover pastures are characterised by a crude protein (CP) content typically above 20% of dry matter (DM) (Litherland and Lambert 2007) of high solubility, resulting in a large proportion of dietary N being excreted in the urine (Tamminga 1992). Urinary nitrogen (UN) excreted by dairy cattle is a significant environmental concern for the NZ dairy industry because nitrate (NO₃) derived from UN contributes to ground and surface water contamination and volatilised nitrous oxides contribute to the greenhouse gas problem (Cameron et al. 2013). Aside from reducing animal numbers, one of the most effective means of reducing UN losses on grazed pasture is to reduce total CP concentration of the diet (de Klein et al. 2010) and/or alter the type of protein in the diet. A higher proportion of rumen undegradable protein will reduce the amount of circulating blood urea and, therefore, the amount of N excreted in urine (Tas 2006; Gregorini et al. 2010).

Increased interest has developed in the role of alternative plant species in altering protein intake of dairy cows and ultimately reducing the environmental impacts of dairy farming in NZ. In an industry where the low cost pasture feed base underpins the competitive edge of the industry, alternative species growing as pure swards or mixtures have to produce at least similar amounts of metabolisable energy compared with the standard ryegrass-clover pastures, and have to produce with an acceptable seasonality that will allow the species to fit into the farm system. Previous studies have attempted to explore the potential benefits of mixtures of alternative species (diverse pastures hereafter). In a study of the DM production and botanical composition of diverse pastures in the Canterbury region, South Island, Nobility et al. (2013) evaluated standard
ryegrass-white clover pastures against diverse pastures where herbs (chicory *Chicorium intybus* and plantain *Plantago lanceolata*), legumes (red clover *Trifolium pretense* and lucerne *Medicago sativa*) and prairie grass (*Bromus wildenowii*) were added to the standard pasture. Both pasture types were irrigated and grazed by dairy cows. They showed that, on average over 2 years, annual DM production was 11% higher from the diverse compared with the standard pasture, primarily reflecting greater DM production from diverse pastures in summer. In another trial in the Waikato region, North Island, Woodward et al. (2013) showed over a 3-year period that diverse pastures (perennial ryegrass, white clover, chicory, plantain, lucerne) had similar annual DM production compared with standard pastures, with greater yields of diverse pastures during summer (December, January, February) when lucerne and chicory grew better than perennial ryegrass in the warm, dry conditions.

The studies of Nobly et al. (2013) and Woodward et al. (2013) indicate that diverse pastures in these two regions have the potential to produce quantity and quality of herbage at least comparable with standard perennial ryegrass-white clover pastures, and that they may offer benefits of more consistent DM production during drier seasons. Furthermore, diverse pastures show potential to reduce UN losses from lactating cows in late lactation without reducing milk production (Woodward et al. 2012; Totry et al. 2013). However, it is important to evaluate the potential benefits of diverse pastures in the system context by integrating seasonal growth rates, pasture quality changes, effects on cow N metabolism and UN excretion, and ultimately effects on N leaching across a full lactation season. It is likely that farmers will start experimenting with diverse pastures on a proportion of their farm, which raises the question of what proportion should be sown with diverse pastures to capture the benefits of reductions in N leaching. The objective of this study was to integrate the available data on diverse pastures in the Waikato region into the DairyNZ Whole Farm Model (WFM) connected to the Agricultural Production System Simulator (APSIM) model (Romera et al. 2012) in order to evaluate farm scale impacts of diverse pastures and their potential contribution to dairy farm systems with lower N leaching.

**Materials and methods**

**Approach**

The modelling exercise was designed to use measured nutritive qualities of standard and diverse pastures conducted in two regions, Waikato and Canterbury, and run these qualities through a mechanistic cow model, Molly, that simulates N metabolism in a dairy cow and predicts N outputs in milk, faeces and urine. These predictions were then compared with observed data from short-term (5–10 days) metabolic stall and field trials where cows were fed standard and diverse pastures, and where UN output was measured. Once it was established that the cow model satisfactorily represents N metabolism when grazing diverse pastures, the next step was to use observed pasture growth rate and quality data in a farm-scale model (that includes Molly) to scale the effect of short-term feeding of diverse pastures up to farm and a full season (1 June–31 May).

The farm-scale model extrapolates the short-term reduction in UN as a result of diverse pasture feeding to an annual UN load from all the cows deposited onto paddocks. The UN load onto paddocks from the farm-scale model is then simulated through a urine patch framework (UPF) that enables a patch-scale model (APSIM) to predict N leaching from single and overlapping urine patches as affected by UN concentration, soil and weather conditions. The flexibility of the connected models allows N leaching predictions for two hypothetical farms; a farm with 20% of the milking platform in diverse pasture and the rest in standard pasture, and a farm with 50% of the milking platform in diverse pasture and the rest in standard pasture.

**Data sources**

Pasture growth rates, botanical composition and feed composition data were obtained from two pasture trials, one in Canterbury (Nobly et al. 2013) and one in Waikato (Woodward et al. 2013). The Canterbury trial was conducted between June 2010 and May 2012 at the Lincoln University Research Dairy Farm outside Christchurch, New Zealand. Among other treatments there was a standard mix of perennial ryegrass-white clover and a diverse pasture where herbs (chicory and plantain), red clover and prairie grass were added to the standard mixture. All pastures were rotationally grazed (strip grazed with 24-h pasture allocation) by dairy cows, were cut for silage when necessary, and were fertilised with 200 kg N/ha/year which was applied in four applications of 50 kg N/ha as urea in early spring, mid-spring, mid-summer and mid-autumn. Herbage mass was measured weekly with a calibrated rising plate meter. Herbage DM production was calculated on an annual and seasonal basis (winter: June–August, spring: September–November, summer: December–February and autumn: March–May). Botanical composition was measured before each grazing. Fresh samples of herbage were dissected into sown grass, herbs, legumes, weeds and dead material before dry weight of each component was determined. The oven-dried sub-samples were bulked for nutritive analysis using near infrared spectroscopy (NIRS).

In the Waikato standard and diverse pastures were established in autumn 2010 at DairyNZ’s Scott Farm, Hamilton, New Zealand. The standard pasture consisted of perennial ryegrass-white clover whereas the diverse pasture also contained prairie grass, chicory, plantain and lucerne. All pastures were harvested (either grazed by cows or cut for silage) at the same time and received the same level of nitrogen fertiliser (urea) targeting 200 kg N/ha/year. Herbage DM yield was estimated from cuts to grazing height (~4–5 cm) before every grazing or silage cut. Herbage samples were collected for measurement of DM% and for determining botanical composition. Pasture samples were collected seasonally for nutritive analysis. Samples were freeze-dried, ground, then bulked by treatment and analysed using NIRS.

**Models**

**Molly**

Molly is a mechanistic and dynamic model representing the critical elements of digestion and metabolism of a dairy cow (Baldwin 1995, modified by Hanigan et al. 2013). Molly’s feed intake is driven by metabolic demand. Feed quality is described in a feed composition table where the user defines feed fractions
for all the feeds used in the farm system. The feed fractions are then processed through Molly’s digestive system, nutrients absorbed into the bloodstream, and metabolised into tissue products (i.e. milk). The metabolisable energy content of the feed is, therefore, not an input but a product of digestion and absorption. Molly predicts UN, faecal-N and milk-N as influenced by feed quality, genetic merit and lactation status.

Botanical and nutritive quality data from the Woodward et al. (2013) and Nobilry et al. (2013) trials were used to construct the feed composition tables required to simulate different diet composition through Molly. The trials provided crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), water-soluble carbohydrate (WSC) and ash, which were averaged per month. The NDF, ADF, WSC and ash were partitioned into the corresponding fractions (i.e. Ce = cellulose, Hc = hemicellulose, Lg = lignin, Sc = soluble carbohydrate, St = starch, As = soluble ash, and Ai = insoluble ash) following the default proportions for ryegrass-white clover pastures currently used in the model. The CP content was partitioned into non-protein N (Np), soluble protein (Ps) and insoluble protein (Pi) using the known partitioning for each pasture species (Burke 2004). Once feed composition input tables were compiled for standard and diverse pastures, four Molly cow models were initialised that were similar in terms of age, breed, start liveweight, start body condition score, genetic merit, and planned calving date. The models were run over a full season (1 June – 31 May) while each cow was fed to energy demand on one type of pasture (standard Waikato; diverse Waikato; standard Canterbury; diverse Canterbury) throughout the year. The total amount of N partitioned to UN per year was predicted.

WFM, APSIM and the Urine Patch Framework

The WFM (Beukes et al. 2008) represents a pasture based dairy farm with individual paddocks and cows simulated on a daily time step. Molly is the mechanistic and dynamic model that simulates cow metabolism in the WFM. The pasture model within the WFM (Romera et al. 2009) is climate-driven using weather data provided by the National Institute of Water and Atmospheric Research (NIWA) from the nearest weather station, or using interpolations from the nearest weather stations (virtual climate) for a particular location. Pasture growth responds to N applied as either mineral fertiliser or irrigated effluent N. Some or all paddocks can be irrigated according to a user-defined irrigation policy. Pasture response to irrigation water is determined by soil moisture levels. Paddocks are grazed rotationally. Post-grazing herbage mass influences pasture re-growth. Previous studies showed adequate performance of the pasture model when validated against pasture growth data from commercial dairy farms (Romera et al. 2010; Romera et al. 2013). Paddocks can be eliminated from the grazing rotation for all or part of the year as part of a cropping policy, e.g. maize, cereal or brassica crops. Supplements (home-grown or bought) can be fed to cows according to policies created by the user. Other user-defined policies related to cow management include breeding, grazing off the farm, drying off, culling and replacement. In the WFM, the deposition of the excreted N (urinary- and faecal-N) from each cow is based on the proportion of the daily active time spent on different surfaces (pasture, bark-covered stand-off pad, milking parlour, walkways or concrete feed pad).

The Agricultural Production System Simulator (APSIM) is a suite of models that provides a flexible structure for the simulation of climatic and soil management effects on growth of crops and pastures in farming systems (Probert et al. 1998). SoilWat, the default soil water model in APSIM, is a cascading layer model that simulates surface runoff, saturated and unsaturated water flow with the associated solute movement and soil evaporation (Probert et al. 1998). For this exercise, SoilWat was parameterised to describe a Horoatu silt loam for the Waikato. Pasture growth in APSIM was simulated using a version of the pasture model described by Romera et al. (2009) adapted for APSIM. The adaptation included the use of the root module part of the Plant2 (generic plant model in the APSIM suite), which enables N and water uptake by the pasture. Also, the senescent tissue from the aerial parts of the pasture contributes to SurfaceOM. The same weather files used in the WFM simulation were used to drive the weather-dependent models in APSIM.

The modelling in this study uses a framework called the Urine Patch Framework (UPF) that post-processes the results of the WFM and runs APSIM to simulate the urine patches (Romera et al. 2012). The WFM extracts the urine information for each grazing event on each paddock, accounting for the partitioning of the urine between paddocks, walkways, milking parlour, feed pad and the stand-off pad. Only the fate of UN directly excreted onto pastures was analysed in this study. The UPF breaks each paddock into areas with different urination patterns (i.e. dates of deposition and amount excreted on each date) and saves the information into text files. The software reads these files and prepares input files (.xml) for APSIM model runs, which are used to invoke APSIM for each pattern. Finally, the leaching data are collected to calculate N leaching for the whole paddock and subsequently the whole farm. The detail of the UPF connection between WFM and APSIM is described in Romera et al. (2012).

Model modifications

Studies by Woodward et al. (2012) and Totty et al. (2013) showed lower total UN excreted by cows feeding on diverse compared with standard pastures. Cows feeding diverse pastures also showed lower N concentrations in the urine because of a combination of lower total UN excreted and larger urine volumes. Leaching risk is determined by both the total UN load onto paddocks and the concentration (Li et al. 2012). It was, therefore, important to capture the differences in UN concentration in the WFM-UPF-APSIM simulations. Molly estimates UN, but not urine volume excreted per day. As documented by Romera et al. (2012) the current WFM calculation of urine volume per cow per day uses an equation developed by Bannink et al. (1999) based on DMI; Na, K and %N in the diet; daily milk yield; and % protein in the milk. As part of preparing the models for this study, urine volumes measured in a metabolic stall trial (Woodward et al. 2012) were compared with predictions from the Bannink model. Urine volume predictions for pasture-fed cows were too low, indicating that Bannink probably developed his equation for European diets with high DM%. Data from several published
studies (Kolver et al. 1998; Mooby et al. 2006; Soder et al. 2006), plus historic DairyNZ metabolic stall trials (Trial 1–5, Woodward BW; Woodward et al. 2012) where urine volumes, DMI and feed DM% were measured, were collated (M. Bryant, pers. comm.). A linear relationship was derived between water intake in the feed and urine volume (Fig. 1). Outlier urine volumes from Totty et al. (2013) were excluded from the empirical model. Also data from Valadares et al. (1999, 2000) were excluded because urine volumes were probably high because of high salt content in the diet. The linear relationship in Fig. 1 replaced the Bannink equation in the WFM and a new column was added to the feed composition table for feed DM% data. The effect of feed DM% on daily urine volume was assumed to be reflected in the number of urinations per cow per day and not different volumes per urination. This assumption was required to reduce the complexity of the urinate patch simulations (see Romera et al. 2012), and because we assumed minimal effect on N leaching at the farm scale.

Development of the farm scenarios

The ‘Control’ farm at DairyNZ’s Scott farm, Hamilton represents a typical Waikato farm. It was initialised in the WFM as the baseline scenario for the Waikato. Climate data from the local meteorological station (Ruakura) for the 2011–2012 season were used and feed compositions for standard and diverse pastures were loaded into the scenario. Stocking rate on this farm was 3.2 cows/ha, N fertiliser 142 kg/ha year, maize silage imported 162 kg DM/cow, young stock were grazed off, dry stock were wintered on the farm, and final dry-off date was 4 May. No stand-off was used during wet conditions. The baseline scenario was run with 100% of the milking platform in standard ryegrass-clover pasture giving an annual pasture yield very close to that reported by Woodward et al. (2013). This baseline scenario was altered by growing diverse pasture on 20% or 50% of the milking platform with user-defined growth rates and annual yield (Table 1). The rest of the platform grew standard pasture. In the WFM only standard pasture growth rates and annual yields are climate-driven. Currently there is no climate-driven model for diverse pasture. The diverse pasture block was, therefore, regarded as a ‘crop’ with user-defined growth rates and annual yields. Cows were allowed to graze the diverse pasture ‘crop’ for several days every month depending on the yield for that month. On any given day cows did not receive their full feed requirements from the diverse pasture and were also allowed to graze standard pasture in an attempt to fulfil their feed demand. Daily diets, therefore, consisted of a mixture of diverse and standard pasture, and grass or maize silage when necessary.

Results

Diverse pastures showed lower CP content and higher water soluble carbohydrate to protein ratio throughout the year (Fig. 2). Molly predicted a reduction in UN excretions on an annual basis of 23% when fed diverse pastures compared with standard ryegrass using feed composition from the Waikato region (Table 2). This is much lower than the 50% measured by Woodward et al. (2012) in a 5-day metabolic stall trial in late lactation in the Waikato. However, Molly’s predictions were acceptable when compared with results from Totty et al. (2013) when they measured a reduction of 17% in UN excreted per day when cows were fed a high-sugar ryegrass diverse pasture compared with a high-sugar ryegrass-white clover pasture in a 10-day grazing trial in late lactation in Canterbury. In the Canterbury trial UN excretion was estimated from urine spot samples collected at morning and afternoon milking and analysed for N concentration and creatinine, with urinary N excretion calculated according to equations presented by Pacheco et al. (2009).

Predictions of farm-scale results are presented in Table 3. Predicted yields for standard pasture differed between the three systems (control, 20% diverse, 50% diverse) because, in the model, area in diverse pasture affects cow rotations between paddocks, pasture utilisation, and, therefore, pasture yield. Area in diverse pasture also affected the number of paddocks in each system because paddocks were aggregated into blocks representing either 20% or 50% of the farm growing diverse pasture. Herbage yield for the whole farm (weighted yield from standard plus diverse pastures) tended to decrease with a larger area in diverse pastures because diverse pastures had a lower average yield (16 300 kg DM/ha) compared with 100% standard pasture (18 000 kg DM/ha for the 2011–2012 climate year).

![Fig. 1](image_url)

Fig. 1. Predictive equation for urine volume per cow per day using amount of ingested water, derived from dry matter (DM) intake and feed DM%.
There was a trend for milk production to increase with an increase in the proportion of the farm in diverse pasture, but this resulted in minor changes in the amount of N partitioned into milk. In the WFM the predicted UN excreted by mature cows on a daily basis is affected by the amount and type of protein eaten, which is the product of the combination of different amounts of standard pasture, diverse pasture, and maize and pasture silages offered to the herd. Daily UN excreted summed is the annual UN excreted per hectare. The changes in the combination of the diet in the 20% diverse and 50% diverse scenarios compared with the control resulted in a reduction in UN excreted of ~2% and 6% respectively. Only a proportion of the total UN excreted gets deposited onto the paddocks. UN deposited onto paddocks was also reduced by ~2% and 6%. The reduction in UN plus the urine dilution effect of diverse pastures in the diet resulted in predicted N leaching reductions of 11% and 19% in the two treatment scenarios (Table 3). Paddocks differ in the frequency and load of UN they receive because of numerous system interactions. For this reason each individual paddock had to be simulated with the WFM-UPF-APSIM model to obtain an average N leaching for the farm, resulting in different paddock numbers per scenario (Table 3).

Discussion

Previous short term studies by Totty et al. (2013) and Woodward et al. (2012) showed that diverse pastures containing herbs (chicory, plantain) can reduce UN losses from dairy cows in late lactation. Modelling predictions for a single cow presented in this study suggest that the UN reduction in late lactation may be extrapolated to hold true for the full lactation, mainly driven by lower N intakes and a higher WSC : CP ratio, which has been associated with reduced UN losses (Gregorini et al. 2010). The

![Graph](image)

**Fig. 2.** (a) Crude protein (CP) content for standard ryegrass–white clover and diverse (ryegrass, white clover, prairie grass, chicory, plantain, lucerne) pastures and (b) the ratio of soluble carbohydrates (CH) : CP for Waikato. Generated from Burke (2004) and Woodward et al. (2013) data.
Table 2. Nitrogen partitioning predicted by Molly cow model when fed to energy demand over a full year on either standard or diverse pastures using input data from two trials in two regions

<table>
<thead>
<tr>
<th>Trial (region)</th>
<th>N source</th>
<th>Standard pasture (kg/cow.year)</th>
<th>Diverse pasture (kg/cow.year)</th>
<th>Change (kg/cow.year)</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nobilly et al. (2013) (Canterbury)</td>
<td>Intake</td>
<td>199</td>
<td>178</td>
<td>–21</td>
<td>–11</td>
</tr>
<tr>
<td></td>
<td>Milk</td>
<td>26</td>
<td>26</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Urine</td>
<td>128</td>
<td>106</td>
<td>–22</td>
<td>–17</td>
</tr>
<tr>
<td></td>
<td>Feces</td>
<td>43</td>
<td>44</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Woodward et al. (2013) (Waikato)</td>
<td>Intake</td>
<td>193</td>
<td>163</td>
<td>–30</td>
<td>–16</td>
</tr>
<tr>
<td></td>
<td>Milk</td>
<td>25</td>
<td>23</td>
<td>–2</td>
<td>–8</td>
</tr>
<tr>
<td></td>
<td>Urine</td>
<td>124</td>
<td>96</td>
<td>–28</td>
<td>–23</td>
</tr>
<tr>
<td></td>
<td>Feces</td>
<td>42</td>
<td>41</td>
<td>–1</td>
<td>–2</td>
</tr>
</tbody>
</table>

Table 3. Predicted herbage DM production, milk-solid production, nitrogen (N) intake, milk N, urinary nitrogen (UN) excretion and N leaching for Waikato farms feeding cows standard pasture alone (control) or standard pasture in combination with diverse pasture sown in 20% or 50% (20% or 50% diverse) of the farm

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Herbage production (kg DM/ha.year)</th>
<th>Purchased feed (kg DM/ha.year)</th>
<th>Milk solids (kg/ha.year)</th>
<th>N intake by mature cows</th>
<th>N in milk</th>
<th>UN excreted by mature cows</th>
<th>UN deposited onto paddocks</th>
<th>N leaching with urine patches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>18 000</td>
<td>1000</td>
<td>1122</td>
<td>530</td>
<td>74</td>
<td>321</td>
<td>273</td>
<td>53 ± 8.5</td>
</tr>
<tr>
<td>20% diverse</td>
<td>17 700</td>
<td>900</td>
<td>1134</td>
<td>523</td>
<td>75</td>
<td>314</td>
<td>267</td>
<td>47 ± 5.4</td>
</tr>
<tr>
<td>Change (%)</td>
<td>1</td>
<td>–1</td>
<td>1</td>
<td>–1</td>
<td>1</td>
<td>–2</td>
<td>–2</td>
<td>–11</td>
</tr>
<tr>
<td>50% diverse</td>
<td>17 100</td>
<td>1500</td>
<td>1153</td>
<td>511</td>
<td>76</td>
<td>301</td>
<td>256</td>
<td>43 ± 8.4</td>
</tr>
<tr>
<td>Change (%)</td>
<td>3</td>
<td>–4</td>
<td>3</td>
<td>–6</td>
<td>–6</td>
<td>–6</td>
<td>–6</td>
<td>–19</td>
</tr>
</tbody>
</table>

Modelling predictions align with the trial results showing lower N intakes for diverse pastures, but they did not predict higher milk N output as recorded in both trials (Woodward et al. 2012; Totty et al. 2013). The predictions further suggest that the UN reduction effect of diverse pastures can be scaled up for the whole herd over a full lactation, but the effect is diluted by the proportion of the farm in diverse pasture. Furthermore, the dilution is not proportional to the area of the farm sown in diverse pastures, for example, when 50% of the farm was sown in diverse pastures the total UN from the herd was reduced by 6% and not the anticipated 11.5% (half of the 23%, Table 2). When the proportions of the different pastures change at the farm scale, there are several rippled effects through the system that affect how cows are fed on a daily basis, i.e. mixtures of standard pasture, diverse pasture and supplements. Also, there are implications for the daily break sizes (part of the paddock made available each day), herbage allowances, post-grazing residuals, conservation and silage making decisions, and ultimately the annual yield of the pastures (although in this study only the standard pasture yield varied depending on the scenario; diverse pasture yield was user-defined in all scenarios). All this affects the total amount of feed N going through the cows and ultimately the amount of UN deposited onto paddocks. To illustrate this point some model results were compared for the 50% diverse and control systems (Fig. 3). With higher feed intakes and milk production in the first part of the season the 50% diverse showed the same or higher total N intakes compared with the control, which converted into minor differences in UN onto paddocks over that part of the season. Lower N intakes resulting in consistently lower UN onto paddocks only became apparent in the 50% diverse for the second half of the season. It is important to keep in mind that the situation depicted in Fig. 3 only represents the 2011–12 season, implying that seasonal effects may be important in determining the effectiveness of diverse pastures in reducing N leaching at the farm scale. It is possible that in this case the model is approximating the real-world situation where the combination of mixtures of daily rations with different crude protein content and protein (or N) fractions being fed to the cows over the course of a season, plus the effect of grazing patterns on pasture yield and availability are likely to dilute the effect of diverse pastures when compared with theoretical diets.

Both total UN deposited onto paddocks and the UN concentration are important factors contributing to the N loading in the urine patch, and the subsequent nitrate-N leaching (Li et al. 2012). The model predictions show a decrease in UN concentration from 10.9 g N/L for standard pasture (N load per patch equivalent to 546 kg N/ha) to 9.5 g N/L with 50% diverse pasture (N load per patch equivalent to 475 kg N/ha). This decrease is partly the result of the lower total UN excretion driven by lower N intakes, but also partly the result of larger urine volumes from cows grazing diverse pastures. The amount of water ingested with the feed is an important factor driving urine volume (Fig. 1), with lower DM
% feeds generally resulting in higher urine volumes. Trial data (from SL Woodward and RH Bryant, unpubl. data) show that diverse pastures have, on average over the year, DM% ~3 units lower compared with standard pastures, which supports the general consensus that pastures containing herbs have lower DM% (Piggot 2009; Minnée et al. 2012; Wynn and Piggot 2012). The effect of this can be demonstrated by an example; with a daily intake of 15 kg DM/cow the three units lower DM% will result in an increase in daily urine volume from 32 L/cow.day for standard pasture to 37 L/cow.day for diverse pasture (with 100% diverse pasture diet and using the equation in Fig. 1). With an average daily UN excretion of 300 g/cow the urine gets diluted by diverse pasture from 9.4 to 8.1 g N/L, and when the reduction in UN excreted is considered in this equation (using data from Table 2) the urine is diluted from 10.6 for standard pasture to 7.1 g N/L for diverse pasture, a reduction of 33%. In studies conducted early in lactation (RH Bryant, unpubl. data), UN concentrations in spring and summer were lower for cows grazing diverse pasture. Averaged across the three trial periods, UN concentration was 23% lower from cows grazing the diverse (4 g N/L) compared with the standard pastures (4.9 g N/L). The model results showed higher UN concentrations compared with this study, but the same decreases in concentration when diverse pastures were fed. Considering a 19% leaching reduction in the 50% diverse scenario when UN onto paddocks was only reduced by 6%, then it would appear that the larger percentage of the leaching reduction must be attributed to the urine dilution effect. This aspect needs further work because it will have implications for how species are selected for diverse pastures. Not only is yield, seasonal growth, protein content important, but also DM content.

Several traits of diverse pastures were not included in this study that may have an important bearing on the suitability of these pastures for NZ dairy systems. Chicory and plantain have limited life spans in diverse pastures (Li and Kemp 2005), making pasture persistency and the maintenance of the mixture important. Lower persistency may result in more frequent re-grassing of diverse pastures or require over-sowing to maintain the mixture. These costs need to be considered in the evaluation of profitability of systems with proportions of the farm sown in diverse pastures. It will also be important to model systems over
different climate years to evaluate the potential of diverse pastures with deeper and more complex root systems to outperform standard pastures during dry seasons. This will require the development of a climate-driven diverse pasture model for the WFM, which presents a considerable challenge because of the complex interactions between species and the dynamic nature of the mix within and between years. By not modelling the root structure of diverse pastures it is likely that an important positive trait of these pastures is missed. In this context, it has been suggested that deeper rooting pasture species than perennial ryegrass, such as chicory and plantain, could be useful to reduce N leaching losses from grazed pasture systems by capturing more nitrate-N in the soil arising from urine patches (Sanderson et al. 2004). A study at Lincoln University, NZ, compared N leaching losses from perennial ryegrass-white clover pasture with those from diverse pastures and Italian ryegrass-white clover pastures (Malcolm et al. 2014). This study, and an associated study measuring nitrate leaching from 13 temperate grass species present in New Zealand pastures (Moir et al. 2013), demonstrated strong negative linear relationships between nitrate-N leaching and plant N uptake and root mass. Plants with greater growth during the cool season had greater N uptake and lower N leaching losses. This may mean that plants such as chicory, which have deeper roots but low cool season growth, may be beneficial for dry-season growth, but give less benefit in terms of capturing N in the soil before it being leached in winter drainage.

Diverse pastures had lower growth rates in winter (average over three years of 28 vs 24 kg DM/ha.day for standard and diverse, respectively). This relatively small difference in daily growth rate can make a substantial difference in the feed budget over a winter of at least 3 months (cf. 15%) and this partly explains the reluctance to consider converting 100% of the farm into diverse pasture. Unpublished modelling results using the deterministic farm-scale model Farmx support this statement that feed budgets for the winter months were more positive with 100% of the farm in standard pasture compared with the situation with 50% in diverse pastures. Using a higher percentage of the farm may be more aligned with dairy systems in southern NZ, where cows are wintered off the pasture-based milking platform during the winter non-lactation period, and hence where less reliance is based on cool season growth to support the feed demands.

Annual herbage DM production decreased with increasing proportion of the farm sown in diverse pastures. The lower DM production had no negative impact on milk-solid production. A possible explanation is that greater feed energy content from inclusion of diverse pasture in 20% of the farm, more than compensated for reduced DM production. However, in the 50% diverse scenario purchased feed increased by 50% compared with the control, indicating the greater effect of reduced DM production compared with the benefit of increased feed energy. This suggests that in an average year in the Waikato (average year determined by the 18 t DM/ha.year production for standard pasture), incorporating diverse pasture in >20% of the farm is likely to reduce total farm-grown feed, with implications for purchased feed and potentially the economic performance of the farm.

Conclusions
The modelling results suggest that diverse pastures consisting of perennial ryegrass-white clover plus prairie grass, chicory, plantain and lucerne have the potential to reduce N leaching from Waikato dairy farms by 11% or 19% depending on the proportion of the farm sown, 20% or 50% respectively. This potential to substantially reduce N leaching needs to be further evaluated in the context of farm profitability when other aspects of diverse pastures like yield, persistency, drought resistance and ability to extract soil-N becomes part of the farm system analysis.

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References
Diverse pastures and nitrogen leaching

Brookes, AM Nicoll pp. 81–96. (New Zealand Society of Animal Production Inc.)