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Productivity, botanical composition and insect population of seven dryland pasture species in Canterbury after eight years

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Declaration

All of the data presented in this thesis was collected by the candidate except for

a) Sample preparation for nitrogen analysis
b) Grass grub population data for 2008 and 2009

Productivity, botanical composition and insect population of seven dryland pasture species after eight years

Nicole Jane Morris

Abstract

The annual and seasonal water use efficiency of six pasture combinations were calculated from the 'MaxClover' grazing experiment at Lincoln University, Canterbury. Pastures had been established for seven years and were grazed by best mangement practises for each species combination. Measurements from this study are from individual plots of six replicates of cocksfoot (CF)/Subterranean clover (Sub), CF/Balansa clover (Bal), CF/White clover (Wc), CF/Caucasian clover (Cc), ryegrass (RG)/Wc and lucerne (Luc).

Dry matter measurements of yield, botanical composition and herbage quality were assessed from 1 July 2009 to 30 June 2010. Lucerne had the highest total annual yield of 12880 kg DM/ha/y, followed by CF/Sub at 9460 kg DM/ha/y. All other pastures produced 6600 to 8360 kg DM/ha/y. Soil water measurements showed that all pastures had a plant available water content of 316 ± 24 mm. All pastures used 655 ± 22 mm/y of water. Lucerne had the highest annual water use efficiency (WUE) of 23 kg DM/ha/mm/y. The annual WUE of CF/Sub was 16 kg DM/ha/y and the lowest was 11 kg DM/ha/mm/y from RG/Wc and CF/Wc pastures.

The CF/Sub and CF/Bal pastures had the highest total annual legume (sown and volunteer white clover) content of all grass based pastures at 18%. Because of yield differences CF/Sub had the highest annual nitrogen yield of 216 kg N/ha of the grass based pastures although it was less than half that from lucerne (462 kg N/ha). RG/Wc pastures had the highest proportion of weeds which represented 62% of total dry matter in Year 8 (2009/10).

For dryland farmers spring is the crucial period for production before growth slows when soil water becomes limiting. For the spring period (1/7/2009 to 29/1/2010) lucerne produced

11120 kg DM/ha, which was the highest yield of all pastures follwed by CF/Sub (1/7/2009 to 16/11/2009) which produced 6020 kg DM/ha. When dry matter production was regressed against thermal time, CF/Sub pastures grew at 5.7 ± 0.08 kg DM/° Cd between 1/7/2009 and 16/11/2009 compared with lucerne which grew at 4.2 ± 0.46 kg DM/° Cd between 1/7/2009 and 29/1/2010 which was an extra 74 days of linear spring growth. WUE during the initial period for lucerne (1/7/09 to 29/1/10) was 22.3 ± 0.5 kg DM/ha/mm (R^2=1.00). The CF/Sub pastures produced 20 ± 1.5 kg DM/ha/mm (R^2=0.98) from 1/7/09 to 16/11/09 from 306 mm of water used. The lowest WUE was 11.7 ± 0.21 kg DM/ha/mm by CF/Wc pastures.

Insect pests within CF/Sub, CF/Wc, RG/Wc and lucerne pastures were quantified in winter. Pests included Argentine stem weevil, clover root weevil, Sitona weevil and grass grub. Argentine stem weevil populations were highest in CF/Sub pastures (63 weevils m^{-2}) whereas clover root weevil populations were highest in CF/Wc (5 weevils m^{-2}). Grass grub was present in all grass based pastures and was the highest in RG/Wc with 208 grubs m^{-2}. Present pest levels were not at damaging thresholds.

Based on the results from this research, dryland farmers should maximize the use and potential of lucerne on farm and sow cocksfoot as the main grass species due to persistence and insect tolerance compared with perennial ryegrass. Subterranean clover should be the main companion legume within cocksfoot pastures. Increased legume content ensures scarce water is used more efficiently because N deficiency in the grass is alleviated.

Keywords; *Dactylis glomerata* L., *Lolium perenne* L., *Medicago sativa* L., *Trifolium ambiguum* L., *T. subterranean*, *T. repens* L., *T. michelianum* S., *Sitona lepidus* (Gyllenhal), *Listronotus bonariensis* (Kuschel), *Sitona discoideus* (Gyllenhal), *Costelytra zealandica.*

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List of Abbreviations

Abbreviation	Description	Units
DM	dry matter	kg DM/ha
DUL	drained upper limit	% v/v or mm
LL	drained lower limit	% v/v or mm
LSD	least significant difference	
ME	metabolisable energy	MJ/kg DM
N%	nitrogen concentration	%
PAWC	plane available water capacity	mm
PET	potential evapotranspiration	mm
R^2	coefficient of determination	
SEM	standard error of the mean	
t	time	d
T_b	base temperature	°C
Tmax	maximum temperature	°C
Tmin	minimum temperature	°C
Tt	thermal time	°C d
VWC	volumetric water capacity	% v/v
WU	water use	mm
WUE	water use efficiency	kg DM/ha/mm
Y	yield	kg/ha or t/ha

1 General Introduction

Eastern regions of the North and South Islands of New Zealand receive less rainfall than evapotranspiration in summer in most years (Brown & Green 2003). This water deficit imposes a severe limitation to the productivity and sustainability of sheep and beef farms in these regions, which depend primarily on rainfall to produce meat and wool from pastures. The efficient use of the limited water supply for pasture growth is therefore a major concern and farmers are continually interested in different pasture species that can persist and produce high quality feed on these dryland farms (Avery *et al.* 2008).

The most common type of pasture used in New Zealand is a mixture of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), but these species are best suited to summer moist environments and moderate to high soil fertility (Brock *et al.* 2003). They tend not to persist well in dryland regions where annual rainfall is less than 750 mm (Knowles *et al.* 2003). This is mainly due to their shallow root systems (Brock *et al.* 2003) and growing points that are exposed to high soil surface temperatures and severe grazing in summer (Watson *et al.* 1998). Other reasons include a typically lower level of soil fertility on dryland than summer moist farms (Knowles *et al.* 2003) and their susceptibility to insect pests (Watson *et al.* 1998), although new strains of novel endophytes (*Neotyphodium lolii*) such as AR1 have improved the tolerance of perennial ryegrass to insect pests in some summer dry environments. On dryland farms, this type of pasture usually has a higher proportion of invasive grasses and a low proportion of clover, making it nitrogen deficient and unproductive when moisture is available in spring and early summer.

Cocskfoot (*Dactylis glomerata* L.) is the second most common pasture grass used in New Zealand (Mills *et al.* 2006). It is more persistent and higher yielding than perennial ryegrass in dryland conditions. It has a deeper root system than ryegrass (Charlton & Stewart 2000) and does not require endophyte for protection against insect attack. Cocksfoot is valued by dryland farmers for its grazing tolerance and survival over summer, but it is very competitive against white clover for water and nutrients, where the two species are sown together (Mills *et al.* 2006). As a consequence, cocksfoot dominant pastures often have a low nutritional value and can be difficult to manage by grazing, particularly on hill country. Furthermore, nitrogen has a major influence on the yield and water use efficiency of cocksfoot pastures in spring, when moisture is still available, and after autumn rain (Mills *et al.* 2006). Pasture legumes that can fix nitrogen and compete with cocksfoot in dryland conditions may therefore be able to improve the yield, quality and water use effiency of cocksfoot based pastures.

Several alternative pasture legumes have the potential to complement cocksfoot. Subterranean clover (*Trifolium subterranean* L.) and Caucasian clover (*Trifolium ambiguum* L.) may be more successful than white clover (Smetham 2003; Watson *et al.* 1998). Balansa clover (*Trifolium michelianum* S.) is an annual pasture legume and yield, persistence and management is not well understood (Monks, 2009). Lucerne (*Medicago sativa*) monocultures are also highly productive in dryland systems and are suitable for grazing with sheep and cattle. It can persist for 5-7 years. Since the conception of the experiment described in this thesis, there have been no long-term direct comparisons of each of the above pasture options and with perennial ryegrass/white clover, in terms of their yield, persistence and water use efficiency.

Insect pests can compound the effects of water stress on the yield and persistence of dryland pastures. Insect damage depends on the size of the insect population and pest threshold levels give an indication of when control should take place (Langer 1973). Clover root weevil (*Sitona lepidus* Gyllenhal) and Argentine stem weevil (*Listronotus bonariensis* (Kuschel)) are pests detrimental to perennial ryegrass and white clover in New Zealand. Threshold levels of these pests depend on the abundance of clover (Mowat & Shakeel 1988) and control is either by sowing alternative pasture species or biological control. Potentially pastures that are persistent in dryland conditions may harbour a low population of insect pests.

The aim of this thesis was to investigate different pasture options for dryland sheep and beef farms in New Zealand. The scientific literature was reviewed to describe the yield and water use of perennial ryegrass and white clover compared with cocksfoot, subterranean clover, Caucasian clover, balansa clover and lucerne in dryland conditions. A grazing experiment was carried out to compare the yield, composition, water use and insect populations of six swards during their eighth year after establishment in a dryland environment at Lincoln University.

2 Review of Literature

This review describes the primary variable within this study which is dry matter (DM) production. This chapter reviews literature associated with dryland pasture species which were used in this study. Also explained is how water use efficiency is determined and pasture pests that may be associated with the ‘MaxClover’ experiment.

2.1 Dryland pasture species

2.1.1 Perennial ryegrass

Perennial ryegrass is the most widely sown temperate grass in New Zealand (Charlton & Stewart 2000). It establishes easily, grows in a wide range of environments, is easy to manage and has high nutritive value (Litherland & Lambert 2007). Perennial ryegrass tolerates grazing and treading due to its ability to produce many tillers. It requires a plentiful soil water supply due to a shallow root complex. It requires moist and fertile conditions, but can also grow and persist in very wet environments (Langer 1973). It does not produce well in hot dry climates with high temperatures compared to deeper rooted grasses (Charlton & Stewart 2000). In Australia, there have been major improvements in the performance of perennial ryegrass. However persistence under grazing is unsatisfactory which fails to make it a reliable feed source in similar environments (Lowe 2009).

Perennial ryegrass has many insect pests which can hinder growth and development. A primary pest is the Argentine stem weevil (Section 2.2.1). Ryegrass fungal endophyte can be incorporated to give insect resistance due to the production of alkaloids from the plant. The fungus has a symbiotic relationship with the plant (Langer 1973). Recent developments have reduced potential impacts on animal health while still reducing insect attack.

Perennial ryegrass is compatible with white clover and other pasture species. Ryegrass and white clover pasture mixes are the dominant mix sown within New Zealand, even in dryland conditions (Knowles *et al.* 2003).

2.1.2 Cocksfoot

Cocksfoot is a drought tolerant perennial grass that grows well in summer (Charlton & Stewart 2000), so it is an important component of dryland pastures. It is generally pest tolerant, recovers from continual set stocking and suits light to free draining soils of moderate fertility. Its forage quality is normally lower than perennial ryegrass. Perennial or annual clovers could potentially improve the nutritive value of cocksfoot in mixtures. Previous results from the experiment described in this thesis showed that cocksfoot pastures were more productive than the perennial ryegrass/white clover in four out of five years after sowing. In the fifth year, the yield of cocksfoot averaged 6 t DM/ha compared with 4 t DM/ha/y for perennial ryegrass (Figure 2.1).

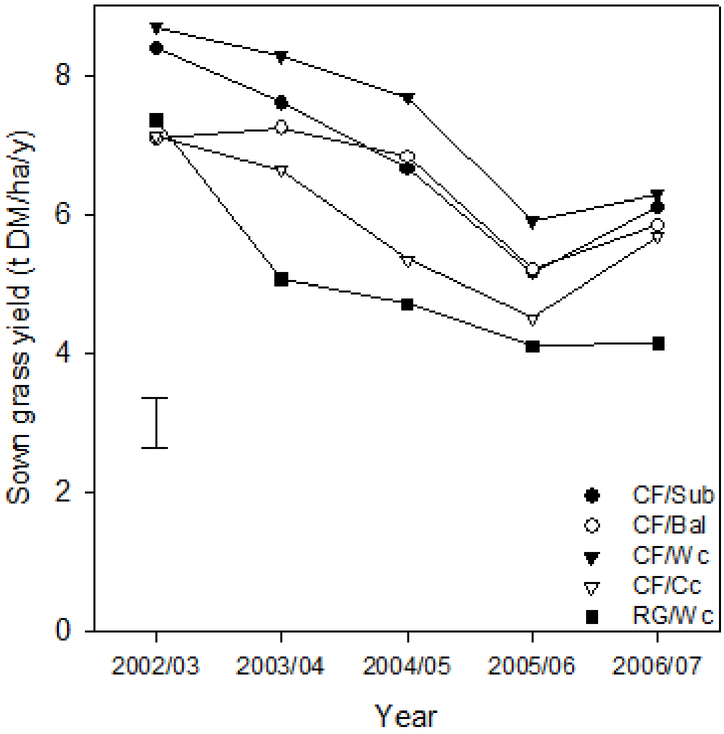

Figure 2.1 **Annual yields (t DM/ha/y) of cocksfoot (CF) and perennial ryegrass (RG) in five pasture mixtures (CF/Sub, CF/Bal, CF/Wc, CF/Cc and RG/Wc) over five growth seasons at Lincoln University, Canterbury, New Zealand. Error bar is the maximum SEM (Mills *et al.* 2008).**

Cocksfoot is aggressive against companion pasture species for water and nutrients (Stevens *et al.* 1992). Therefore, it is normally sown at a low rate of 2 -3 kg/ha in mixed swards. At higher rates cocksfoot is likely to dominate and reduce clover content, which leads to decreased N supply and pasture quality (Peri *et al.* 2002b). Cocksfoot is slow to establish and has a lower digestibility than ryegrass when soil moisture is limiting (Langer 1973). Its winter growth can be lower but summer growth is usually higher than perennial ryegrass.

Animal performance is greater from cocksfoot/clover pastures than from RG/Wc in dryland conditions. Mills *et al.* (2008) found that lambs grazing cocksfoot/clover grew 25 g/head/day faster than lambs on ryegrass/white clover, which grew at 65 g/head/day.

Cocksfoot responds well to soil moisture in dry summers so it recovers better than ryegrass after drought (Fraser 1994). Brown *et al.* (2006) found the incompatibility of cocksfoot and white clover in pastures was partly due to the ability of cocksfoot to extract more moisture from the soil throughout the summer. This resulted in the pasture becoming cocksfoot dominant due to white clover being outcompeted (Brown *et al.* 2006). Pasture production and nutritive value subsequently decreased due to N deficiency. Hyslop *et al.* (2003) stated that annual clovers are more suitable as companion species grown with cocksfoot than white clover in dryland systems, because they set seed and die in summer and thus avoid competition from cocksfoot when soil moisture is limiting.

Stevens *et al.* (1992) reported cocksfoot production was 7.6 t/ha compared with 4.9 t/ha for ryegrass and cocksfoot yielded 131% more in summer and 74% more in autumn. The nutritive value of cocksfoot declines in summer when seed heads emerge (Charlton & Stewart 2000).

Peri *et al.* (2002b) reported an annual yield of 28.6 t DM/ha for cocksfoot with irrigation and N fertilizer. Without irrigation or N fertilizer, cocksfoot yielded 9.2 t DM/ha/y. Mills *et al.* (2006) at Lincoln found that an 8 year old cocksfoot pasture produced annual yields of 22.0 t DM/ha when N and soil moisture were not limiting, 9.1 t DM/ha/y with irrigation and no N fertilizer, 5.0 t DM/ha/y without irrigation and N fertilizer and 16.4 t DM/ha/y without irrigation and non-limiting N. Their conclusion was that N, rather than water, was the most limiting factor for annual yield of cocksfoot. Thus, strategies that can improve the spring N content of soil will increase yield and quality of dryland pastures.

2.1.3 White Clover

White clover is a perennial forage legume that originated from West Asia, Africa and Europe (Langer 1973). It is the most widely sown pasture legume in New Zealand agriculture due to its ability to fix atmospheric N and compatibility with perennial ryegrass. It spreads vegetatively by a prostrate network of stolons and it has an adventitious root system. It is generally a high quality component of pasture (Charlton & Stewart 2000). It is susceptible to a major pasture pest which is the clover root weevil (*Sitona Lepidus* (Gyllenhal)), which is now a major pasture pest in New Zealand (Section 2.2.2).

White clover performs adequately in moderate to high fertility environments and in cool, moist environments, but not in dry situations. However, it is successful on sandy soils when water is available and on irrigated droughty soils in warm climates. It is adapted to silt and clay soils which have adequate moisture or are irrigated (Brock & Kane 2003). White clover also lacks persistence in Australia in regions which have an annual rainfall less than 700 mm (Lowe 2009).

The persistence of white clover is directly proportional to its stolon density. Adventitious roots must develop from nodes on the stolons and the plant relies on these roots to persist once the tap root has died, which normally occurs after 18 months (Knowles *et al.* 2003). After this time, adequate moisture must be available for white clover to persist. The roots of white clover seldom grow longer than 0.5 m, so it is only suited to shallow soils when moisture is available (Brock & Kane 2003). Growing white clover in dryland environments is difficult due to drought and plant competition. Sheath and Hay (1989) stated that white clover is only successful in dry environments with greater than 750 mm rainfall per annum. Knowles *et al.* (2003) surveyed the presence of white clover seedlings after a severe drought (2000/01) in North Otago and found they contributed only 0.3% to the total population after 10 mm of rain in May.

Persistence of white clover in dryland environments is aided by the regeneration of seed. This depends on seedling recruitment from seeds which have been in the soil (Knowles *et al.* 2003). Lax grazing allows the plant to flower and produce seed (Charlton & Stewart 2000).

2.1.4 Caucasian Clover

Caucasian clover is a perennial legume which spreads by underground rhizomes, has a deep taproot and is slow to establish (Watson *et al.* 1998) but is persistent once it is established (Charlton & Stewart 2000). It has strong pest and cold tolerance and these contribute to its strong persistence (Watson *et al.* 1998). It suits temperate tableland regions of the South Island high country (Woodham *et al.* 1992) and requires free draining soils with a pH over 4.5, but can tolerate sporadic water logging. It can also tolerate low fertility environments, but will respond well to P and S fertilizer. It grows well in spring and summer when established and is winter dormant. The rhizomes offer protection from elevated soil temperature in summer and hard grazing. Caucasian clover can also persist from seed set where conditions are appropriate. Grazing intensity and ploidy affect density of Caucasian clover (Scott 1998). The hexaploid cultivar 'Endura' is the only commercially available cultivar in New Zealand. Scott (1998) stated that regrowth rates of Caucasian clover are lower than those of white clover and Caucasian may take up to twice as long to grow back to the same cover as white clover.

When established with perennial grasses, Caucasian clover is more adaptable to water stress than white clover. Black and Lucas (2000) found that on dryland lowlands, Caucasian clover was more productive under drought conditions than white clover. They found that the legume content of white clover pastures was only 1% when sown with cocksfoot, compared with 46% for Caucasian clover in summer. Black *et al.* (2003) investigated the yield of sown monocultures of white and Caucasian clovers at Lincoln, under irrigated and dryland conditions and found that Caucasian clover yielded 2.5 t DM/ha/y more than white clover under both conditions. This was due to higher mean daily growth rates in spring and summer than white clover. However, in autumn the yield of white clover exceeded that of Caucasian clover which was partially attributed to Caucasian clover having a higher base temperature for leaf development (5 °C) compared with white clover (1 °C).

2.1.5 Subterranean Clover

Subterranean clover is a prostrate annual legume which establishes from autumn each season (Charlton & Stewart 2000). It is originally from the Mediterranean region and therefore suits New Zealand’s temperate climate (Langer 1973). It has a tap root, grows from a rosette and develops horizontal stems each winter and spring.

Subterranean clover is self pollinating. After pollination the flowers form burrs which are pushed into the soil surface to survive the summer as a seed (Langer 1973). Seeds then germinate in the following autumn. However, ‘false strikes’ can occur in summer when seed germinates too early.

Subterranean clover is valuable in dryland farming systems and persists longer in extremely dry conditions than white clover. It can contribute up to 20% of the total herbage in spring (Charlton & Stewart 2000). However, grazing management must be appropriate to ensure survival of subterranean clover in a sward (Moot *et al.* 2003a). After germination in autumn, seedlings should have six leaves before their first grazing. Grazing can continue until cool temperatures reduce growth. In spring, during seed set, low post grazing pastures masses of less than 1000 kg DM/ha can reduce seed set (Ates *et al.* 2008). In summer, hard grazing should take place to reduce competition for light and shading by companion grasses. This can allow high numbers of seed to germinate. Ates *et al.* (2008) stated that this is important in moist summers where grass growth is high. Results to date from the ‘MaxClover’ grazing experiment suggested subterranean clover with cocksfoot has been the most successful grass based pasture to date in the experiment (Mills *et al.* 2010) (Figure 2.4).

2.1.6 Balansa Cover

Balansa clover is an annual legume which germinates in autumn and is capable of long-term persistence. It flowers and sets seed in spring and has optimum production in October and November. However, it is usually taken for hay or grazed before seed development has occurred. It has hollow stems and a semi-prostrate growth habit (Charlton & Stewart 2000) and is tolerant of waterlogged soils in winter. It is adapted to a range of soil types and can tolerate pH levels of between 5.0 and 8.6, but it is more sensitive to low pH than subterranean clover (Evans *et al.* 1990).

Balansa clover can tolerate hard grazing from emergence, in autumn, to flowering, in spring (Monks *et al.* 2008). However, yield and persistence are dependent on grazing management. Monks *et al.* (2008) found that stands sown in February and closed in October yielded only 50% of potential yield over the following 3 years (Figure 2.2). In contrast, stands closed in September to allow flowering, resulted in sufficient seed produced for successful re-establishment for the following 3 years. Therefore, balansa clover requires careful management in the establishment year and then in three yearly cycles (Monks 2009).

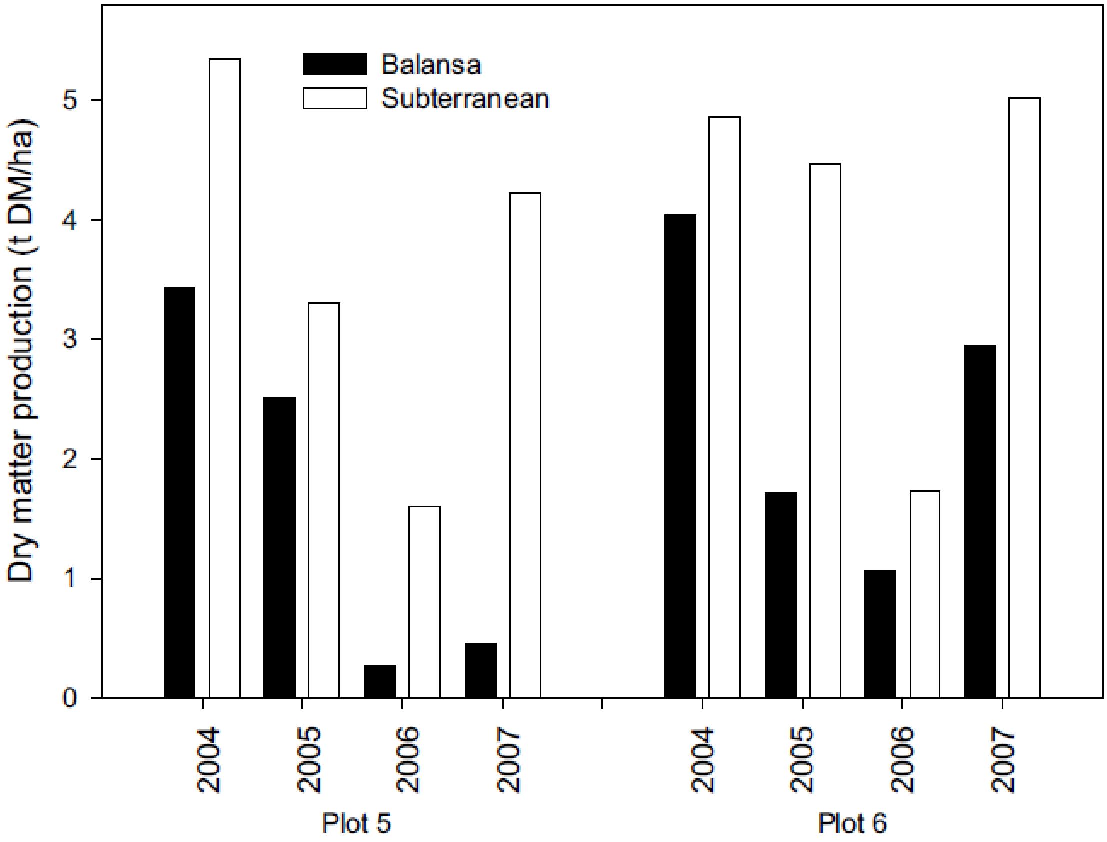

Figure 2.2 **Total annual yield of balansa clover and subterranean clover in cocksfoot pastures in years 2 to 5 after sowing in dryland conditions at Lincoln (Monks *et al.* 2008).**

Cool soil temperatures and wet summers can soften its seed and encourage grass growth, which increases competition within the sward at the crucial time of emergence.

2.1.7 Lucerne

Lucerne, also known as alfalfa, is a member of the Fabaceae family. It is a perennial forage legume with an erect growth habit and is suitable for sheep, cattle and deer grazing (Charlton & Stewart 2000). It is usually sown in pure swards. It requires high fertility, free draining soils and a pH over 6.0. High levels of Al affect root development in the subsoil. Lucerne is sensitive to salt in soil (White 1982). Establishing lucerne crops prioritise root development compared with shoot development (Charlton & Stewart 2000). Grazing should be avoided in mid winter. Lucerne should be rotationally grazed at 4 to 6 week intervals to ensure optimum production. Hard grazing should occur in summer drought conditions because, water stress causes yield to decline and increases leaf senescence (Moot *et al.* 2003b). Therefore hard grazing will reduce dry matter losses. Previous grazing recommendations were that lucerne should not be grazed in spring until flowering. However, it is now recommended that grazing can start when stands are 0.2 m in height (Moot *et al.* 2003b). Late summer/autumn flowering is critical to stand performance in the subsequent spring, as root reserves are replenished then.

Lucerne can grow up to 1 m in height and has a tap root system up to 4.5 m deep. It is capable of living for up to 20 years, depending on management, cultivar and environment (Langer 1973). Lucerne typically persists for between 4 to 8 years in a pasture system, depending on stocking rate, (Charlton & Stewart 2000). Lucerne is able to extract more water than other pasture species. Brown *et al.* (2003) found that lucerne was able to extract 358 mm to a depth of 2.3 m on a Wakanui soil at Lincoln, which was more ($P<0.01$) than red clover or chicory (Figure 2.3). They also found that lucerne was the only species to persist past the fourth season of dry conditions, and reasonable stands lasted eight years. In the Australian subtropics, where irrigation is the key resource needed for production, lucerne is one of the few species which can survive under rain grown conditions (Lowe 2009).

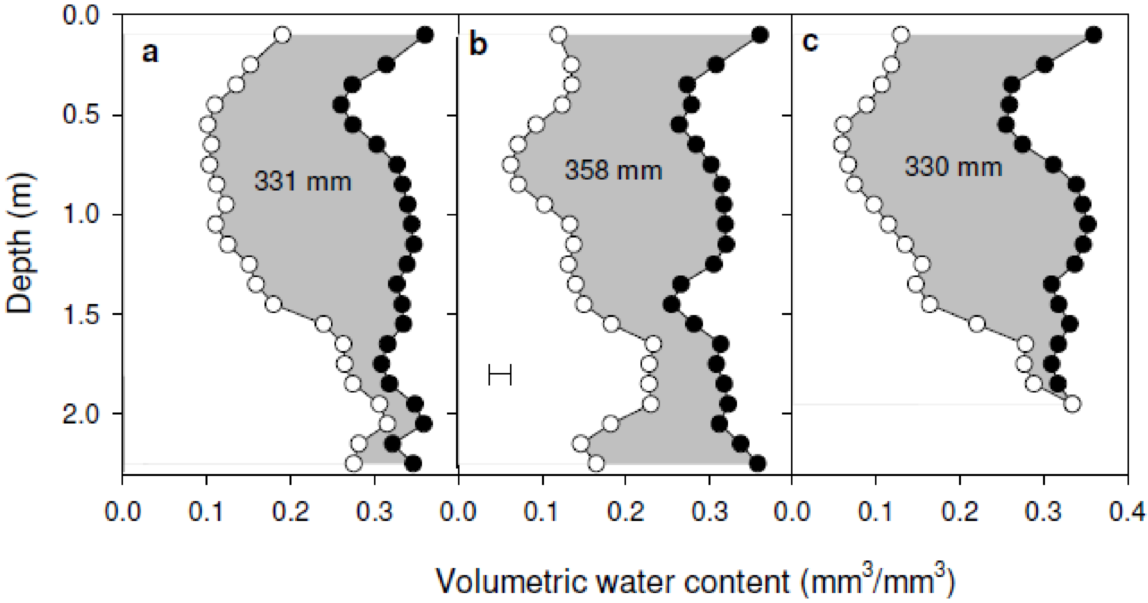

Figure 2.3 **Volumetric water content of soil upper (●) and lower (○) limits of a) chicory, b) lucerne and c) red clover water extraction measured to 2.3 m depth from 18 August 1997 – 29 May 1998 at Lincoln University, Canterbury. Note: Shaded area and numbers represent the total water extraction. (Brown *et al.* 2003).**

Lucerne has a reputation for high yields in dryland environments. Brown *et al.* (2003) reported an annual yield for lucerne of 20 t DM/ha, compared with 16 t DM/ha for red clover and chicory with irrigation. Mills *et al.* (2008) reported that lucerne yielded 13.1 to 18.5 t DM/ha/y in 4 of 5 years in the 'MaxClover' experiment, which was greater than the total yields from the cocksfoot/clover pastures.

In the past, lucerne was susceptible to insect pests such as Sitona weevil (*Sitona discoideus* Gyllenhal), stem nematodes (*Ditylenchus medicaginis*) and aphids (*Aphidoidea* spp.). The impact of these pests on production has been reduced through plant breeding, crop management (Langer 1973) and biological control agents (Goldson *et al.* 2005). Herbicide control is necessary to control annual weeds which establish quickly in lucerne stands (Charlton & Stewart 2000).

2.2 Pasture Pests

2.2.1 Argentine Stem Weevil (ASW)

Argentine stem weevil (ASW) is a primary insect pest of pastures in New Zealand. It is found nationwide. Two to three generations of ASW occur per year, depending on climate and location, 1 to 2 cycles per year in Canterbury. If a plant is damaged in a summer moist region or under irrigation, it can usually recover.

ASW causes considerable damage to perennial ryegrass and lay eggs on the psuedostems of the plant. The adults feed on the leaves (Prestidge *et al.* 1991). The larvae then hatch and burrow into the tillers of the plant (Popay *et al.* 2009). Each larva may damage between 3 and 8 tillers. Young pastures less than 3 years old are most at risk because they are less tolerant to insect attack (Prestidge *et al.* 1991). The effects of ASW damage are most obvious in drought prone regions (Barker *et al.* 1986). If drought strikes, seedlings sown in spring/summer can be affected by both water stress and ASW damage. With the discovery of endophyte and advances in biological control, mitigation strategies are now available.

Plant persistence is reduced by ASW attack which affects yield and botanical composition. Effects are often noticed in hot summers in pastures with high stocking rates, as both of these factors create further stress on ryegrass. For example, during a drought, early senescence, disease, inadequate grazing management and soil factors will all limit plant growth and development.

Prestidge *et al.* (1986) reported that adult ASW feed on cocksfoot 8.5 times more than on endophyte infected ryegrass but feed the same on cocksfoot and endophyte free ryegrass. Goldson *et al.* (1998) investigated the bionomics of ASW in Canterbury over 5 years. They assumed the population was a poisson distribution. Five weevils per deep turf sample were found (Goldson *et al.* 1998). Adult ASW numbers fluctuated over years, reaching over 400 weevil m^{-2} in the 1992/1993 season. In three out of the five seasons, adult numbers were below 200 weevils m^{-2}. McNeill *et al.* (2001) measured ASW populations in a dairy pasture at Lincoln, and used the same floatation method as Goldson *et al.* (1998). Population of adult ASW was highest in the first year of establishment and peaked at <40 weevils m^{-2} in the summer of the second year. Over the entire trial, the population was 12.5 ± 1.6 in spring, and 63.3 ± 3.6 m^{-2} in summer.

2.2.2 Clover Root Weevil (CRW)

Clover root weevil (CRW) is now a primary insect pest of pastures in New Zealand (Barratt *et al.* 1996). It targets *Trifolium* spp. and has a strong preference for white clover (Murray & Clements 1994). CRW is the second *Sitona* species to become established in New Zealand. The first was the lucerne weevil (*Sitona discoideus*). CRW has rapidly spread throughout New Zealand and is a considerable threat to the pastoral industry (Eerens *et al.* 2005). It was discovered in the Canterbury region in 2006 (Gerard *et al.* 2010) and recent sightings have been as far south as Gore in Southland.

CRW prefers cool temperatures and low light intensities because it is found near soil level or lower areas of the plant canopy (Barratt *et al.* 1996). New Zealand is a very suitable environment with a cool temperate climate. Once CRW is established in an area, rainfall and temperature determine pasture impact levels from season to season (Eerens *et al.* 2005). Three generations a year occur in Northland, two in the northern South Island and one in the cooler southern regions of Otago and Southland.

Adult CRW feed on the clover leaves and emerge in late spring and autumn to carry on the life cycle. A distinct notch on clover leaves can be recognised if CRW is present in a pasture. The notch has a very even distribution. The female CRW lay their eggs above ground. Once the larvae hatch, they burrow below ground to feed on active clover nodules (Eerens *et al.* 2005). The eggs require a moist environment and 230 degree days above a base temperature of 6.5 °C to hatch (Willoughby & Addison 1997). There are five instar stages the larvae go through. As the larvae mature, they start to feed on larger nodules and at the final instar stage, they attack nodal roots and stolons. Root function is impaired which increases the sensitivity of clover to water stress and plant competition. If nodules are damaged, N fixation cannot occur. Clover content and pasture quality are reduced (Eerens *et al.* 2005).

There is limited information on the effects of clover root weevil on annual legumes (Crush *et al.* 2007). Hardwick (1998) found no feeding preference between several annual and perennial clovers at the cotyledon stage, mature leaves of white clover were preferred more than subterranean clover and white clover roots were preferred more by newly hatched CRW larvae than subterranean clover roots (Hardwick 1998). Crush *et al.* (2008) reported root masses of white clover of 2327 kg DM/ha without CRW larvae compared with 867 kg DM/ha with CRW larvae. They found more CRW larvae amongst roots of white clover compared with subterranean and balansa clover. Effects of CRW were more severe in swards where soil moisture was not limiting. It was concluded that the annual legumes in the study were tolerant to CRW and summer drought areas were less prone to CRW damage.

Gerard *et al.* (2010) reported that during the establishment of CRW at two sites in Waikato, larval populations reached 1800 larvae m^{-2} during ‘boom’ phases and then stabilised to between 450 and 750 larvae m^{-2} in winter. Adult populations at the Ruakura site fluctuated but reached just over 100 adult CRW m^{-2}.

2.2.3 Sitona weevil

Sitona weevil or lucerne weevil was first recorded in New Zealand near Napier in 1974 (Kain & Trought 1982). It then quickly spread and can now be found in most parts of New Zealand where lucerne is present. It was previously thought to be *Sitona humeralis*. A successful biological control agent, *Microctonus aethiopoides*, has reduced weevil populations to well below threshold levels.

Adult Sitona weevils have a lifespan of 9 to 11 months and females are capable of laying eggs most of the year, apart from in January and February (Wood 1980). Sitona weevil has two flight periods: the first is in December and January to aestivate outside the crop (Kain & Trought 1982) and the second flight is in autumn (March and April) when Sitona weevils will fly to lucerne crops and lay eggs until December. This flight behaviour results in ‘boom’ and ‘bust’ cycles within lucerne stands. Reproductive weevils scatter eggs over the soil surface and any one female can lay up to 1000 eggs (Wightman 1980). Larval populations peak in November of each season and larvae do not appear in Canterbury until August when the temperature is warm enough. This results in large populations of larvae appearing in Canterbury during several months with potential to cause a lot of damage (Kain & Trought 1982). The feeding patterns of Sitona weevil mimic that of CRW, with adults feeding on leaves and larvae feeding on roots and root nodules. Goldson *et al.* (1985) found that larval populations of over 4000 m^{-2} could destroy all of a plant’s root nodules and cause mid season production losses of up to 50%. They found that once a larval threshold of between 1100 and 2000 m^{-2} was reached, the growth of the lucerne stand ceased. These threshold levels are very easy to reach due to lucerne being grown in monocultures, but populations are now successfully controlled by *M. aethiopoides* and are therefore not normally an issue.

2.2.4 Grass grub

Grass grub (*Costelytra zealandica*) is a native pasture pest in New Zealand. It feeds on both grasses and clovers and will disperse from previously populated areas by flight (Hardwick 2004). These flights occur in autumn, spring and summer in the beetle stage. Grass grubs in the damaging stage are between 15 to 20 mm in length with a pale cream body and a tan head.

Damage occurs to pastures in autumn and winter (Langer 1973). Grass grub infestation can result in severe reduction of pasture production (Toor & Dodds 1994). Pest threshold levels for action are derived from the relationship between pasture quality and yield losses and the pest density. These often serve as a guide to when control methods should be undertaken to reduce economic losses, either direct or indirect. Langer (1973) states that the pest action threshold for grass grub in pastures is between 100 and 200 third instar larvae m^{-2}. Pastures should be sampled in autumn for grass grub presence and a lower threshold should be used when pasture growth is limited by a drier than average autumn.

Toor & Dodds (1994) reported that the yield of a RG/Wc pasture in Southland was reduced for every increase of 100 grubs m^{-2} by 6% in autumn, 8% in winter and less than 4.5% in spring and summer. In dryland regions, Fraser (1994) reported grass grub populations in Years 2, 3 and 5 of 220, 59 and 51 grubs m^{-2} in ryegrass pastures compared with 97, 30 and 39 grubs m^{-2} in cocksfoot pastures.

Grass grub populations can vary between seasons. Hardwick *et al.* (2004) found 9 grubs m^{-2} in spring, 145 grubs m^{-2} in summer and 113 grubs m^{-2} in winter over 2 years after RG/Wc pasture was renovated in Waikato.

Drainage within paddocks can also affect grass grub populations. Hardwick (2004) found 1.5 to 6.5 times more grass grubs in drained compared with undrained paddocks. East *et al.* (1982) found that wet winter and spring periods caused high mortality and population fluctuation of grass grub. Shelterbelts also affected populations of grass grub (Hardwick 2004).

Watson *et al.* (2000), in ryegrass/clover pastures in Coastal Bay of Plenty found more than 50 grubs m^{-2} in the establishment year and 200 to 300 grubs m^{-2} in Years 2 and 3 but populations declined in Year 4 to 50 to 125 grubs m^{-2} due to drought conditions and extreme soil temperatures. They found that grass grub populations were more associated with disease build-up rather than pastoral factors; milky disease (*Bacillus popilliae*) was present in Year 5. There was also evidence of superficial scarring on Caucasian clover taproots and rhizome surfaces, but it did not lead to plant death or secondary disease infection.

2.3 Water use efficiency

Water use efficiency (WUE) of pastures can be defined as the ratio of total dry matter accumulation to total water input (Moot *et al.* 2008) as shown in Equation 1:

Equation 1 **WUE = Y / (R+I+ASWC-D)**

Where **Y** is total dry matter yield (kg DM/ha)
R is rainfall
I is irrigation
ASWC is available soil water content
D is drainage which is calculated from water lost from the lower soil layers in the absence of pasture production

Water use efficiency is influenced by soil depth, soil texture, plant species and rooting depth. Brown *et al.* (2003) showed that lucerne was able to extract 358 mm annually compared with 330 mm for red clover and chicory at Lincoln (Figure 2.3). For example, lucerne was found to be able to extract more water from a deep Wakanui soil than a shallow stony Lismore soil, near Lincoln (Moot *et al.* 2008). The Wakanui soil held 339 mm of water compared with the Lismore which only held 130 mm. The Lismore soil would be at field capacity before the Wakanui soil, resulting in drainage if further rainfall entered into the system.

WUE can increase when the plant canopy is closed and soil evaporation is reduced. Seasons can also influence WUE, with values being highest in spring because daytime temperatures are adequate for growth and night temperatures and evapotranspiration are lower than in summer (Martin 1984).

Species which increase the N content of pastures are valuable in dryland systems to increase WUE. For example Moot *et al.* (2008) found that in spring lucerne had a WUE of 24 kg DM/ha/mm of water used and a yield of 6 t DM/ha compared with a WUE of 20 kg DM/ha/mm and a yield of less than 5 t DM/ha for RG/Wc. Higher photosynthetic ability was gained from growing lucerne which has a higher herbage N content than ryegrass. Different plant species on different soil types also influences WUE. Available soil water use depends on rooting depth and proliferation within a crop or pasture. Generally, plants which have a larger and deeper root system will extract more water further down the profile compared with shallower rooting plants. For example Moot *et al.* (2008) showed lucerne rooted to a depth of 2.3m, and extracted more water than ryegrass, which only reached 1.5 m (Figure 2.3). These findings are due to lucerne’s taproot which can extract more water from the system. However, ryegrass has a fibrous root system and is capable of extracting more water within the top layers of the soil profile. Therefore, different species have competitive advantages under certain conditions. Similarly cocksfoot has a fibrous root system which is able to extract water within the top of the soil profile. Caucasian clover has a taproot so is able to extract water from deeper in the profile in summer.

Mills (2007) stated that the N concentration of the soil affected WUE. The WUE of cocksfoot based pastures in dryland conditions ranged from 12.9 to 81.2 kg DM/ha/mm with N fertilizer compared with 6.9 to 30.6 kg DM/ha/mm without N. Moot *et al.* (2008) stated that different N contents between different pastures resulted in differences in WUE. Therefore pastures with high legume content are likely to have higher WUE than grass dominant pastures.

In dryland Australia, similar issues affect water use as in New Zealand dryland regions. Infiltration, storage capacity and the ability of the plants roots to extract water have major effects on pasture yields (Carberry *et al.* 2010).

2.4 Soil moisture measurements

The moisture content of soil can be measured at depth with a neutron probe and time domain reflectometry (TDR). The neutron probe consists of two parts: the probe and the gauge. The probe contains fast neutrons and the gauge measures the quantity of slow neutrons returned from the soil (Topp *et al.* 1980). The neutron probe is lowered into a cased hole in the soil and the moisture content is measured at a range of depths. However, only a proportion of the moisture measured is available for plant uptake. The soil moisture deficit is calculated from the measured neutron probe value subtracted from the total water holding capacity of the soil (Karray *et al.* 2008).

The TDR is used to measure the soil moisture content in the top 0.2 m of the soil profile. It measures the permittivity of the soil through wave transmission. The permittivity of the soil is the dielectric constant rate between two rods pushed into the soil (Robinson *et al.* 2002). TDR rods are usually between 10 and 30 cm in length (Topp *et al.* 1980) and are connected through a cable.

2.5 How water, temperature and nitrogen affect pasture plants

When CO_2 is not limiting, pasture production is predominantly limited by the interaction of temperature, water and nitrogen (Peri *et al.* 2002b). These factors affect production through limiting physiological processes. Growth of cocksfoot is limited by water at a leaf water potential of -10.0 bar or higher (Jackson 1974).

Peri *et al.* (2002b) reported that the optimum temperature for maximum photosynthetic rate of cocksfoot was between 19 and 23 °C. Photosynthetic rate increased as temperature increased from 10 to 19 ° C and decreased by 0.077 units per ° C as temperature increased from 23 to 31 °C.

Water stress reduces photosynthesis due to stomatal closure and reduction in enzyme activity (Jackson 1974). Nitrogen deficiency in plants reduces the photosynthetic potential of leaves by decreasing protein activity and content. In cocksfoot, leaf photosynthesis was 80% of maximum at leaf N contents between 3.3% and 3.8% (Peri *et al.* 2002a).

2.6 Previous results from the 'MaxClover' experiment

The 'MaxClover' experiment was established in 2002 at Lincoln University (Mills *et al.* 2008). This section summarises the main results over the seven seasons before the study described in this thesis began.

Annual dry matter yield of lucerne was greater than the other pastures in Years 1, 2, 3 and 5 at between 13.1 and 18.5 t DM/ha. In Year 4, a snow storm flattened the lucerne crop and the cocksfoot/subterranean clover pasture yielded 16% more than lucerne. CF/Sub produced greater or equal to cocksfoot/white clover and ryegrass/white clover pastures in all years from 2002 to 2007 (Figure 2.4).

The sown grass component of the grass based pastures declined and contributed less to the total annual dry matter production over time. The RG/Wc yielded 7.4 t DM/ha in Year 1 compared with less than 4.7 t DM/ha in Years 3 to 5. Lucerne produced the highest legume yield of 9.5 to 17.3 t DM/ha/y and the sown legume content of the grass based pastures ranged from 4% (CF/Cc) to 40% (RG/Wc). Weed content increased from 4% in Year 1 to 24% in Year 5 (RG/Wc).

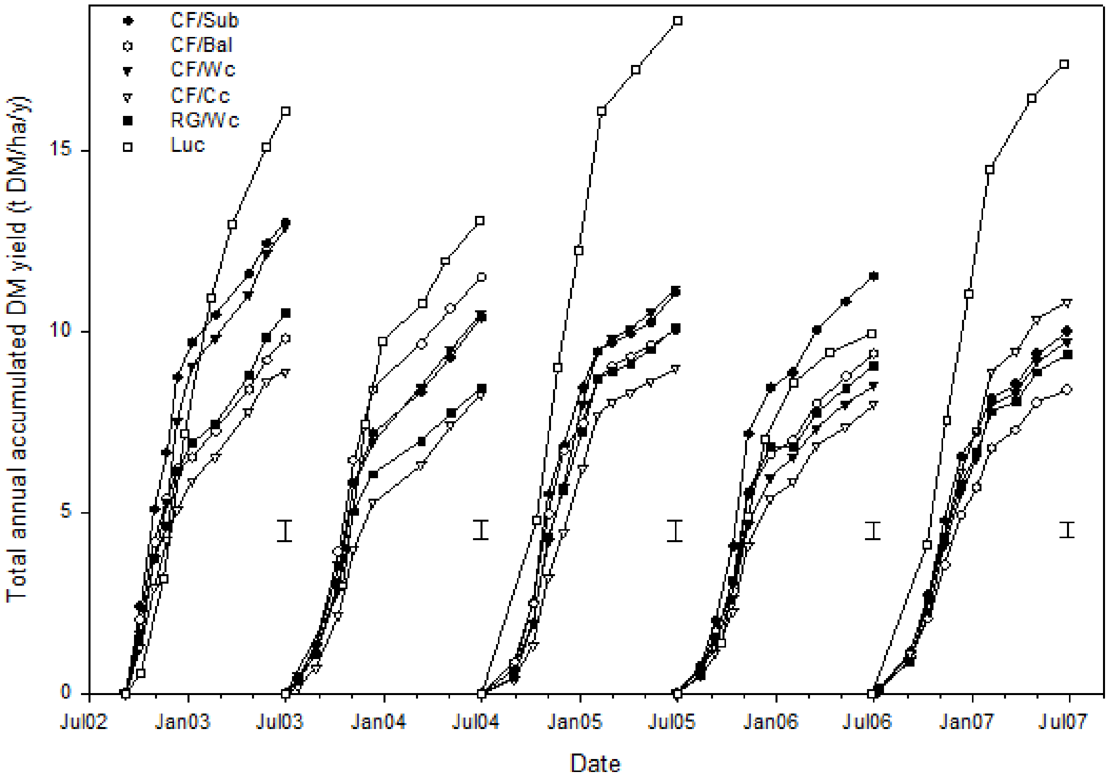

Figure 2.4 **Total annual dry matter yield of CF/Sub (●), CF/Bal (○), CF/Wc (▼), CF/Cc (▽), RG/Wc (■) and Luc (□) pastures of five regrowth seasons (2002-2007). Error bars are SEM for total annual yields for each growth season (Mills *et al.* 2008). Full details of acronyms are given in Table 3.1.**

Mills and Moot (2010) reported the results from Years 6 and 7. Lucerne produced an annual yield of 14 t DM/ha and the cocksfoot based pastures produced 9.8 to 11.2 t DM/ha (CF/Sub). N yields from lucerne exceeded 500 kg N/ha/y compared with 269 to 316 kg N/ha/y from CF/Sub. In Year 7 unsown weeds and grasses contributed 28% to the total annual yield of cocksfoot based pastures compared with 55% in RG/Wc pastures. Therefore lucerne and cocksfoot/subterranean clover pastures produced the greatest yields (Mills & Moot 2010) as well as higher water use efficiency and live weight gain by lambs.

Over the past seven years of the ‘MaxClover’ experiment the main conclusion is that lucerne and cocksfoot/subterranean clover pastures have given greater dry matter and animal production. These options should therefore be promoted and incorporated within dryland farming systems.

3 Materials and Methods

3.1 Experimental Site

The experiment was carried out at Lincoln University, Canterbury, New Zealand (43°38’S, 172°28’E 11 m.a.s.l). The soil type was a Templeton silt loam over lying gravel from 0.85 to 1.45 m deep (Raeside & Rennie 1974). The profile consists of small quantities of sand and clay with primarily silt sized particles. The alluvial gravels in the lower layers consist of stones and gravels (Khonke & Bertrand 1959) and rocks as well as large sandy particles.

The experiment compared six pastures in a randomised complete block design with six replicates. Each plot was 0.05 ha (23m × 22m). Four blocks were sown in February 2002 and blocks 5 and 6 were sown in autumn 2003. Plots were individually fenced and supplied with water troughs.

Seven species were sown within the ‘MaxClover’ experiment (Table 3.1). These included two perennial (Caucasian and white) and two annual (balansa and subterranean) clovers individually sown with cocksfoot and then compared with a ryegrass/white clover control and a lucerne monoculture.

Table 3.1 Species, cultivar and seed sowing rate of the seven dryland pasture species used in the ‘MaxClover’ grazing experiment, at Lincoln University, Canterbury, 2002.

Species sown	Common name	Acronym	Cultivar	Sowing rate (kg/ha)
Trifolium michaelianum	Balansa clover	Bal	‘Bolta’	3.5 kg/ha
Trifolium ambiguum	Caucasian clover	Cc	‘Endura’	5.9 kg/ha
Trifolium subterraneum	Subterranean clover	Sub	‘Denmark’	10 kg/ha
Trifolium repens	White clover	Wc	‘Demand’	3 kg/ha
Dactylis glomerata	Cocksfoot	CF	‘Vision’	4 kg/ha
Lolium perenne	Perennial ryegrass	RG	‘Aries AR1’	10 kg/ha
Medicago sativa	Lucerne	Luc	‘Kaituna’	5.7 kg/ha

3.2 Grazing Management

The plots were grazed by Coopworth ewes with twin lambs in spring and weaned lambs or hoggets in summer and autumn of each year. The periods when pastures were grazed in 2009/10 are shown in Table 3.2.

Table 3.2 Grazing periods on the six pasture treatments in 2009/2010.

Treatment	Graze period	Stock class	Date on	Date off	Grazing duration (days)
CF/Sub	1	Ewes/Lambs	14/8/2009	7/12/2009	116
CF/Sub	2	Lambs	18/12/2009	14/1/2010	33
CF/Sub	3	Hoggets	15/1/2010	2/2/2010	18
CF/Sub	4	Lambs	8/4/2010	6/5/2010	30
CF/Bal	1	Ewes/Lambs	18/8/2009	7/12/2009	112
CF/Bal	2	Lambs	15/12/2009	22/1/2010	38
CF/Bal	3	Hoggets	15/1/2010	30/1/2010	15
CF/Bal	4	Lambs	8/4/2010	5/5/2010	27
CF/Wc	1	Ewes/Lambs	18/8/2009	7/12/2009	112
CF/Wc	2	Lambs	15/12/2009	22/1/2010	38
CF/Wc	3	Hoggets	15/1/2010	2/2/2010	17
CF/Wc	4	Lambs	8/4/2010	7/5/2010	31
CF/Cc	1	Ewes/Lambs	17/8/2009	7/12/2009	113
CF/Cc	2	Lambs	15/12/2009	22/1/2010	38
CF/Cc	3	Hoggets	15/1/2010	2/2/2010	17
CF/Cc	4	Lambs	8/4/2010	6/5/2010	30
RG/Wc	1	Ewes/Lambs	17/8/2009	7/12/2009	113
RG/Wc	2	Lambs	15/12/2009	14/1/2010	30
RG/Wc	3	Hoggets	15/1/2010	2/2/2010	17
RG/Wc	4	Lambs	8/4/2010	3/5/2010	27
Luc	1	Ewes/Lambs	1/9/2009	7/12/2009	98
Luc	2	Lambs	15/12/2009	22/1/2010	38
Luc	3	Lambs	26/2/2010	22/3/2010	24
Luc	4	Lambs	31/5/2010	6/6/2010	7

During the eight years of the experiment, clover treatments have been grazed regularly in spring, with longer rotations in summer and autumn due to dry periods where growth is limited. For the previous seven years of the experiment, hoggets have been introduced in spring and grazed through until autumn, followed by ewes for a clean-up phase at sometime in winter. Hoggets have then been reintroduced the following spring.

In contast, for this study, Coopworth ewes and lambs were used for grazing and measuring the liveweight production from each treatment. A ‘put and take’ system was used. This is where stock are added or subtracted depending on the grazing conditions. Each ‘flock’ grazed plots in a set sequence within their allocated treatment.

The stocking rate was approximately 2-3 ewes/plot (38-57/ha), each with twin lambs in spring and 8-10 lambs/plot (152-190/ha) between December and June. This was based on soil moisture availability and dry matter production in ‘spring’, ‘summer’ and ‘autumn/winter’. Spring was the period where growth was linear and moisture continued to be non-limiting for growth. Summer was defined as the period where soil moisture was the limiting factor to growth and dry matter accumulation was severely restricted. Autumn/winter was defined as the period where soil moisture levels started to increase. Spring was from 1/7/09 to 16/11/09 for grass based pastures and 1/7/09 to 29/1/10 for lucerne. Summer was from 16/11/09 to 5/5/10 for grass based pastures and 29/1/10 to 30/6/10 for lucerne. Autumn/winter was from 5/5/10 to 30/6/10 for grassed based pastures and lucerne did not have an autumn/winter period due to continued growth.

Rotation length was varied according to pasture growth and season. In spring, rotations for clover based pastures were between 8 and 13 days per six replicates. Two or three paddock rotations were used to simulate set stocking. In summer and autumn rotation length was between 16 and 21 days. During February and March, grass/legume treatments were on a 21 day rotation involving all six replicates. Pastures were de-stocked in winter for six weeks. Hoggets were used to clean up in May and June. This was in preparation for spring 2010. Ewes were also required to clean up in summer when the pastures became dry and had a low grazing preference for young stock. The stocking rate for clean-up was between 15 to 25 hoggets or ewes per plot which is equivalent to 40-80/ha. There were six plots per treatment rotation.

The lucerne was rotationally grazed, but started two weeks later than for the other five pastures. Lucerne was managed similarly to the grass/clover treatments in late summer and early autumn. Spelling time in autumn was longer than the grass/clover treatments to encourage build-up of root reserves (Moot *et al.* 2003b).

3.3 Weed Management

Lucerne plots have undergone weed control every second winter. A mixture of Gramoxone 250 at 400 g.a.i/ha and Atrazine 500 at 408 g.a.i/ha was last applied in winter 2009. The active ingredient of Paraquat dichloride salt in the form of a soluble concentrate is present in Gramoxone 250 and Atrazine in the form of a suspension concentrate is present in Atrazine 500.

Soil tests were carried out on 12 May 2009 prior to measurements on the experiment (Table 3.3).

Table 3.3 Soil test results from the 'MaxClover' experiment from May 2009 at Lincoln University, Canterbury.

Treatment	pH	Olsen P	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	S (ppm)
CF/Sub	6.3	18	8	21	15	7	4
CF/Bal	6.2	17	8	19	14	5	3
CF/Wc	6.3	19	9	20	14	6	3
CF/Cc	6.3	22	7	20	14	6	3
RG/Wc	6.3	14	8	19	11	6	4
Luc	6.3	19	8	18	17	4	5

Fertilizer was applied to all plots on August 3 2009 as Sulphur Super Maxi (50% Sulphur) at a rate of 50 kg/ha.

3.4 Measurements

3.4.1 Pasture dry matter (DM) yield and composition

The yield and botanical composition of the five grass based pastures were determined by placing a cage (0.76 × 1.14 m) on an area of each plot, mown to a stubble height of approximately 2-3 cm. After 4 weeks (11 weeks in winter), a sample (0.2 m^2 quadrat) was cut from the area to 2-3 cm above ground level using electric hand shears and a subsample (approximately 50 g) was separated into sown grass, legume, grass weeds, dicotylendonous weeds and dead material before drying (65 °C) to a constant weight. The cage was moved to a new area after each harvest and there were seven harvests from July 2009 to June 2010.

For the lucerne, five samples (0.2 m^2 quadrats) from eachplot were cut to gound level using hand shears immediately before grazing and a subsample (approximtaely 50 g) was separated into legume, grass weeds, dicotyledonous weeds and dead material before drying (65 °C) to a constant weight. There were six harvests of the lucerne from July 2009 to June 2010. The harvest date was taken as the mean pre-grazing date of each rotation. Yield of the total biomass and the proportions of the separated components in the total biomass per plot and harvest were determined. The accumulated yields of total biomass per plot per harvest were caluated and annual yield was defined as the accumulated yield at the final harvest.

Botanical composition was also determined using the Botanal method in summer (26 Dec 2009) and autumn (5 May 2010). The Botanal method is a dry-weight-rank (DWR) method with a weighting factor (Jones & Hargreaves 1979). The weighting factor reduces bias that can occur in DWR methods. Twenty random quadrats (0.1 m^2) of each plot were observed. The species present in each quadrat were ranked from most to least abundance on a visual dry matter basis.

The species were defined as cocksfoot, perennial ryegrass, sown legume, unsown legume, annual grass weeds and dicotyledonous weeds. Sown and unsown legume of the same species (e.g. white clover) could not be differentiated. More than one rank was given when the quadrat was heavily dominated by one species (referred to as a'cumulative ranking'). Only the ranks of the three most dominant species were recorded. A multiplier was given to each rank (8.04 for Rank 1, 2.41 for Rank 2 and 1.0 for Rank 3) and then each multiplier was expressed as a percentage of the sum of the multipliers (11.45) to determine the proportions of the three most dominant species in the total biomass.

3.4.2 Nitrogen yield

Nitrogen concentration and yield were determined using the dried samples of sown grass, sown legume, annual grass weeds and dicotyledonous weeds which were milled (Cyclotec Sample Mill) and analysed for total N by NIR (near infrared spectroscopy). If the sample was too small, due to low pasture growth, samples from two or more replicates of the same treatment were combined.

Equation 2 shows how total N yield of sown species was calculated for each component:

Equation 2 Total N yield (kg/ha) = %N herbage × kg DM/ha

The N yield of total biomass, sown grass, sown legume and weeds per plot per harvest were determined.

3.4.3 Insect populations

The insect populations of four pastures (CF/Sub, CF/Wc, RG/Wc and Luc) in four blocks (1, 2, 3 and 6) were determined on 22 June, 28 July and 15 September. Fifteen quadrants (0.2 m^2) per plot were vacuumed (Echo ES 2400 blower-vac with a mesh net attached to the intake pipe) and any insects were identified and counted. This was undertaken in a wet lab where samples were laid out on trays, with heat lamps underneath. This caused insects to move and they were able to be indentified and counted.

The populations of CRW larvae were determined between 28 July and 20 September by digging 20 core samples (each 0.00385 m^2 wide by 0.1 m deep) from each of the four pastures and four replicates described above and any larvae were identified and counted. This was undertaken in the field by laying samples out on trays and sifting through soil for larvae. Grass grub populations of all pastures and replicates had also been determined in August 2008 and August 2009.

3.4.4 Environmental conditions

Rainfall and soil temperature recorded by a meteorological station at Broadfields, 2 km North of the experimental site (Table 3.4) was 40 mm below the LTM in November, half of the LTM from February to April and three times the LTM in May. Mean monthly soil temperature at 0.1 m was 1-2°C warmer than the LTM in 9 of the 12 months.

Table 3.4 **Rainfall and soil temperature (0.1 m depth) recorded at Broadfields Meteorological Station located 2 km north of the experimental site. Long-term means (LTM) are for 1975-2002.**

	Rainfall (mm)		Soil temperature (°C)	
Month	LTM	Actual	LTM	Actual
Jul 2009	64	37	4.0	4.9
Aug 2009	62	52	5.4	7.7
Sept 2009	43	15	8.1	9.4
Oct 2009	51	83	11.2	11.1
Nov 2009	52	9	14.0	15.1
Dec 2009	50	37	16.5	16.8
Jan 2010	51	49	17.6	17.9
Feb 2010	41	22	17.1	19.4
Mar 2010	50	23	14.9	16.3
Apr 2010	46	25	11.1	13.3
May 2010	50	153	7.4	10.0
Jun 2010	64	109	4.7	6.3
Annual	624	614	11.0	12.4

3.4.5 Soil moisture content

The ‘MaxClover’ experiment was dryland/rainfed with no irrigation treatments. Soil moisture percentage was measured every 7 to 10 days and used to calculate water use efficiency (WUE) of each pasture treatment. Soil moisture content in the top 0.2 m was measured by Time Domain Reflectometry (TDR) as described in Section 2.4.

Below 0.2 m depth, separate aluminium cased holes were located in each plot for neutron probe (Troxler 4301) measurements. The neutron probe was used to measure the soil moisture percentage every 0.2 m between 0.25 m and 2.25 m (Section 2.4).

From these measurements, temporal and spatial changes in volumetric soil water content at each depth were observed for individual plots over time. For example, Figure shows the change in soil moisture content and rainfall over the experimental period for Plot 5 (CF/Sub) from 0-0.2 m of the profile. At the first measurement the top 0.2 m of the soil had around 33% moisture in the soil. Rainfall was lower than the long term mean in July (37 mm compared with 64 mm) and was lower again in August and September (Table 3.4). This is shown in Figure by a decrease in soil moisture to around 27%. Soil moisture then declined to just over 5% around mid October before rainfall returned it to almost 30%. Soil moisture declined again through a lack of rainfall to below 10% in December, before rainfall in early January, meaning pastures needed to be restocked until mid January. Rainfall was variable over late summer and autumn with lower levels than the LTM, especially in February, March and April where rainfall was 50% below the LTM. This is illustrated in Figure with soil moisture remaining below 15%. Pastures were therefore destocked in February until April to allow pasture cover to increase.

May rainfall was three times the LTM with a total of 153 mm and soil moisture in the top 0.2 m of Plot 5 then returned to field capacity of around 35%. It is likely that some drainage occurred during this time because the rainfall continued when the soil was at field capacity.

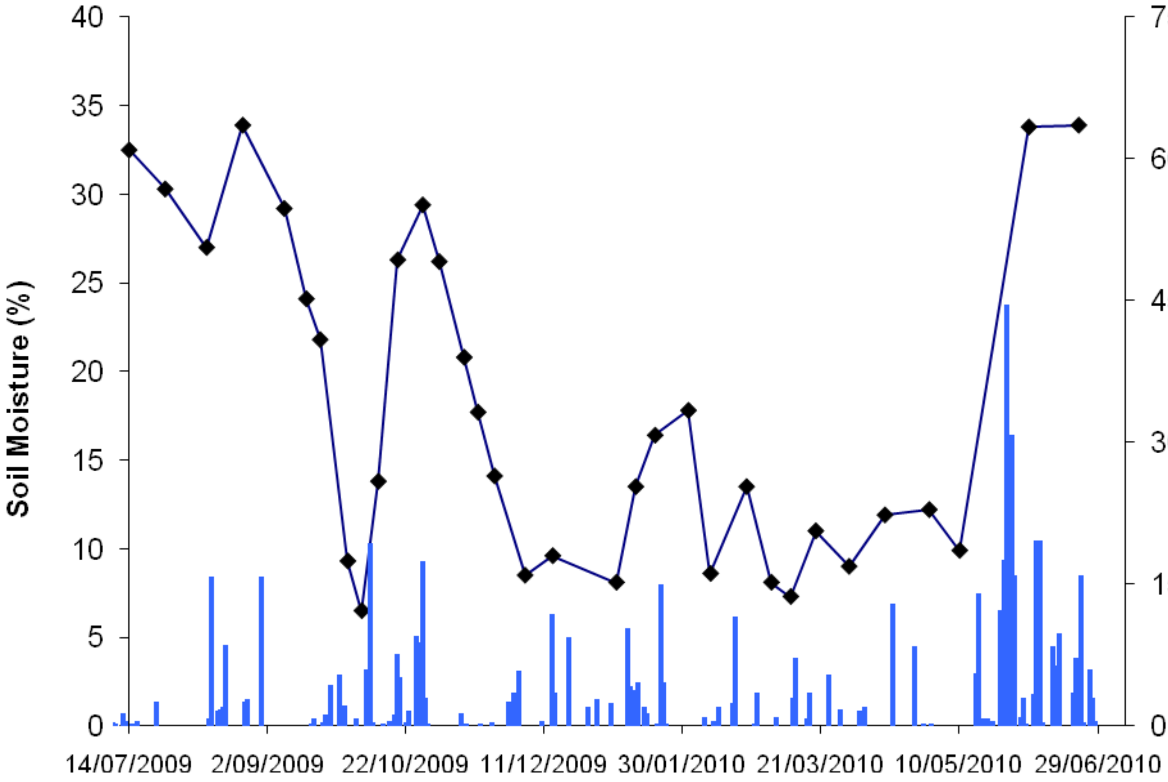

Figure 3.1 **Soil moisture content to 0.2 m depth of one replicate of cocksfoot/sub clover (Plot 5) from 14/7/2009 to 29/6/2010 at Lincoln University, Canterbury.**

Water use and availability calculations involved dry matter yield data from replicates 1, 2, 3, and 5 only. This is because soil water availability was not measured in replicates 4 and 6.

3.4.6 Plant available water

Plant available water content to 2.3 m depth was calculated as the difference between the drained upper limit (DUL) and lower limit (LL) of each plot. The DUL was taken as the mean of the second and third highest soil moisture readings and is used as an indication of field capacity. This is a conservative approach which helps to avoid abnormally elevated readings of SWC at any given depth, which may occur after heavy rainfall or before drainage can occur. The LL was the mean of the second and third lowest soil moisture readings for each plot. It is equivalent to permanent wilting point, when no additional moisture can be extracted. The DUL and LL were calculated from 4 years of soil moisture data taken in the experiment since 2003.

Actual water use (WU) (Equation 3) of each plot was calculated as:

Equation 3 $$WU = P - \Delta SWC - D$$

P is the precipitation (rainfall),ΔSWC is the change in soil water content (SWC) between consecutive soil moisture measurements and D is drainage from the soil. Drainage occurs when rainfall causes the SWC to exceed the DUL of the soil profile. An example of values for DUL and LL are shown in Figure 3.2 and Figure 3.3. Results for all other plots are given in Appendix 2. A WU factor was calculated and applied to daily PET (Penman potential evapotranspiration) to estimate daily WU between consecutive measurements. The factor was calculated as the ratio between actual water use and PET.

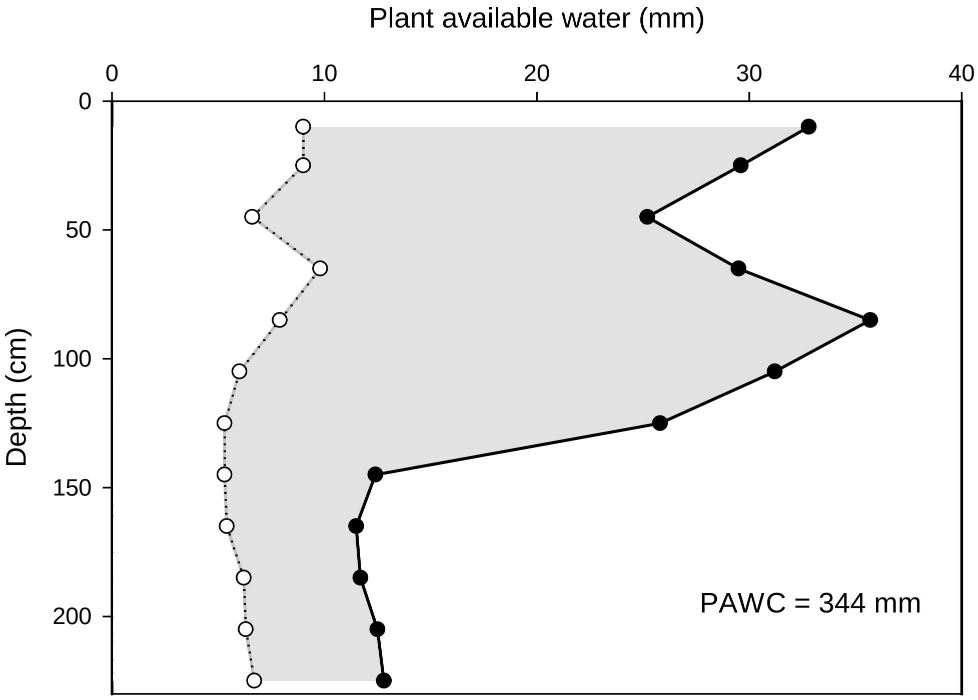

Figure 3.2 **Plant available water (mm) from 0-2.3 m depth for Lucerne (Plot 2 Luc) sward on Templeton silt loam at Lincoln University, Canterbury for July 2009 to June 2010.**

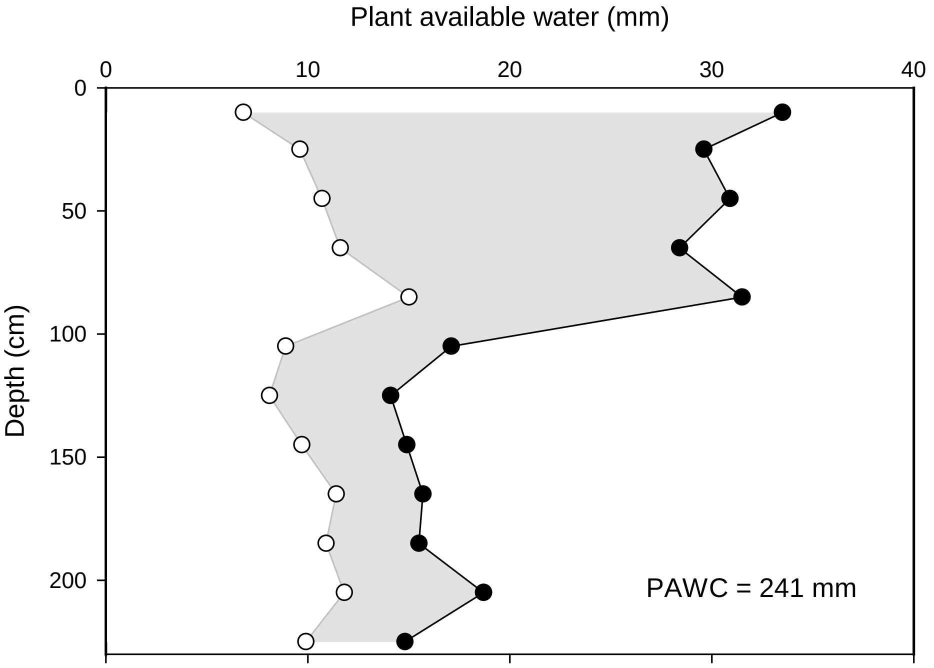

Figure 3.3 **Plant available water (mm) from 0-2.3 m depth for cocksfoot/subterranean clover (Plot 5 CF/Sub) pasture on Templeton silt loam at Lincoln University, Canterbury for July 2009 to June 2010.**

3.5 Statistical Analyses

Statistical analysis was performed using Genstat (Version 12.2, VSN International Ltd, 2009). Least squares linear regression and one way analysis of variance (ANOVA) with means separation using least significant differences. Data were analysed as a randomised complete block design using six replicates.

3.5.1 Thermal time

The relationship between accumulated yield of total biomass and thermal time (Tt) (Mills *et al.* 2006) was analysed by regression analysis. Daily thermal time values were calculated using Broadfields meteorological station temperature data. The basic equation for calculating thermal time is in Equation 4 as follows:

Equation 4

$$\boldsymbol{Tt = \frac{T_{max+T_{min}}}{2} - T_b}$$

Where T*min* and T*max* are the minimum and maximum daily temperatures and Tb is the base temperature. An 8×3 sinusoidal function was used when the minimum daily temperature was below T_b. The function was used to fit 8×3 hourly fractions of a day, which excluded the periods when T*min* < T_b.

The first step was to calculate the base temperature. Linear regressions were fitted between accumulated yield (kg DM/ha/y) and accumulated thermal time (°C d), with a series of base temperatures. The base temperatures varied from 0 to 8 °C and were calculated from 0.1 m soil temperatures. This was done for each treatment during the spring period. The highest coefficient of determination (R^2) was obtained using a base temperature of 0 °C. Appendix 6 shows an example of the R^2 values plotted against base temperature for cocksfoot/subterranean clover, ryegrass/white clover and lucerne treatments. Mills *et al.* (2006) reports a base temperature of 3 °C for pastures and Teixeira (2006) states 5 °C for lucerne using air temperature.

The analysis used was based on soil temperatures at 0.1 m depth from Broadfields meteorological station with t_b= 0 °C (Tonmukaykul 2009). Values were not forced through the origin from the regression analysis between accumulated dry matter and accumulated thermal time. This showed that the x-axis had a different intercept for each treatment, which showed when growth first began and thermal time was accumulated to this point. This was once critical LAI (leaf area index) was obtained.

For the autumn/winter period, no regression equations were run for the grass based pastures as there were only two points to analyse. Therefore, the dry matter produced from the 5/05/2010 to the 30/06/2010 was calculated.

Mean daily growth rates were also calculated from averaging accumulated dry matter divided by the number of days between cage cuts. They were calculated for all treatments but only grass based pastures were included in the analysis. Lucerne was excluded because of having different harvest dates and seasons compared with grass based pastures, based on dry matter production and water use efficiency. Data for lucerne are included in figures for comparison.

3.5.2 Water use efficiency

Water use efficiency (WUE) (kg DM/ha/mm) for specific seasonal periods was calculated by dividing the accumulated dry matter yield by the accumulated water use for that period. Least squares linear regression (Genstat Version 12) analysis was then used to calculate seasonal WUE for treatments and plots.

The annual plant available water and accumulated water use for each plot was analysed using one-way ANOVA. This is shown in Table 3.5 and Table 3.6 respectively. Annual plant available water at field capacity was similar across treatments ($P<0.84$) at 316 ± 24 mm. Annual accumulated water use was also similar across treatments ($P<0.82$) at 655 ± 22 mm.

Table 3.5 **The annual plant available water (mm) of individual plots from 1/7/09 to 30/6/10 at Lincoln University, Canterbury. Full details of treatment acronyms are given in Table 3.1**

Treatment	Rep 1	Rep 2	Rep 3	Rep 5	Mean	SEM	Sig.
CF/Sub	323	346	372	175	304	24.3	P<0.84
CF/Bal	372	333	287	265	314		
CF/Wc	375	356	329	299	340		
CF/Cc	284	365	267	278	299		
Rg/Wc	357	278	373	236	311		
Lucerne	431	317	271	298	329		

Table 3.6 **The annual accumulated water use (mm) of six dryland pastures in individual plots from 1/7/09 to 30/6/10 at Lincoln University, Canterbury. Full details of the treatment acronyms are given in Table 3.1.**

Treatment	Rep 1	Rep 2	Rep 3	Rep 5	Mean	SEM	Sig.
CF/Sub	643	667	737	582	657	22	P<0.82
CF/Bal	656	715	631	633	659		
CF/Wc	641	707	687	675	677		
CF/Cc	580	674	626	644	631		
Rg/Wc	648	664	707	601	655		
Lucerne	719	633	606	649	652		

There were two phases of WUE which could be defined from changes in the linear relationship between accumulated water use (mm) and accumulated dry matter yield (kg DM/ha) around harvest dates. They are based on where water stress starts to affect dry matter production in individual treatments. Linear regressions of accumulated water use and accumulated dry matter yield were undertaken and coefficients of determination compared for individual treatments. Coefficients of determination generally decreased with annual accumulated water use and dry matter yield. Therefore points could be defined when production was compromised by water stress by using the R^2 value and looking at linear portions of the relationship. The initial period of WUE was forced through zero, based on the assumption that no water is used for growth before growth occurs, but the second period was not constrained.

Water stress occurred earliest in annual clover pastures around the 16/11/09 (Harvest 3), in perennial clover pastures around 5/1/10 (Harvest 4) and in lucerne on 29/1/10 (Harvest 4). Therefore, these cannot be called seasons as they occur in mid-summer and have different break points depending on treatments. Seasonal accumulated water use values therefore have different time periods (Appendix 6).

3.5.3 Insect Populations

Data collected for populations of CRW, ASW, lucerne weevil and clover root weevil larvae were transformed prior to statistical analysis (Clewer & Scarisbrick 2001). This was because of the non-normal distribution of the data (Poisson). A square root transformation was undertaken on all data which was in units of insects per square metre. Therefore, insect populations per square metre are used to describe results in Section 4.5. The original untransformed data are presented in Section 4.5 but P values are stated to show what was statistically different. Error bars presented in graphs originated from the data undergoing a square root back transformation. The grand mean was used and therefore both ends of the error bars differ. Grass grub data were not transformed.

3.5.4 Botanical composition

The data were treated as a sum of all harvests on a weighted basis and seasons were the same as for dry matter production.

3.5.5 Nitrogen concentration

The grass components for all seasons involved all seven pasture harvests being analysed. The clover component involved only five harvests for analysis as there was insufficient clover present at harvests six and seven for sample analysis. However, for harvests four and five, the annual clover treatments (CF/Sub and CF/Bal) were excluded from the legume analysis as they were present only as buried seed over the summer period and no herbage was present for sample analysis. Lucerne treatments only had five harvests to analyse as there were no samples taken for nitrogen analysis at the final harvest. Harvest dates were different compared to grass based pasture treatments but were matched according to each harvest and similar dates. For completeness of nitrogen yield, volunteer white clover was included in the legume analysis for spring and summer seasons of those grass pastures that did not have sown white clover measured. For spring an N% of 4.4%

was used, based on the white clover samples from sown white clover plots (CF/Wc and RG/Wc) and in summer a N% of 3.2% was used. Seasons were the same as differentiated for dry matter production.

Herbage nitrogen results for the weed component of pastures was estimated based on true values for RG/Wc plastures. Weed yield was measured across all treatments but weed N% was only measured in RG/Wc plots. Therefore, N yields for RG/Wc pastures could be calculated. Estimated yields were calculated for other grass based pastures by using the ditcotylendous weed and annual grass weed N% measured for RG/Wc pastures and multiplying it by the measured dicotyledonous and annual grass weed yield. Lucerne was excluded from this analysis. Nitrogen concentrations of 3.2, 2.6 and 2.9% were used for spring, summer and annual dicotyledonous weed yields, repectively. Nitrogen concentrations of 3.5, 2.2 and 2.5% were used for spring, summer and annual grass weed yields, respectively. No weed nitrogen samples were undertaken in the autumn/winter season.

Plate 1 Neutron Probe and TDR used for soil moisture measurements.

Plate 2 Echo ES 2400 blower-vac and 0.2 m^2 quadrat used for weevil population sampling.

Plate 3 View of Plot 33 Rep 6 (CF/Sub) on 20/9/09 (Spring).

Plate 4 View of Reps 6 and 5 on 17/12/09 (Summer).

Plate 5 View of Reps 6 and 5 on 19/3/2010 (Late summer).

Plate 6 View of Reps 6 and 5 on 5/7/10 (Autumn/winter).

4 Results

4.1 Annual pasture dry matter yield

The total annual dry matter yield differed (P<0.001) among grass based pastures and the lucerne (Figure 4.1). Lucerne had the highest annual yield of 12880 kg DM/ha. Among the grass based pastures CF/Sub had the highest annual yield of 9460 kg DM/ha and the RG/Wc control produced the lowest at 6600 kg DM/ha.

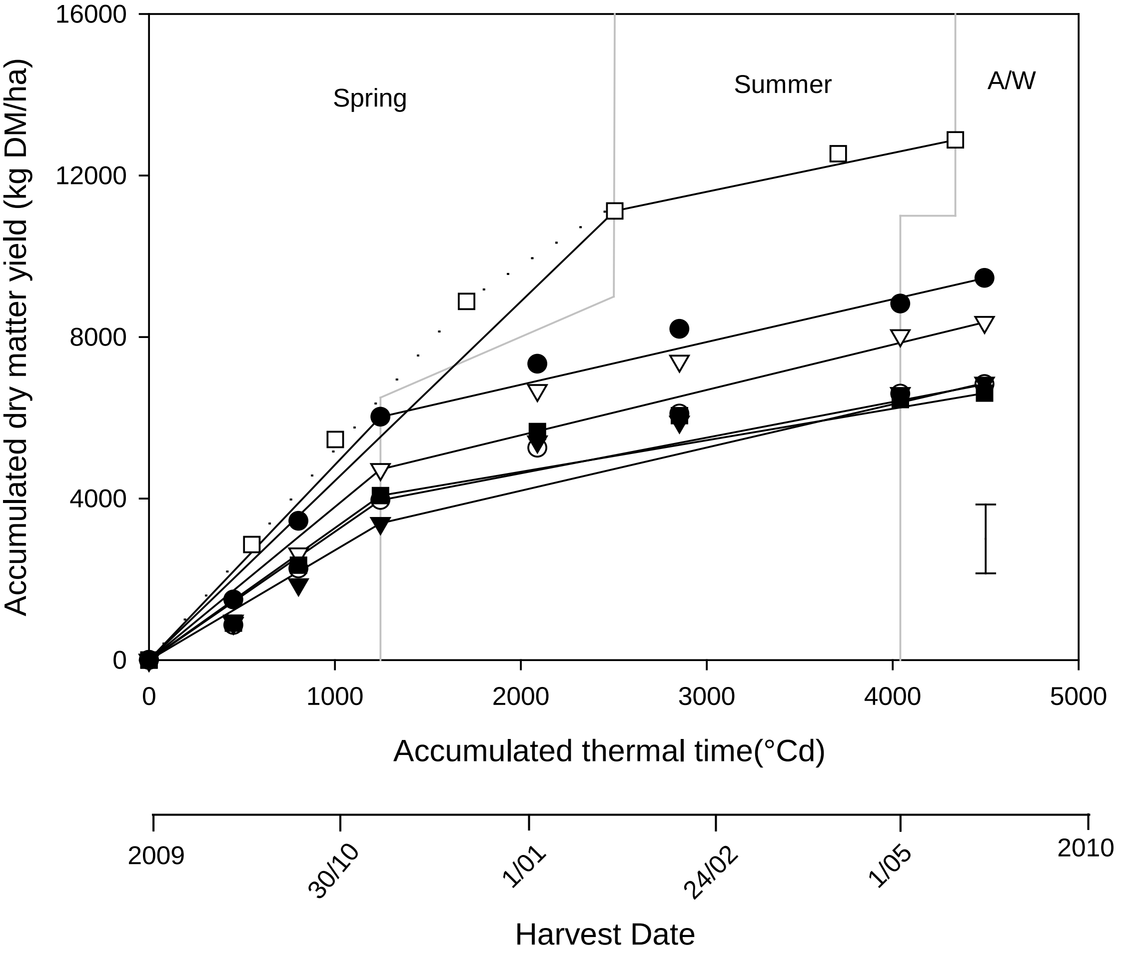

Figure 4.1 **Total annual accumulated dry matter (DM) yield of CF/Sub (●), CF/Bal (○), CF/Wc (▼), CF/Cc (▽), RG/Wc (■) and lucerne (□) pastures over the season from 1/7/2009 to 30/6/2010 at Lincoln University, Canterbury. The error bar is the LSD for the final accumulated dry matter. Vertical gray lines separate the period of measurement into spring, summer or autumn/winter (Section 3.2). Dotted line for lucerne indicates where linear growth deviated from the regression. Note the difference in the duration of each period between grass pastures and lucerne. Full regression equations are given in Appendix 4.**

4.2 Thermal Time

The fitted linear regression equations of dry matter against thermal time accumulation give an x-axis intercept of between 180 and 250 °Cd in spring (Appendix 4).

4.2.1 Spring

The relationship between dry matter and thermal time accumulation was linear during the period defined as spring (Section 3.2). The growth rates among the species were different ($P<0.001$) even though there was no water stress. The CF/Sub treatment produced at an average of 5.73 kg DM/°Cd and a total of 6018 ± 360 kg DM/ha. This was 20% higher than the next highest producing pasture (CF/Cc) while CF/Wc was the lowest producing pasture during the spring period with an average of 3385 kg DM/ha of spring growth at a rate of 3.13 kg DM/°Cd ($P<0.001$). Lucerne (4.23 kg DM/°Cd) and CF/Cc (4.75 kg DM/°Cd) produced at a faster rate than CF/Wc. Lucerne produced the highest spring yield of 11121 kg DM/ha which was 45% more than that of CF/Sub. This was because it grew at an almost linear rate for a longer duration than other pastures. This meant the defined spring period was longer for lucerne (213 days) than the pasture treatments (139 days), finishing on the 29/01/2010 compared with the 16/11/2009. Across all pastures the spring period produced at least 49% of the annual yield.

4.2.2 Summer

Dry matter production of all pastures was reduced over the summer period as water stress became a limiting factor. This is indicated by the deviation from linear spring growth (Figure 4.1). There were no significant differences between any of the grass based pastures during this period. Lucerne production was lower than that of CF/Cc and CF/Wc with an average of 1760 kg DM/ha produced, compared with 3315 and 3218 kg DM/ha respectively for the pastures. This difference is an artefact of the definition of the duration of the summer phase which was 139 days for the grass based pastures and 214 days for the lucerne. All grew at about 1 kg DM/°Cd for the period.

4.2.3 Autumn/Winter

During the short autumn/winter period, CF/Sub produced 636 ± 75 kg DM/ha from May 5 to June 30. This was higher (P<0.001) than the other four grass based pastures but only 7% of its total annual yield. RG/Wc produced the least with 157 kg DM/ha and CF/Cc 328 kg DM/ha. For all pastures, this period represented less than 7% of their annual yield.

4.3 Mean daily growth rates

Mean daily growth rates differed among grass pastures (Figure 4.2). Lucerne was excluded from the statistical analysis (Section Thermal time). CF/Sub pastures grew at the highest (P<0.001) rate of 23.0 kg DM/ha/d from 1/7/2009 to 9/09/2009. This was approximately 40% more than the 14.0 ± 1.5 kg DM/ha/d produced by the other grass based pastures. Growth rates then increased between 9/09/2009 to 13/10/2009 with CF/Sub producing 57.3 kg DM/ha/d compared with the 28.0 kg DM/ha/d for CF/Wc. Growth rates were highest during the third measurement period from 13/10/2009 to 16/11/2009. CF/Sub had the highest rate of 75.8 kg DM/ha/d (P<0.009). CF/Cc produced 61.5 kg DM/ha/d during the final spring period but CF/Wc was lowest at 44.7 kg DM/ha/d.

Soil moisture became limiting during the summer period and therefore caused the mean daily growth rates of the pasture species to slow. From mid November 2009 to the start of January 2010, all pastures grew at approximately 25.0 kg DM/ha/d with no significant differences among pastures. From the 16/02 to the 5/05/2010 all pastures grew at approximately 5 to 10 kg DM/ha/d.

During the autumn/winter period (5/05/2010 to 30/06/2010), CF/Sub grew the fastest at 11.4 kg DM/ha/d. This was double that of the other treatments. The mean daily growth rate of the CF/Sub pastures increased in response to the higher than average rainfall in May (Table 3.4). The lowest growth rate was the RG/Wc at 2.81 kg DM/ha/d during this period.

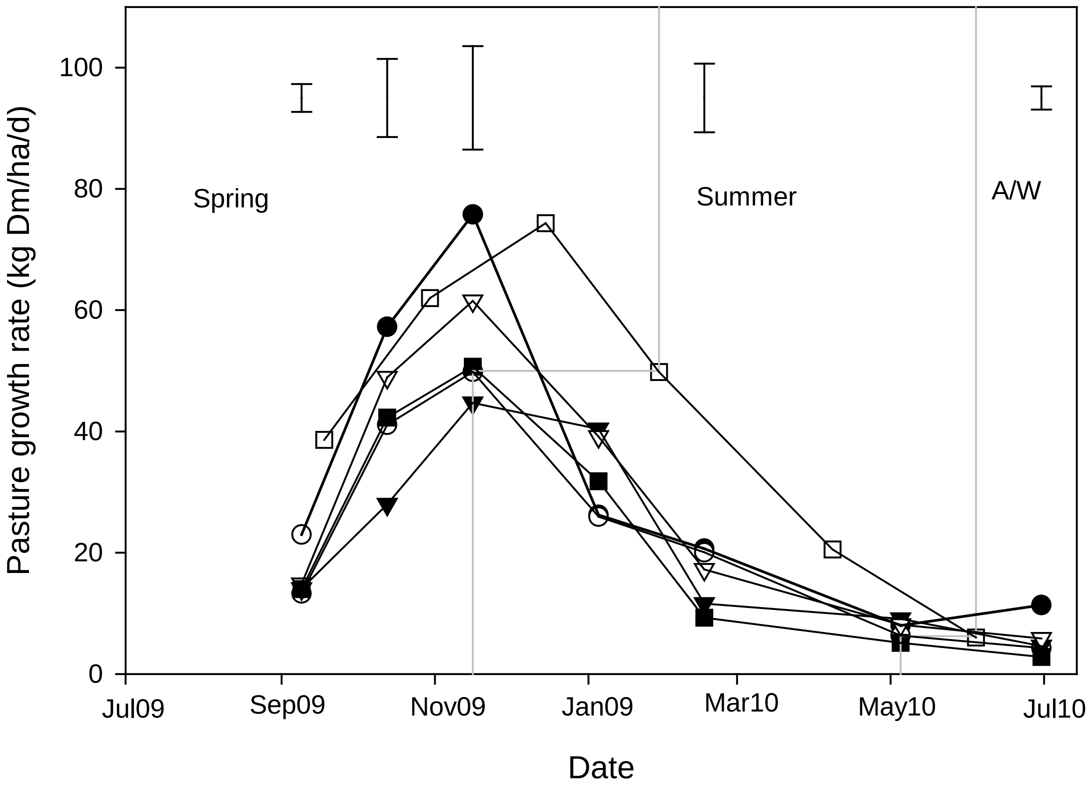

Figure 4.2 Mean daily growth rates of CF/Sub (●), CF/Bal (○), CF/Wc (▼), CF/Cc (▽), RG/Wc (■) and Luc (□) pastures for regrowth cycles between 1/7/2009 to 30/6/2010 at Lincoln University, Canterbury. The mean daily growth rate of every pasture was calculated by dividing total dry matter yield by the number of days in the measurement period. Error bars are LSDs for grass based pastures when there was a significant difference. Vertical gray lines separate the period of measurement into spring, summer and autumn/winter (Section 3.2) with a difference in the duration of each period between grass pastures.

4.4 Water use efficiency (WUE)

Lucerne had the highest (P<0.001) annual WUE of 23 kg DM/ha/mm. Of the grass based pastures, CF/Sub had an annual WUE of 16 kg DM/ha/mm of water used. This was higher (P<0.001) than the other grass based pastures which ranged from 10 to 13 kg DM/ha/mm of water used. For all pastures, the annual water used was calculated as 652 mm for lucerne and between 631 and 677 mm for grass based pastures (Figure 4.3). Table 4.1 shows the seasonal WUE of the six dryland pastures.

The regression equations, standard errors of the means and coefficients of determination for regression of accumulated dry matter against accumulated water use, in initial and secondary water use periods, of six dryland pastures are given in Appendix 5. Arrows show the point where water stress started to affect production. The first arrow is for annual clover pastures, the second arrow is for perennial clover pastures and the third arrow at the top is for lucerne (Section Water use efficiency).

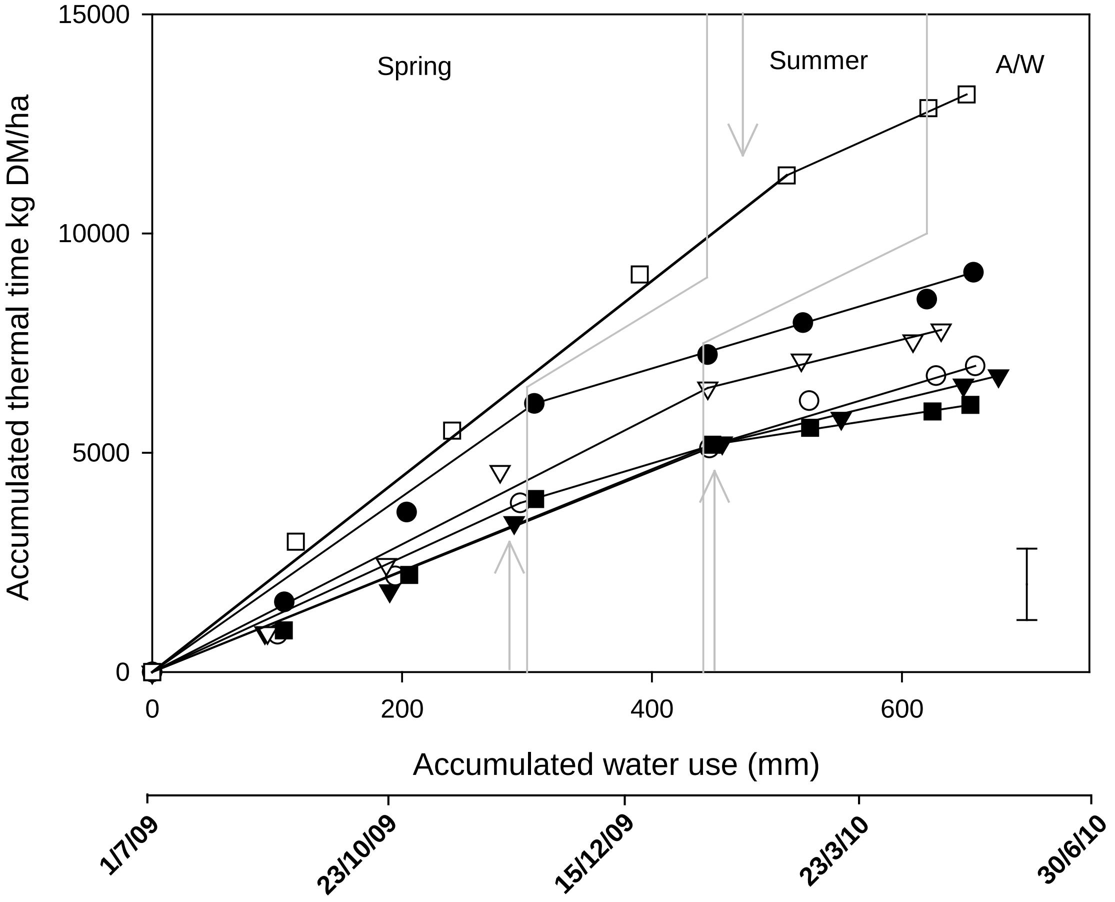

Figure 4.3 **Total annual accumulated dry matter yields (kg DM/ha) of CF/Sub (●), CF/Bal (○), CF/Wc (▼), CF/Cc (▽), RG/Wc (■) and Luc (□) pastures against the annual water use (mm) from 1/7/2009 to 30/6/2010 at Lincoln University, Canterbury. The error bar is SEM for final accumulated dry matter (on 30 June 2010). Arrows approximate when water stress occurs in annual clover (first arrow), perennial clover (second arrow) and lucerne pastures (third arrow) (Section Water use efficiency) due to changes in the linear relationship. Values in bold show the WUE of the pastures. Full regression equations are presented in Appendix 5. Note: WU was measured in 4 of the 6 replicates, consequently DM yields shown here are also the mean from 4 replicates and may differ from those reported in previous sections.**

4.4.1 Initial water use period

During the initial linear period water was not a limiting factor on dry matter production. Lucerne had the highest (P<0.01) WUE at 22 kg DM/ha/mm of water used. Lucerne had the highest (P<0.001) initial accumulated water use of 509 mm. For CF/Sub, the WUE was 20 kg DM/ha/mm of water used for 306 mm. The lowest (P<0.001) accumulated water use was for the cocksfoot and annual clover pastures. This is because they had a shorter initial water use period and were affected by water stress earlier (Section Water use efficiency).

Variation in root depth of the species affects their ability of water uptake from the soil (Section 3.4.6 Plant available water). The analysis for each plot showed different plant water use, even in the adjacent plots (Appendix 6). This is probably caused by difference in soil profiles.

4.4.2 Secondary water use period

In the second water use phase, the values of all pastures decreased due to the effects of water stress. Lucerne once again had the highest ($P<0.01$) value of 13 kg DM/ha/mm of water used, with only 144 mm of water used. The WUE of cocksfoot based pastures ranged from 6.7 to 8.7 kg DM/ha/mm of water used, with cocksfoot and annual clover pastures using over 60% more water than that of the lucerne (Appendix 6), over a longer period (Section Water use efficiency). RG/Wc had the lowest WUE with 4.3 kg DM/ha/mm of water used, while using a total of 204 mm during this period.

Table 4.1 **The annual, initial and secondary water use efficiency (WUE) of six dryland pastures grown between 1/7/2009 and 30/6/2010 at Lincoln University, Canterbury. Full details of acronyms are given in Table Table 3.1.**

Treatment	Annual WUE (kg DM/ha/mm)	Initial WUE (kg DM/ha/mm)	Secondary WUE (kg DM/ha/mm)
CF/Sub	16.2_b	20.0_b	8.2_b
CF/Bal	11.1_c	13.2_c	8.7_b
CF/Wc	10.5_c	11.7_c	7.0_{bc}
CF/Cc	13.3_{bc}	15.2_{bc}	6.7_c
RG/Wc	10.7_c	12.1_c	4.3_c
Luc	22.6_a	22.3_a	13.0_a
SEM	1.5	1.9	1.3

Note: Treatment means followed by the same letter are not significantly different at $\alpha=0.05$.

4.5 Insect populations

4.5.1 Argentine stem weevil

Adult Argentine stem weevil populations across the measurement periods are shown in Figure 4.4. In June, density of ASW adults was greatest in pastures containing the CF/Sub and CF/Wc treatments with 14 and 10 m^{-2} respectively, compared with 1 m^{-2} in pastures with lucerne. By August, weevil densities in pastures containing CF/Sub (63 m^{-2}) and CF/Wc (26 m^{-2}) were higher ($P<0.01$) than those containing lucerne (0 m^{-2}), and the RG/Wc (5 m^{-2}). September sampling showed that the ASW population in plots containing CF/Sub had declined to 46 m^{-2} from the levels recorded in August but more (32 m^{-2}) in CF/Wc. Again these populations were higher ($P<0.001$) than for lucerne (2 m^{-2}) and RG/Wc (5 m^{-2}).

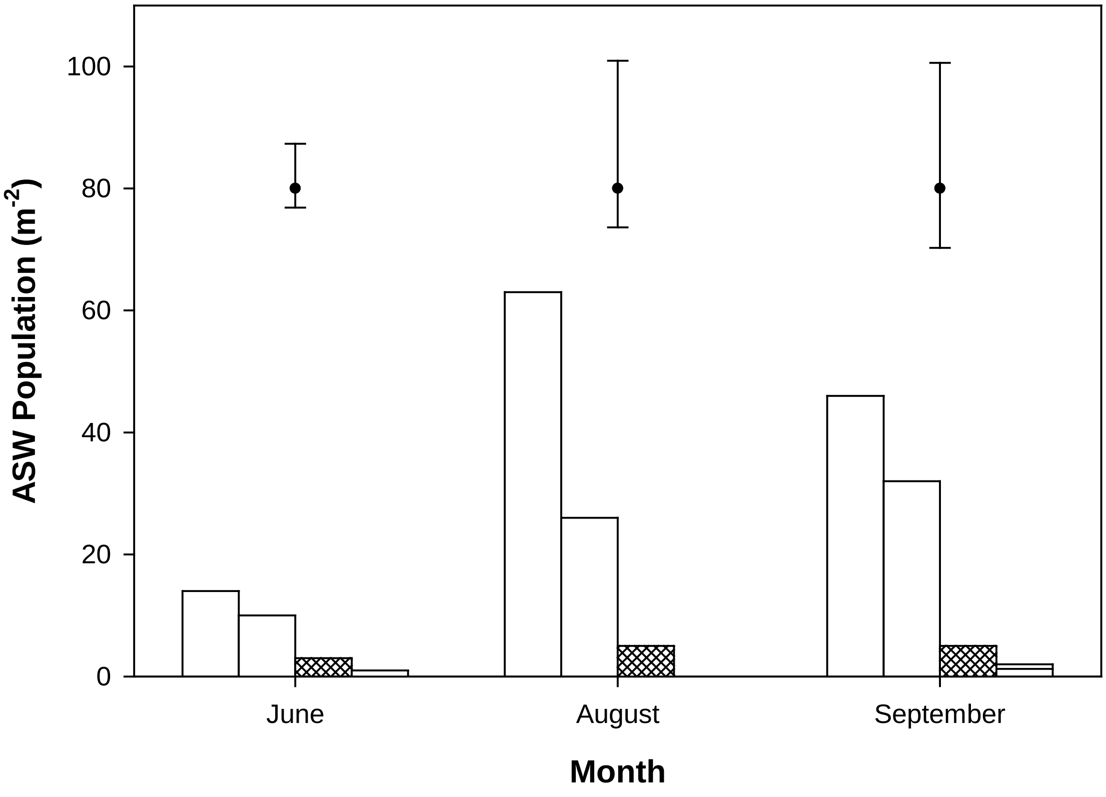

Figure 4.4 **Adult Argentine stem weevil (ASW) populations per square metre of CF/Sub (■), CF/Wc (☐), RG/Wc (☒) and Luc (▤) pastures for June, August and September 2010 at Lincoln University, Canterbury. Back transformed error bars are SEM's of grand mean for the sampling date (Section 3.4.3).**

4.5.2 Clover root weevil

Dissections from all adult clover root weevil (CRW) collected over the three measurement periods showed that all had eggs inside and were capable of laying with no evidence of parasitoid predation. Populations of adult CRW were consistently low from June to September (Figure 4.5). In June 2010, adult CRW densities were greater ($P<0.01$) in pastures containing CF/Wc (4 m^{-2}) and CF/Sub (3 m^{-2}) than in those RG/Wc (2 m^{-2}). Similar low numbers of weevils were found in all grass based pastures during August and September 2010. Across all dates adult CRW density in pastures containing lucerne was 0 or 1 weevil per m^2.

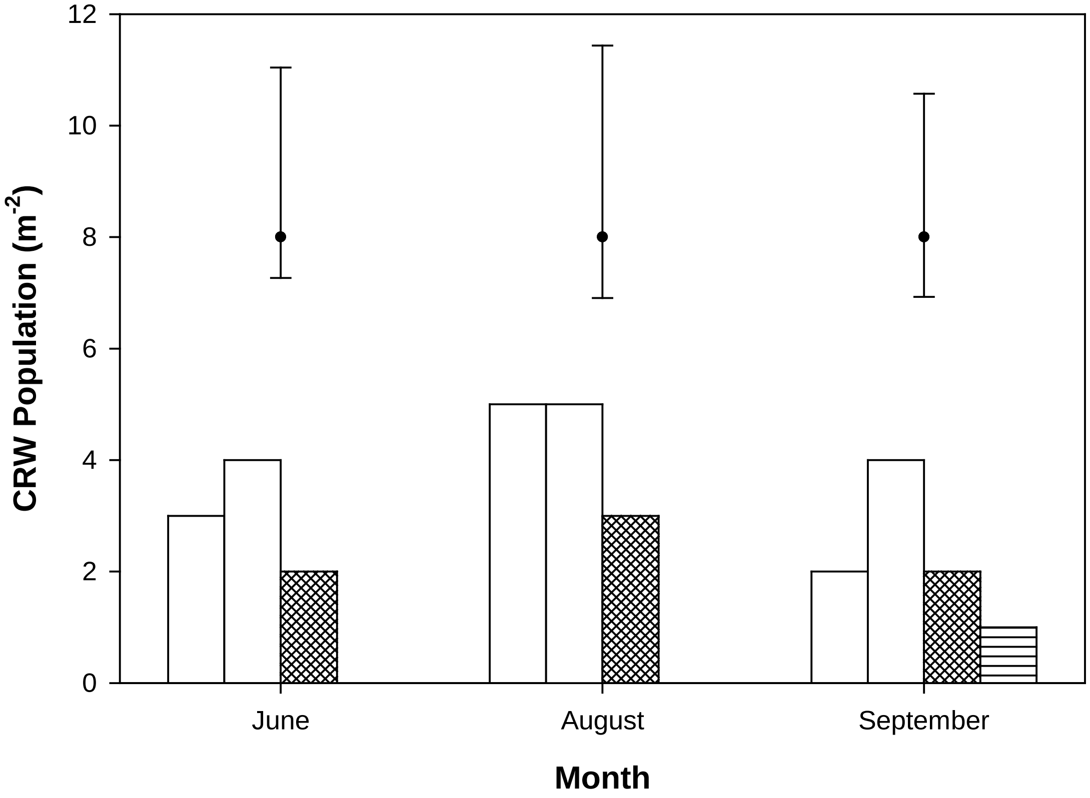

Figure 4.5 Adult clover root weevil (CRW) populations per square metre of CF/Sub (■), CF/Wc (☐), RG/Wc (☒) and Luc (▤) pastures for June, August and September 2010 at Lincoln University, Canterbury. Back transformed error bars are SEM's of grand mean for the sampling date (Section 3.4.3).

When sampling for CRW larvae was undertaken in August and September they were only found in pastures containing CF/Wc and RG/Wc (Figure 4.6). While there was a trend for greater densities of CRW larvae in the RG/Wc pastures compared to those containing CF/Wc this was not significant ($P<0.05$).

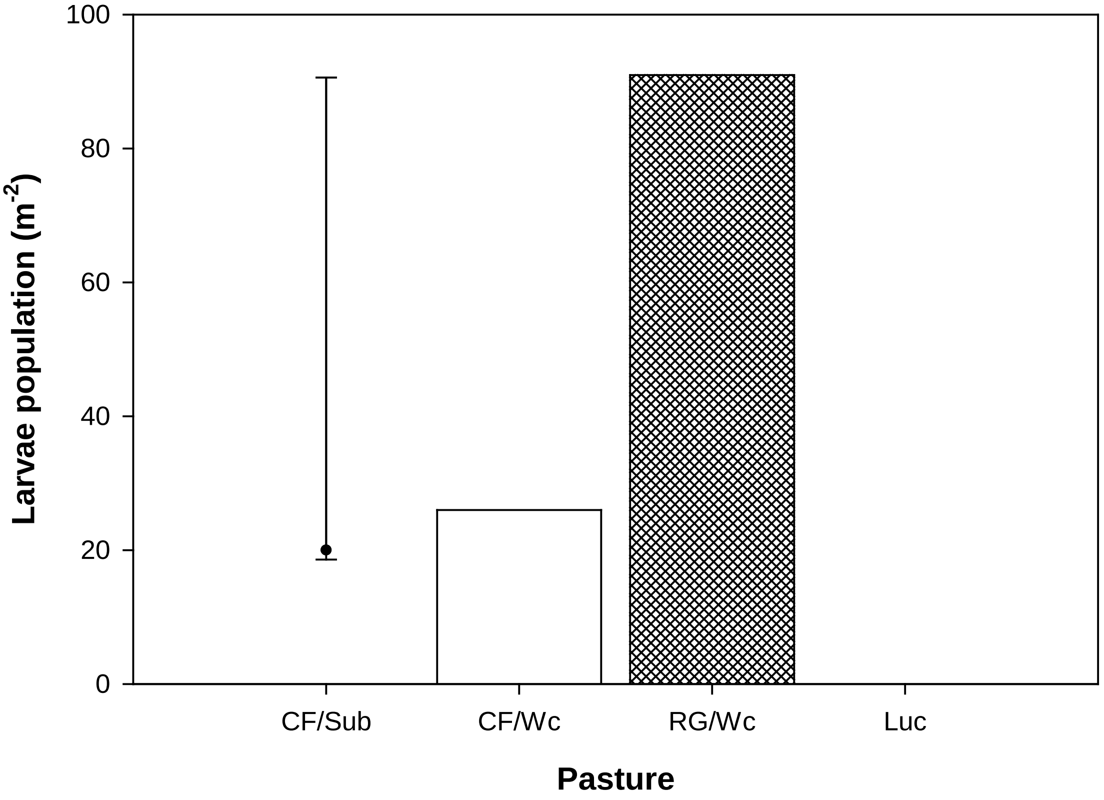

Figure 4.6 Clover root weevil (CRW) larvae populations per square metre of CF/Sub (■), CF/Wc (☐), RG/Wc (☒) and Luc (▤) pastures for July to September at Lincoln University, Canterbury. Back transformed error bars are SEM's of grand mean (Section 3.4.3)

4.5.3 Sitona weevil

Sitona weevil was also present within the ‘MaxClover’ trial but only within the lucerne plots. Populations of 3, 9 and 5 m^{-2} were recorded in June, August and September respectively (Table 4.2). No evidence of a parasitoid was located.

Table 4.2 Lucerne weevil populations per square metre of RG/Wc, CF/Wc, CF/Sub and RG/Wc pastures for June, August and September 2010 at Lincoln University, Canterbury.

Treatment	June	August	September
CF/Sub	0	0	0
CF/Wc	0	0	0
RG/Wc	0	0	0
Luc	3	9	5
Grand mean	0.52	0.73	0.53
SEM	0.20	0.0.17	0.14
P value	0.002	0.001	0.001

4.5.4 Grass grub

Grass grub (GG) larvae were detected in all treatments on all five sampling dates from 2008 to 2010 (Figure 4.7).

In July/Aug 2008, CF/Bal had the highest density of grass grub larvae at 197 m^{-2} ($P<0.01$). RG/Wc pastures had 106 GG larvae m^{-2}. The lowest GG larval densities were found in lucerne and CF/Sub pastures with 24 and 84 m^{-2}, respectively.

The June 2009 measurement showed CF/Cc pastures had 160 grubs m^{-2} which was higher ($P<0.001$) than all other treatments. RG/Wc was similar to 2008 with 104 larvae m^{-2} but only 30 larvae m^{-2} were found in lucerne. The subsequent measurements in Aug/Sept 2009 gave similar results with the highest ($P<0.01$) population of 128 larvae m^{-2} in RG/Wc followed by 119 m^{-2} in CF/Wc. Other grass based pastures had between 63 and 84 larvae m^{-2} and there were only 41 m^{-2} in the lucerne.

The first measurement in June 2010 showed RG/Wc and CF/Wc had higher densities than in 2009, with 208 and 143 larvae m^{-2}, respectively. The final sampling in Aug/Sept showed there were no significant differences between the grass based pastures. The grass grub larval density in lucerne was similar to the previous sampling with 63 grubs m^{-2} but was only significantly less than larval densities in CF/Bal (P<0.5) pastures.

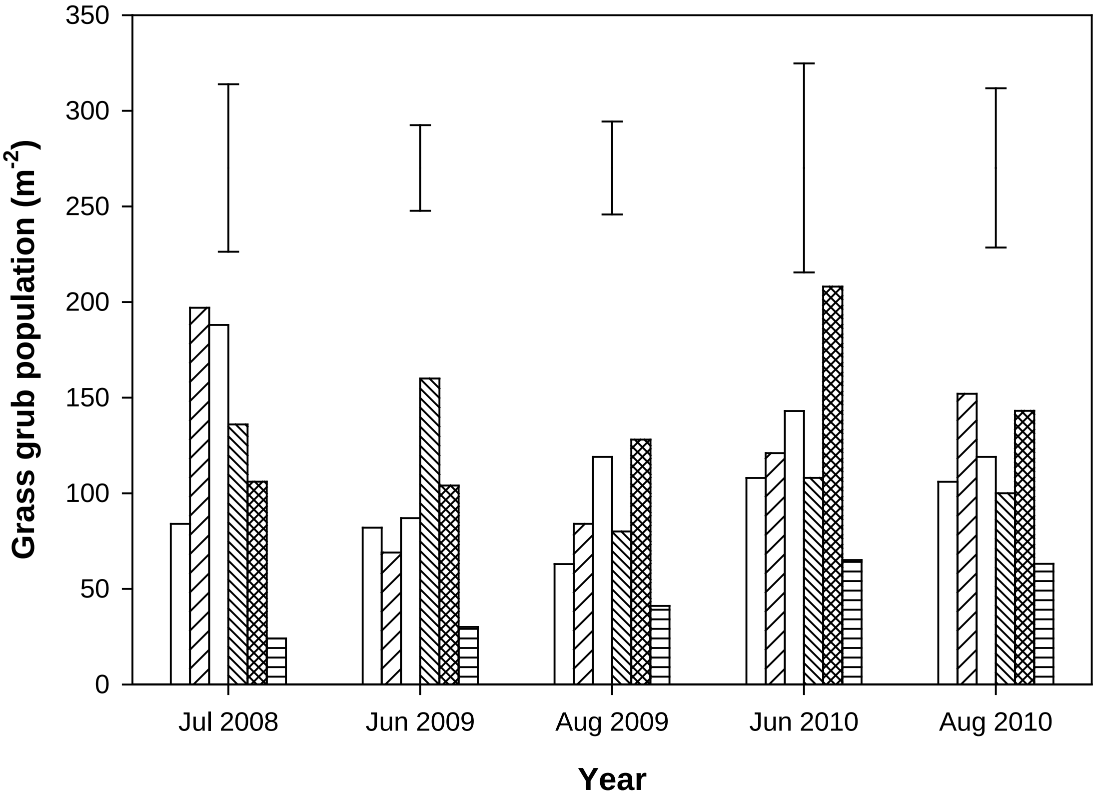

Figure 4.7 **Grass grub larval populations per square metre of CF/Sub (■), CF/Bal (▨), CF/Wc (☐), CF/Cc (▧), RG/Wc (▩) and Luc (▤) pastures for 2008 to 2010 at Lincoln University, Canterbury. Error bars are LSD's for grass based pastures and lucerne when there was a significant difference.**

4.6 Botanical composition

4.6.1 Annual

Table 4.3 shows the annual mean botanical composition of these dryland pastures. The sown grass component ranged from 13% for RG/Wc to 57% for CF/Wc. The legume component of the grass based pastures ranged from 6% for CF/Bal to 16% for CF/Sub. Dicotyledonous weed content was highest in lucerne with 14% and mainly consisted of yarrow (*Achillea millefolium*) and hawkbeard (*Crepis capillaris*). In the grass based pastures RG/Wc had 11% and CF/Sub 1% of dicotyledonous weed species. The weed grasses were highest in RG/Wc at 51% and lowest in CF/Bal. Other grass consisted of many annual grasses such as annual poa (*Poa annua*), barley grass (*Hordeum* spp.), goose grass (*Bromus mollus*) and browntop (*Agrostis capillaries*).

Table 4.3 Annual botanical composition of six dryland pastures. Numbers within brackets are contributions of volunteer (unsown) white clover in each treatment. Values may not sum to 100% due to rounding. Lucerne was not included in the ANOVA so LSD and P levels are for the comparison of grass based pastures only. Full details of the acronyms are given in Table 3.1.

Treatment	Sown grass (%)	Legume (%)	Dead (%)	Weed grasses (%)	Dicot weeds (%)
CF/Sub	48.3_{ab}	16.3_{a} (1.9)	7.6_{b}	25.5_{b}	0.7_{d}
CF/Bal	50.5_{ab}	5.9_{b} (12.2)	12.3_{ab}	14.3_{c}	4.8_{bc}
CF/Wc	56.8_{a}	13.3_{a}	10.5_{ab}	16.8_{bc}	2.6_{cd}
CF/Cc	47.0_{b}	6.0_{b} (9.5)	9.1_{ab}	23.9_{b}	4.4_{bc}
RG/Wc	13.1_{c}	10.9_{ab}	13.8_{a}	50.5_{a}	11.2_{a}
Lucerne	-	84.0	1.9	-	14.1
Grand mean	43.1	10.5	10.7	26.2	4.8
LSD	9.51	6.28	5.43	6.97	2.85
P value	0.001	0.003	0.173	0.001	0.001

Note: Treatment means followed by the same letter are not significantly different at α=0.05.

4.6.2. Spring

The botanical composition of the six dryland pasture treatments at the last harvest date in spring (1/7/2009 to 16/11/2009) is shown in Table 4.4. In the final spring rotation for these seven year old pastures, the sown grass component ranged from 15% for the RG/Wc pastures to 48% for the CF/Wc. The legume component of the grass based pastures was higher ($P<0.001$) in the CF/Sub at 38% than for the other grass based pasture treatments which had ≤20% sown legume. Dicotyledonous weeds were highest in RG/Wc pastures with 13% being mainly dandelion (*Taraxacum officinale*) and storksbill (*Erodium cicutarium*). Other grass weeds were highest ($P<0.001$) in the RG/Wc pastures (51%) and between 19 and 32% for other species.

Table 4.4 Botanical composition during the spring period from 1/7/2009 to 16/11/2010 for grass based pastures and 1/7/2009 to 29/1/2010 for lucerne. Numbers within brackets are contributions of volunteer (unsown) white clover in each treatment. Values may not sum to 100% due to rounding. Lucerne was not included in the ANOVA so LSD and P levels are for the comparison of grass based pastures only. Full details of the acronyms are given in Table 3.1.

Treatment	Sown grass (%)	Legume (%)	Dead (%)	Weed grasses (%)	Dicot weeds (%)
CF/Sub	35.9_a	37.5_a (1.1)	3.6	20.8_c	1.1_b
CF/Bal	43.4_a	13.0_{bc} (15.5)	3.5	19.4_c	5.0_b
CF/Wc	47.8_a	19.9_b	4.4	24.2_{bc}	3.6_b
CF/Cc	37.6_a	6.7_c (13.7)	4.2	31.9_b	5.9_b
RG/Wc	15.3_b	18.1_b	3.1	50.5_a	12.9_a
Lucerne	-	83.0	1.5	-	15.5
Grand mean	36.0	19.0	3.8	29.4	5.7
LSD	12.58	9.67	1.57	10.49	5.44
P value	0.001	0.001	0.044	0.001	0.003

Note: Treatment means followed by the same letter are not significantly different at $\alpha=0.05$.

4.6.3 Summer

The botanical composition for the summer period (16/11/2009 to 5/5/2010) is shown in Table 4.5. The sown grass component was similar in all grass based pasture treatments except that of RG/Wc with only 10%. CF/Wc had the highest value with 58% sown grass and the highest legume content with 11%. CF/CC and Rg/Wc each had 7% sown legume and CF/Sub and CF/Bal had ≤1%. The values from the annual clover treatments reflect the fact that the clover had died in late spring to re-establish from buried seed in autumn. However, autumn rains had not arrived at the time of the last summer harvest (5/5/2010). Lucerne pastures consisted of 89% sown legume and other components were 4% dead material and 7% weeds. Dicotyledonous weeds in the RG/Wc pastures were highest with 12% compared with ≤1% in CF/Sub pastures. RG/Wc also had the highest ($P<0.001$) weed grass component of 43% compared with all other grass based pasture treatments which had ≤27%.

Table 4.5 **Botanical composition during the summer period from 16/11/2010 to 5/5/2010 for grass based pastures and 29/1/2010 to 30/6/2010 for lucerne. Numbers within brackets are contributions of volunteer (unsown) white clover in each treatment. Values may not sum to 100% due to rounding. Lucerne was not included in the ANOVA so LSD and P levels are for the comparison of grass based pastures only. Full details of the acronyms are given in Table 3.1.**

Treatment	Sown grass (%)	Legume (%)	Dead (%)	Other grass (%)	Weeds (%)
CF/Sub	56.3_a	0.2_b (3.4)	13.1_b	26.5_b	0.5_b
CF/Bal	53.5_a	0.7_b (11.5)	17.6_b	10.7_c	6.0_{ab}
CF/Wc	58.2_a	11.0_a	17.8_b	10.9_c	2.1_b
CF/Cc	45.7_a	7.3_a (8.6)	15.9_b	18.4_c	4.1_b
RG/Wc	9.5_b	7.1_a	27.7_a	42.8_a	12.0_a
Lucerne	-	88.5	4.2	-	7.3
Grand mean	44.7	5.25	18.4	21.9	5.0
LSD	14.63	5.13	7.88	11.08	5.90
P value	0.001	0.001	0.012	0.001	0.006

Note: Treatment means followed by the same letter are not significantly different at $\alpha=0.05$.

4.6.4 Autumn/Winter

Table 4.6 shows the botanical composition for the autumn/winter period for grass based pastures only. The sown grass component contributed 17% to RG/Wc pastures and 80% in CF/Wc pastures. The legume component of all grass based pastures was ≤1%. Dicotyledonous weed levels were also low ranging from ≤1% for CF/Sub and CF/Bal pastures to 4% for RG/Wc pastures. The other grass component was once again highest ($P<0.001$) in the RG/Wc pastures at 74% reflecting the emergence of winter annual barley grass (*Hordeum* spp.) and annual poa. CF/Sub pastures had 35% other grasses and all other grass based pastures had ≤17%. CF/Bal pastures had 22% dead material with all other treatments having ≤7%.

Table 4.6 **Botanical composition during the autumn/winter period from 5/5/2010 to 30/6/2010 for grass based pastures. Numbers within brackets are contributions of volunteer (unsown) white clover in each treatment. Values may not sum to 100% due to rounding. Full details of the acronyms are given in Table 3.1.**

Treatment	Sown grass (%)	Legume (%)	Dead (%)	Other grass (%)	Weeds (%)
CF/Sub	61.4_{a}	0.8_{a} (0.1)	2.8_{b}	34.7_{b}	0.2_{b}
CF/Bal	62.5_{a}	0.1_{b} (4.4)	22.4_{a}	9.9_{c}	0.8_{b}
CF/Wc	79.6_{a}	0.7_{ab}	6.6_{ab}	12.1_{c}	1.1_{b}
CF/Cc	79.1_{a}	0.2_{ab} (0.1)	3.7_{b}	16.5_{bc}	0.4_{b}
RG/Wc	17.3_{b}	0.5_{ab}	4.5_{b}	73.8_{a}	3.9_{a}
Grand mean	60.0	0.4	8.0	29.4	1.3
LSD	28.45	0.65	17.60	20.11	1.72
P value	0.001	0.178	0.156	0.001	0.002

Note: Treatment means followed by the same letter are not significantly different at $\alpha=0.05$.

4.6.5 The Botanal method

Botanical composition as measured by the Botanal method is shown in Table 4.7 and Table 4.8.

Table 4.7 Botanical composition of six dryland pastures as determined by the Botanal method on the 26/12/2009. Full details of the acronyms are given in Table 3.1.

Treatment	Cocksfoot (%)	Ryegrass (%)	Sown clover (%)	Luc (%)	Other clover (%)	Annual grass (%)	Dicot Weeds (%)
CF/Sub	58.4_a	4.08_a	4.24_b	0.0_b	2.83_{bc}	18.3_b	12.1_b
CF/Bal	64.1_a	0.14_b	0.0_b	0.0_b	14.1_a	20.8_b	0.9_b
CF/Wc	58.4_a	0.0_b	12.8_a	0.0_b	0.0_c	25.1_b	3.7_b
CF/Cc	53.9_a	2.53_b	6.94_a	0.0_b	5.78_b	24.2_b	6.7_b
RG/Wc	25.6_b	0.35_b	12.1_a	0.0_b	0.18_c	49.0_a	12.8_a
Lucerne	4.7_c	2.28_b	-	52.5_a	6.21_b	21.5_b	11.0_b
Grand mean	44.2	1.56	6.0	8.7	4.85	26.5	7.9
LSD	12.7	3.92	6.08	5.9	5.52	11.4	11.4
P value	0.001	0.220	0.001	0.001	0.001	0.001	0.202

Note: Treatment means followed by the same letter are not significantly different at $\alpha=0.05$.

Table 4.7 shows the botanical composition on the 26/12/2009 as determined by the Botanal method. The closest individual harvest date to this was the 5/01/2010 which is 10 days after this summer measurement. CF/Bal pastures had the highest ($P<0.001$) other clover component with 14.1% which consisted of volunteer white clover or subterranean clover. All other grass based pastures had≤6 %. The annual grass component was higher ($P<0.001$) in RG/Wc pastures with 49% and CF/Wc pastures with 25%. Dicotyledonous weeds were highest in RG/Wc pastures. Cocksfoot based pastures had between 54 and 64% cocksfoot and lucerne swards had 53% lucerne.

Table 4.8 shows the botanical composition on the 5/5/2010 as determined by the Botanal method. The cocksfoot component of pastures was lowest in the RG/Wc with 22% but between 70 and 80% for all pastures where cocksfoot was a sown component. Ryegrass was ≤2% for cocksfoot based pastures and just 3% for the RG/Wc pasture. RG/Wc pastures had the highest ($P<0.001$) annual grass component with 63% compared with all other grass based pastures being≤17%. Dicotyledonous weeds were higher in RG/Wc and CF/Cc pastures but were overall greatest ($P<0.001$) in lucerne with 37%.

Table 4.8 Botanical composition of six dryland pastures as determined by the Botanal method on the 5/5/2010. Full details of the acronyms are given in Table 3.1.

Treatment	Cocksfoot (%)	Ryegrass (%)	Sown clover (%)	Luc (%)	Other clover (%)	Annual grass (%)	Dicot weeds (%)
CF/Sub	76.4_{a}	1.58_{b}	4.25_{b}	0.0_{b}	1.43_{b}	13.3_{b}	3.05_{c}
CF/Bal	78.9_{a}	0.49_{b}	0.52_{b}	0.0_{b}	1.73_{a}	15.7_{b}	2.67_{c}
CF/Wc	80.3_{a}	0.17_{b}	1.74_{b}	0.3_{b}	0.96_{b}	13.8_{b}	2.73_{c}
CF/Cc	70.2_{a}	0.84_{b}	0.22_{b}	0.7_{b}	0.52_{b}	17.3_{b}	10.2_{b}
RG/Wc	21.8_{b}	2.94_{a}	1.33_{b}	2.0_{b}	0.09_{b}	63.1_{a}	8.74_{bc}
Lucerne	8.5_{c}	0.94_{b}	-	37.4_{a}	0.64_{b}	15.8_{b}	36.7_{a}
Grand mean	56.0	1.16	1.34	6.7	0.9	23.2	10.7
LSD	12.9	1.99	1.95	7.24	1.35	15.0	6.63
P value	0.001	0.099	0.001	0.001	0.168	0.001	0.001

Note: Treatment means followed by the same letter are not significantly different at α=0.05.

4.7 Nitrogen concentration

4.7.1 Annual

The annual N concentration and yields from grass, legume and total sown species components of six dryland pastures is shown below in Table 4.9.

Table 4.9 Annual nitrogen concentration and corresponding N yields of sown grass and sown legume components of six dryland pastures at Lincoln University. Volunteer white clover component given in brackets. Full details of the acronyms are given in Table 3.1.

Treatment	Grass (%N)	Legume (%N)	Grass N yield (kg/ha)	Legume N yield (kg/ha)	Sown species N%	Sown species N yield (kg/ha)
CF/Sub	3.2_a	3.0_d (3.9_d)	122_a	93.1_b (6.5_d)	3.4_b	216_b
CF/Bal	2.7_b	3.6_c (3.9_b)	87.0_b	21.2_d (39.2_c)	2.8_d	108_{cd}
CF/Wc	2.8_b	3.9_b	87.1_b	44.0_c	3.3_b	131_c
CF/Cc	2.9_b	3.7_c (3.9_b)	85.5_b	29.1_{cd} (29.1_{cd})	3.3_{bc}	115_c
RG/Wc	2.3_c	4.0_a	18.5_c	46.8_c	3.1_c	65.3_d
Luc	-	3.7_c	-	462_a	3.7_a	462_a
Grand mean	2.8	3.7	80.1	87.3	3.3	183
LSD	0.18	0.25	33.17	30.97	0.24	48.35
P value	0.001	0.001	0.001	0.001	0.001	0.001

Note: Treatment means followed by the same letter are not significantly different at α=0.05.

For N% in the cocksfoot based pastures, CF/Sub gave the highest (P<0.001) mean N% of 3.2% in the sown grass component compared with other pastures. This resulted in the highest grass N yield of 122 kg/ha for CF/Sub and other cocksfoot pastures yielding between 85 and 88 kg N/ha. For the legumes, the mean nitrogen concentration was 3.6% but was lower (P<0.001) for CF/Sub (3.0%), than for all other legumes. Lucerne monocultures achieved the highest (P<0.001) legume N yield of 462 kg/ha. CF/Sub was the highest out of all grass based pastures with 93 kg N/ha. Lucerne produced the highest (P<0.001) annual N% and yield of the total of sown species, with 3.7% and 462 kg N/ha. CF/Bal had the lowest sown species N% (2.8%) but RG/Wc had the lowest sown species yield of only 65 kg N/ha. CF/Bal pastures produced an N yield of 39 kg/ha mainly from volunteer white clover within plots.

4.7.2 Spring

Table 4.10 shows the N concentration and corresponding N yields for the spring period during 2009/2010, as defined for DM yields. The N content of the grass in the cocksfoot based pastures was higher ($P<0.001$) than in RG/Wc. This was reflected in the grass N yield, where RG/Wc produced 13 kg N/ha. CF/Sub was highest ($P<0.001$) with 65 kg/ha compared with other cocksfoot based pastures which yielded between 47 and 51 kg N/ha. The N concentration of the legume components were higher ($P<0.001$) in white clover treatments (4.4%) compared with other treatments. Lucerne produced the highest N yield of 426 kg/ha ($P<0.001$) compared with all other treatments. The sown grass component in the CF/Sub pastures produced 93 kg N/ha and a total of 158 kg N/ha, which was almost double that from all other grass based pastures. CF/Cc plots had the highest ($P<0.001$) yield of volunteer white clover with 32.9 kg N/ha while the volunteer white clover contributed just 3.1 kg N/ha in the CF/Sub pastures.

Table 4.10 Spring nitrogen concentration and corresponding N yields of sown grass and legume components of six dryland pastures at Lincoln University for grass based pastures (1/7/2009 to 16/11/2009) and lucerne (1/7/2009 to 29/1/2010). Volunteer white clover component given in brackets. Full details of the acronyms are given in Table 3.1.

Treatment	Grass (%N)	Legume (%N)	Grass N yield (kg/ha)	Legume N yield (kg/ha)	Sown species N%	Sown species N yield (kg/ha)
CF/Sub	3.2_a	4.0_b	65.1_a	93.1_b (3.1_d)	3.6_b	158_b
CF/Bal	3.1_b	3.6_c	48.7_b	21.0_{cd} (28.8_{cd})	3.3_c	69.7_c
CF/Wc	3.0_b	4.4_a	50.8_b	32.2_c	3.7_b	83.0_c
CF/Cc	3.0_b	4.0_b	47.2_b	18.1_{cd} (32.9_c)	3.4_{bc}	65.3_c
RG/Wc	2.2_c	4.4_a	12.7_c	38.5_c	3.3_c	51.2_c
Luc	-	3.9_{bc}	-	426.2_a	3.9_a	426_a
Grand mean	2.9	4.1	44.9	77.1	3.5	142
LSD	0.10	0.33	17.16	26.96	0.27	33.79
P value	0.001	0.001	0.001	0.001	0.001	0.001

Note: Treatment means followed by the same letter are not significantly different at $\alpha=0.05$.

4.7.3 Summer

Nitrogen herbage results for the summer period are given below in Table 4.11. CF/Sub pastures had a grass N% of 2.6 ($P<0.001$) which resulted in a grass N yield of 37 kg/ha. RG/Wc also had an N% of 2.6 but only achieved an N yield of 4 kg/ha due to low dry matter yields. Volunteer white clover present in the annual clover plots was highest in CF/Bal with 10.4 kg N/ha and lowest in CF/Sub with 3.4 kg N/ha.

Legume N% was similar across all pasture treatments analysed. However, lucerne had the lowest legume N% of 2.8%, due to its more stemy growth at this time, but once again produced the highest N yield of 36 kg/ha. RG/Wc produced the least with 8 kg/ha. Sown species N% was similar across all treatments with the exception of CF/Bal which was lowest ($P<0.001$) with 2.2%.

Table 4.11 Summer nitrogen concentration and corresponding N yields of sown grass and legume components of six dryland pastures at Lincoln University for grass based pastures (16/11/2009 to 5/5/2010) and lucerne (29/1/2010 30/6/2010). Volunteer white clover component given in brackets. Full details of the acronyms are given in Table 3.1.

Treatment	Grass (%N)	Legume (%N)	Grass N yield (kg/ha)	Legume N yield (kg/ha)	Sown species N%	Sown species N yield (kg/ha)
CF/Sub	2.6_{a}	-	37.4_{a}	- (3.4_{b})	2.7_{ab}	37.5_{ab}
CF/Bal	2.2_{b}	-	31.5_{a}	- (10.4_{b})	2.2_{ab}	31.7_{ab}
CF/Wc	2.1_{b}	3.3_{a}	28.3_{a}	11.8_{b}	2.7_{a}	40.1_{a}
CF/Cc	2.3_{b}	3.3_{a}	27.2_{a}	11.0_{b} (11.0_{b})	2.8_{a}	38.2_{ab}
RG/Wc	2.6_{a}	3.2_{a}	4.4_{b}	8.3_{b}	2.8_{a}	12.7_{b}
Luc	-	2.8_{b}	-	35.7_{a}	2.8_{a}	35.7_{ab}
Grand mean	2.4	3.1	25.8	13.1	2.5	32.6
LSD	0.23	0.19	19.90	15.01	0.86	25.12
P value	0.001	0.001	0.026	0.005	0.163	0.260

Note: Treatment means followed by the same letter are not significantly different at $\alpha=0.05$.

4.7.4 Autumn/Winter

During autumn/winter there was no legume component to analyse in the grass based pastures (Table 4.12). CF/Sub and CF/Cc pastures had a higher ($P<0.001$) grass N% compared with other treatments (4.9% and 4.5%). RG/Wc was again lowest with 3.2% and thus yielding 1 kg N/ha. CF/Sub yielded 20 kg N/ha and CF/Cc 11 kg N/ha. Sown species results were the same as no legume component was present.

Table 4.12 **Autumn/winter nitrogen concentration and corresponding N yields of sown grass and legume components of five dryland pastures at Lincoln University for grass based pastures (5/5/2010 to 30/6/2010). Full details of the acronyms are given in Table 3.1.**

Treatment	Grass (%N)	Grass N yield (kg/ha)
CF/Sub	4.9_{a}	20.0_{a}
CF/Bal	3.3_{bc}	6.8_{bc}
CF/Wc	4.2_{ab}	8.0_{bc}
CF/Cc	4.5_{a}	11.1_{ab}
RG/Wc	3.2_{c}	1.4_{c}
Grand mean	4.0	9.4
LSD	0.93	9.47
P value	0.005	0.009

Note: Treatment means followed by the same letter are not significantly different at $\alpha=0.05$.

4.7.5 Annual weed N

Weed nitrogen concentration and yields were measured in RG/Wc pastures for the 2009/2010 season (Table 4.13 and Table 4.14). Spring and summer dicotyledonous weed yields in RG/Wc were 5 and 2.2 kg N/ha with an annual yield of 7.2 kg N/ha (Table 4.13). Yield estimates, based on N% of weeds in RG/Wc pastures were calculated for other grass based pastures. RG/Wc N yields were highly significant ($P<0.001$) compared with other grass based pastures in spring and annually. CF/Cc pastures produced an N yield from weeds of 2.6 and 1.5 kg/ha in spring and summer. CF/Sub pastures had the lowest N yield from weeds of just 0.5 kg N/ha annually.

Table 4.13 **Estimated dicotyledonous weed nitrogen concentration and nitrogen yield of five dryland pastures for spring and summer 2009/10 based on measured values from RG/Wc pastures, at Lincoln University, Canterbury. Full details of the acronyms are given in Table 3.1.**

Treatment	Spring N%	Spring N yield (kg/ha)	Summer N%	Summer N yield (kg/ha)	Annual N%	Annual N yield (kg/ha)
RG/Wc	3.2	5.0_a	2.6	2.2_a	2.9	7.2_a
CF/Sub		0.4_c		0.1_b		0.5_c
CF/Bal		1.7_c		1.4_b		3.1_b
CF/Wc		1.5_c		0.9_b		2.4_c
CF/Cc		2.6_b		1.5_a		4.1_b
Grand mean		2.2		1.2		3.4
LSD		1.97		1.39		2.28
P Value		0.001		0.057		0.001

Note: Treatment means followed by the same letter are not significantly different at α=0.05.

Spring and summer annual grass weed yields in RG/Wc were 15.7 and 32.3 kg N/ha with an annual yield of 48.0 kg N/ha (Table 4.14). Yield estimates, based on N% of annual grass weeds in RG/Wc pastures were calculated for other grass based pastures. CF/Sub and CF/Cc pastures produced an estimated annual yield of 37.1 and 37.5 kg N/ha ($P<0.002$). CF/Cc produced the second highest estimated summer N yield of 27.5 kg N/ha. CF/Bal pastures produced the lowest spring, summer and annual estimated yields overall.

Table 4.14 **Estimated annual grass weed nitrogen concentration and nitrogen yield of five dryland pastures for spring and summer 2009/10 based on measured values from RG/Wc pastures, at Lincoln University, Canterbury. Full details of the acronyms are given in Table 3.1.**

Treatment	Spring N%	Spring N yield (kg/ha)	Summer N%	Summer N yield (kg/ha)	Annual N%	Annual N yield (kg/ha)
RG/Wc	3.5	15.7_a	2.2	32.3_a	2.5	48.0_a
CF/Sub		12.3_a		24.8_b		37.1_a
CF/Bal		3.9_b		15.5b		19.5_b
CF/Wc		5.7_b		17.2_b		22.8_b
CF/Cc		10.0_{ab}		27.5_a		37.5_a
Grand mean		9.5		23.5		33.0
LSD		6.82		13.2		14.2
P Value		0.011		0.078		0.002

Note: Treatment means followed by the same letter are not significantly different at α=0.05.

5 Discussion

The aim of this study was to compare the productivity of different pastures in their eighth year under dryland conditions. To achieve this, dry matter production, water use efficiency, insect pressure, botanical composition and nitrogen yield were measured. This chapter discusses the results in relation to previous work (Chapter 2) and quantifies the environmental factors that affected the pastures.

5.1 Pasture yields

Lucerne was the most productive pasture (Figure 4.1). This was consistent with previous results (Mills *et al.* 2008; Tonmukaykul 2009), although, the annual lucerne production was lower in this year than previous years. This was potentially due to a decline in plant population. Wynn-Williams (1982) stated that lucerne stands self-thin over time to a stable population. The stable population is above the minimum population required for maximum production. Plant populations as low as 30 plants m^{-2} can produce maximum yields within established stands. Weeds have invaded the lucerne plots and more bare ground was apparent this year than previous years, as stands are thinning. However, plant population was not measured within this experiment. The mean annual dicotyledonous weed content of the lucerne was 14% in 2009/10 and 10% in 2008/09.

The CF/Sub pasture was the most productive of the grass based pastures (Figure 4.1). Its annual yield of 9.5 t DM/ha was similar to previous yields at 9.9 to 12.9 t DM/ha in Year 1 to 5 (Mills *et al.* 2008) and 9.4 t DM/ha in Year 7 (Tonmukaykul 2009). In contrast the RG/Wc pastures produced only 6.6 t DM/ha/y and had the highest contents of unsown grass weed and dicotyledonous weed (Table 4.3). This was consistent with previous weed contents of 4% in Year 1 and 24% in Year 5 (Mills *et al.* 2008) and 61% in Year 7 (Tonmukaykul 2009). These results emphasise the poor persistence of perennial ryegrass in dryland conditions.

CF/Bal pastures yielded 6.8 t/ha and the CF/Cc pastures yielded 8.4 t/ha, but the balansa clover and Caucasian clover contributed only 6% of the yield. Monks (2009) suggested that the cocksfoot might have out competed the balansa clover seedlings for light and moisture after the autumn rains, therefore reducing photosynthetic rates of the seedlings. For successful regeneration of balansa clover, specialist management must occur in the establishment year and then approximately every three years. However, this was only undertaken in two of the six replicates of the ‘MaxClover’ experiment resulting in compromising overall performance of the balansa clover pastures (Tonmukaykul 2009).

Differences in mean daily growth rate quantified the seasonal pattern of dry matter production in the ‘MaxClover’ grazing experiment (Figure 4.2). These ranged from a minimum of 3 kg DM/ha/d (RG/Wc) in winter through to 76 kg DM/ha/d (CF/Sub) during the spring period. The highest mean daily growth rates occurred in the final spring period (13/10/2009 to 16/11/2009) when temperatures had increased but moisture was not yet limiting. The CF/Sub pastures had the highest growth rates of the grass based pastures in spring, ranging from 23 kg DM/ha/d in September to 76 kg D/ha/d in November. Mills *et al.* (2006) found similar results for cocksfoot monocultures under dryland and non-N fertilizer conditions. In the present study, mean daily growth rates declined in December and continued to decline through to the end of the season in July. Mills *et al.* (2006) states that the loss of yield in these pastures in response to water stress is caused by reduced leaf expansion, photosynthesis and therefore canopy expansion. Similar results were found by Mills *et al.* (2008) in Years 1 to 4 of the ‘MaxClover’ experiment, where CF/Sub pastures produced the highest mean daily growth rates during the late spring period, with between 97 and 105 kg DM/ha/d. Mills *et al.* (2008) also found that pastures established with perennial legumes (CF/Wc, CF/Cc and RG/Wc) had higher summer growth rates than those with annual clovers (CF/Sub and CF/Bal). This is generally because the annual legumes were not present as they had died and would re-establish from seed in the autumn. In this study this was the case through December but from February to April, the mean daily growth rates of CF/Sub and CF/Bal pastures (20 kg DM/ha/d) were higher than that of perennial legume pastures (Figure 4.2).

Dry matter production was directly related to timing of rainfall events and the ability of the pastures to utilise soil moisture. Yield accumulation of the lucerne swards was faster for a longer duration and declined in late December, compared with November for grass based pastures. This was because of nitrogen herbage concentration. There was a slight decline in late spring growth in the lucerne (Figure 4.1) which suggests that the actual onset of water stress was between the measured dates, therefore January, as for the other grass based pastures during their summer period. The yield of all grass based pastures only slightly increased after autumn due to soil moisture and temperature being limiting factors. This reflected the late autumn rain which came in May and was insufficient to increase production, as 0.1 m soil temperature had dropped to 7 °C. Tonmukaykul (2009) stated the same findings for the 2009 autumn, with a decrease in soil temperature to 7.2 °C resulting in reductions in leaf appearance rates, leaf area index development and photosynthetic rate, which in turn limited mean daily growth rates.

5.2 Temperature

Seasonal fluctuations in mean daily growth rate are caused by changes in temperature and water. To summarise the effects of temperature, thermal time was calculated (Tb = 0 ° C). In spring, the relationship between accumulated yield and thermal time was linear and differed between pastures, despite the differences in daily growth rates (Figure 4.2). Moisture was not a limiting factor and therefore the highest growth rates occurred within this season. Growth rates ranged from 3.1 for CF/Wc to 5.7 kg DM/°Cd for CF/Sub (Figure 4.1) and the pastures started to grow at 200 °Cd, after 1 July 2009, which equated to August. This suggested that pasture production in winter was not linearly related to temperature. This can reflect low pasture covers during winter, suggesting autumn grazing removed herbage below the critical leaf area index. This follows the same pattern which took place in 2008 (Tonmukaykul 2009). Fasi *et al.* (2008) reported a similar lag phase on dryland pasture production in Lees Valley, Canterbury. Further research on the predictive behaviour of the apparent lag phase and underlying mechanisms would benefit dryland farmers.

Lucerne grew 4.2 kg DM/ha/°Cd in spring, which was lower than CF/Sub. Lucerne has a reputation for slow growth during initial spring periods, but higher summer growth rates (Mills *et al.* 2008) and it grew at an almost linear rate for a longer duration than other pastures (1200 °Cd) after 1 July 2009. This resulted in the highest spring yield of 11120 kg DM/ha. The defined spring period was longer for lucerne than grass based pastures, concluding on 29/1/2010 compared with 16/11/2009. The additional production of lucerne resulted in high quality feed, which would be more suitable in a dryland farming system for lamb finishing than traditional grass based pastures (Brown *et al.* 2006; Mills *et al.* 2008). The CF/Sub yields in this study support the recommendation that CF/Sub pastures be integrated with lucerne production in dryland systems (Brown *et al.* 2006).

Growth rates were limited over summer due to the onset of water stress, with a deviation from linear growth occurring. Rates declined further during the autumn/winter period due to temperature being a limiting factor. Sufficient rain arrived in May and CF/Sub pastures had higher production than other grass based pastures, due to the germination of subterranean clover (Figure 4.1).

5.3 Water availability and water use efficiency

The plant available water content in the soil profile and root extraction depth influenced the annual WU, and WUE of each pasture treatment (Table 4.1). The mean annual PAWC was 316 ± 24 mm for Year 8 and the mean annual plant water use was 655 ± 22 mm. Lucerne had the greatest annual WUE of 22.6 kg DM/ha/mm, followed by CF/Sub with 16.2 kg DM/ha/mm, because lucerne had a greater dry matter yield (Figure 4.1; Moot *et al.* 2008). Lucerne did not extract more water than the other pastures (Table 3.6). The absolute PAWC was different in all plots throughout the experiment, because of the soil characteristics and gravel layers within the soil profile (Figure 3.2 and Figure 3.3). For example, Plot 5 was a much shallower plot and Plot 2 had deeper soil. The gravel layer responsible for this was apparent at 1.0 m in Plot 5 and 1.5 m in Plot 2. Therefore, the PAWC was 323 mm and 431 mm, respectively (Appendix 2). However, averaged over all replicates, there was no difference in PAWC amongst treatments.

WUE was highest during the initial spring water use period for all pastures, because of lower temperatures and lower vapour pressure deficits than in summer, which meant more water was available for plant growth rather than evaporation. Lucerne had the highest spring WUE of 22.3 kg DM/ha/mm and CF/Sub had 20 kg DM/ha/mm. The WUE of pastures is typically highest in spring (Moot *et al.* 2008; Tonmukaykul *et al.* 2009). Tonmukaykul *et al.* (2009) reported a spring WUE of 30 kg DM/ha/mm for lucerne and 18 kg DM/ha/mm for CF/Sub. The WUE of lucerne was significantly lower in Year 8 than Year 7 which was probably due to thinning of the lucerne stand and weed invasion. Thus, more of the water used and available to the lucerne may actually have been used by weeds.

The CF/Sub pastures had a higher WUE in Year 8 than Year 7 due to a greater water extraction and similar yields. WUE in the initial period was 306 ± 16 mm in Year 8 compared with 223 ± 19 mm in Year 7, because of less plant available water. For example

PAWC was between 268 for RG/Wc and 304 mm for CF/Wc in Year 7 and between 299 for CF/Cc and 340 mm for CF/Wc in Year 8. This was possibly due to different replicates being measured for water use. In Year 7, replicates 1, 2, 3, and 4 were measured, but in Year 8 replicates 1, 2, 3 and 5 were measured to decrease the influence of tree roots from a shelter belt on the results.

During the secondary period, water use was lower than that in the initial period (Figure 4.3) because water stress started to limit pasture production. The WUE of the grass based pastures ranged from 4.3 (RG/Wc) to 8.7 kg DM/ha/mm (CF/Bal) (Table 4.1). Lucerne had the highest WUE during the initial period with 13 kg DM/ha/mm. Water stress had the most significant effects on production during this period with around 50% of the LTM rainfall falling in February, March and April. Lucerne produced more efficiently and was not affected by water stress to the same extent. However, its WUE would possibly be lower due reduced DM production and the focus on partitioning carbohydrates into root reserves for the following spring (Kalista *et al.* 2006). The WUE of grass based pastures reduced during the secondary water use period possibly due to reduction in herbage nitrogen concentration of the grass and clover components. For example, the N content of cocksfoot ranged from 3.0 to 3.2% in spring (Table 4.4) and dropped to between 2.1 and 2.6% in summer (Table 4.5). However, the N concentration of RG/Wc increased from 2.1% in spring to 2.6% in summer. By May and June, sufficient rain fell (153 and 109 mm) but temperature had become the limiting factor (Table 3.4) on pasture production and therefore WUE. Soil temperature dropped from 10 °C in May to 6.3 °C in June.

5.4 Insect populations

Insect pest populations were measured to determine whether pest populations could be contributing to the results observed during the trial period. Clover root weevil, Argentine stem weevil, Sitona weevil and grass grub were all found to be present on the study site. The weevils were measured for the first time in 2010.

During the trial it was observed that plots/treatments containing cocksfoot had significantly higher ASW densities than those containing ryegrass or no grass at all. Perennial ryegrass contains an endophyte (*Neotyphodium lolii*) that confers insect resistence to the host plant (Prestidge *et al.*, 1986). Unlike ryegrass, cocksfoot does not contain an endophyte and hence is a suitable host for ASW. However, with the ryegrass component of RG/Wc pastures diminishing, the weevils may have been feeding on the cocksfoot as an alternative food source. The annual sown grass component in RG/Wc pastures was only 13% (Table 4.3), whereas cocksfoot was abundant with between 47% and 57% in cocksfoot based pastures. There is other evidence of ASW feeding on cocksfoot when ryegrass is not abundant (Prestidge *et al.* 1986). This may explain why populations were higher in CF/Sub and CF/Wc pastures at each measurement date (Figure 4.4). However, despite significantly greater ASW densities, results reported on in Section 4.1 showed that dry matter production from pastures containing cocksfoot was greater than those containing ryegrass. This may be because the density of ASW adults in cocksfoot pastures did not reach levels that result in a reduction in dry matter production. Previously Prestidge *et al.* (1986) reported that summer cocksfoot production was possibly not readily affected by populations of below 100 weevils m^{-2}. ASW densities within this experiment only reached a maximum of around 60 weevils m^{-2} and therefore may not have been high enough to result in significant damage.

The ASW population densities measured during the trial period fall within reported ranges for Canterbury population densities of ASW. For example, Goldson *et al.* (1998) found up to 400 weevils m^{-2}. Conversely McNeill *et al.* (2001) found populations on a Lincoln dairy pasture to be less than 63 weevils m^{-2} over the duration of the entire study. Therefore, it appears from the results that ASW populations were primarily driven by the presence of suitable host material in the form of cocksfoot. It is also possible that the resultant ASW populations were having a minimal effect on cocksfoot dry matter production. Results from the trial suggest that cocksfoot is a suitable grass species for use in Canterbury dryland farming systems. Particularly as in Year 8 of this trial, it was still persistent and out producing the perennial ryegrass pasture.

Clover root weevil was first recorded as being present in the vicinity of the ‘MaxClover’ trial area in spring of 2009 and this was reflected by the low density of CRW adults on the trial site. It is most likely that the adult CRW observed on the trial site resulted from individuals that moved onto the plots from surrounding areas during the summer of 2009/2010. This movement is most likely to have occurred via flight dispersal that occurred between December 2009 and April 2010 (Hardwick 2010).

Populations were consistent but extremely low ranging from 2 to 5 weevils m^{-2} across the three measurement periods. CF/Sub and CF/Wc either had higher or equal CRW populations as RG/Wc and lucerne had no CRW present. CRW larvae sampling in August and September produced significant results (Figure 4.6) and larvae were present in CF/Wc and RG/Wc pastures. Volunteer white clover within the non white clover sown pastures during egg lay in summer could contribute to these results (Table 4.5) as CRW populations are directly related to white clover abundance (Gerard *et al.* 2007). CF/Wc had 11% annual sown white clover whereas CF/Sub only had 3% volunteer white clover. There is other evidence of CRW larvae feeding on annual clover, but preference is for white clover if it is present (Crush *et al.* 2007). The white clover levels in the present study are possibly proportional to the CRW populations measured, as white clover was not abundant in the pastures so there was not an adequate feed source for a higher population.

Previous studies examining CRW's phenology have used a combination of wet sieving and blower vacuum sampling. Sampling technique may have affected the accuracy of weevil populations as smaller instar CRW larvae could have been missed if they were present. A wet sieving floatation technique would have been a better method if time and money allowed. Low rainfall would have impacted on the CRW larval populations (Willoughby & Hardwick 1999). From November to May, 165 mm fell whereas the long-term mean was 290 mm for that period. This possibly caused a low larval recruitment and death of larvae. However, 262 mm of rainfall fell in May and June, but by this time soil temperature could have been limiting and inadequate for larval hatching. Inadequate environmental conditions result in flight muscle development in the reproductive female (Gerard *et al.* 2010). Therefore, it is possible that flights took place in summer through until March leaving a low population of adults to lay. This took place before sampling and could explain the low populations actually measured. The time period over which the CRW populations were measured was short in this study. To improve this, sampling could have been undertaken monthly for 12 months, as most weevil studies require a full season's data due to the nature of insect population behaviour. Therefore, there were low CRW populations due to a very dry period, also low egg lay and low egg survival due to environmental conditions.

Sitona weevil was found to be present in the lucerne stands but only at very low populations of less than 9 weevil m^{-2}. These numbers were not enough to do significant damage (Kain & Trought 1982). There were no Sitona weevils found in the other pastures measured. Low populations, compared with in the 1980's, are possibly due to plant breeding and the biological control by *Microctonus aethiopoides*.

Grass grub was present in all pastures across all three years (Figure 4.7). Populations reached 197 grubs m^{-2} in CF/Bal in July 2008 and 128 and 208 grubs m^{-2} in RG/Wc in August 2009 and June 2010, respectively. Langer (1973) stated that control measures should be undertaken when grass grub numbers reach threshold levels of between 100 and 200 grub m^{-2}, which suggests the grubs should have been controlled in this experiment. This may have affected populations for the subsequent sampling and also pasture composition and dry matter production.

Hardwick (2004) stated that grass grub will feed on both grass and clover and this could explain why there is no definite trend of pasture preference and why there is a fluctuation in grass grub population between seasons. Fraser (1994) stated that grass grub populations are related to botanical composition. In the present study, sown grass and legume species generally decreased each year. For example, there was 19% perennial ryegrass in RG/Wc pastures in 2008/2009 and 13% in 2010. Grass grub populations have maintained or increased over the past season. Therefore environmental factors may be are controlling the population. Hardwick (2004) found that drainage and shelter-belt position affects grass grub populations and that population's increase with drainage. The soil type of the 'MaxClover' experiment is Templeton silt loam and is relatively free draining. Therefore, the experimental site was a suitable environment for grass grub. Population was also increased with shelterbelt presence (Hardwick 2004). This is due to flight behaviour at dusk. The 'MaxClover' experiment has shelterbelts on the east, south and west sides of the trial area. Therefore eggs will be laid by the female immediately after emergence but also a small proportion are laid after flight. The beetles fly towards the horizon and are drawn to the top of the shelterbelt. A primary instinct is to find foliage to feed on (Hardwick 2004). So in theory, beetles will lay around the tallest vegetation they find on their flight which could be the shelterbelts around the trial site and then lay the remainder of their eggs. This could contribute to the fluctuating population of grass grub within the 'MaxClover' experiment. Lucerne had the lowest population of grass grub across the three years.

5.5 Method of measuring botanical composition

In summer, the sown grass component of cocksfoot based pastures was similar for both the separation and Botanal methods (Table 4.5 and Table 4.7). The exclosure cage method found cocksfoot components to be from 46% (CF/Cc) to 58% (CF/Wc) cocksfoot. The Botanal method found the cocksfoot component to be between 54% (CF/Cc) to 64% (CF/Bal). The sown legume component for the Botanal method was slightly higher possibly due to operator error. For cocksfoot based pastures the Botanal method also represented the quantity of annual grasses to be valued between 18 (CF/Sub) and 25% (CF/Wc) respectively. The exclosure cage method valued annual grasses lower than the Botanal method, with the exception of CF/Sub at 26%. This could again be explained by the operator's decision when ranking, as it would have seemed like there were a high proportion of annual grasses within the quadrats but the dry weight would not correspond to this. The weed component in RG/Wc plots was similar for the Botanal method (12.8%) and the exclosure cage method (12%). Sown legume components for lucerne are also very different with 53% (± 5.9%) for the Botanal method and 89% (± 5.1%) for the exclosure cage method. This was potentially due to operator ranking decisions and visual estimations of dry matter not corresponding to quadrat actual values.

Autumn/winter botanical composition measurements resulted in both methods having some similarities with the cocksfoot component of pastures, notably CF/Wc with 80.3% (Botanal) and 79.6% (exclosure cages) (Table 4.6 and Table 4.8). Other Botanal values for cocksfoot were between 69% and 80%, compared with 61% and 79% for the exclosure cage method. The dicotyledonous weed component measured higher in the Botanal method, as well as some sown legume components, apart from CF/Cc which resulted at 0.2% sown legume by both methods. This would be expected as visually they cover a large area.

The main explanation for differences between the two methods is down to operator error and operator estimates regarding the dry weight of different species. The system of cumulative ranking (Jones & Hargreaves 1979) was introduced to the Botanal method for plots which were dominated by one species; however this will still differ depending on the operator measuring. Jones and Hargreaves (1979) state this is because there is no consistent relationship between ranking species and the dry matter yield. For example, quadrats dominated by a Species A are not constantly lower or higher yielding than

Species B. Another issue is the high yielding areas of a pasture. There may be higher yielding areas of cocksfoot or perennial ryegrass and lower yielding areas of legume and as the DWR allocates equal ranks (and weights) to all quadrats, legumes can often be over estimated. This is evident from the results for this experiment (Table 4.7 and Table 4.8).

The Botanal method is a quick method which allows the botanical composition of pastures to be estimated by dry weight ranking, easier than by completing pasture cuts. It saves time and equipment and achieves a non-destructive (Waite 1994) representative result from each plot. Waite (1994) stated that using the Botanal method took 10% of the time it would take for cutting the same number of quadrats. In the ‘MaxClover’ experiment, only one quadrat per plot was cut for hand sorting and this was not representative of the whole plot, whereas 20 quadrats were measured for the Botanal method. There was found to be a reasonably good correlation between estimated and cut dry matter values for both sampling dates. However, an important issue was the diversity in yield between species within different areas of the plots. This may be an issue in a dryland situation where urine nitrogen patches, stock camps and tracking are evident in nitrogen deficient pastures with cocksfoot.

An improvement to correlate the two methods would be to allocate different calibration sets for different pastures (Waite 1994). Overall, both methods achieved portraying the change in yield and botanical composition over time. Regardless of the discrepancies between the two methods, the Botanal method was sufficient to determine the presence and relative abundance of species components in the swards.

5.6 Nitrogen status

Herbage nitrogen concentration influenced the WUE of the six pastures, because N concentration affects photosynthetic efficiency per unit leaf area and higher photosynthesis rates are gained per unit of water lost at higher N contents (Peri *et al.* 2002b), which results in high dry matter production.

Botanical composition also influenced the nitrogen status of the pastures, because the legume component affected the total N yield (Section 4.6). Table 4.3 shows that the contribution of the legume component to the total yield of lucerne was much greater than that of other grass based pastures. Annual botanical composition results show that lucerne has a legume component of 84%. This resulted in an annual N yield of 421 kg N/ha. This is slightly lower than in the 7th year, where the annual legume component of lucerne was 87% and N yield was 471 kg/ha (Tonmukaykul 2009). CF/Sub pastures had the highest sown legume component of all grass based pastures with 16% (Table 4.3) and an annual sown species N yield of 216 kg N/ha (Table 4.9). Year 7 had a similar annual sown species N yield of 188 kg N/ha for CF/Sub. RG/Wc pastures had an annual legume content of 11% and an annual sown species N yield of 65 kg/ha. These results emphasise the continued decline of the ryegrass component of RG/Wc pastures and the dominance of cocksfoot in recent years (Mills *et al.* 2008). Moot *et al.* (2008) support the fact that herbage N concentration influences WUE and states that higher herbage N content gives heed to higher photosynthetic ability and higher dry matter yields.

In spring, N% for sown grass components of cocksfoot pastures was between 2.2% and 3.2% (Table 4.10). Some of these values are consistent with those by Peri *et al.* (2002b) and are within the specified range for cocksfoot to maintain greater than 80% of the maximum photosynthetic capacity. Values which fall below 2.6% result in compromised photosynthesis rates. For example, the RG/Wc pastures had an N concentration of 2.2% for ryegrass and a sown grass N yield of 12.7 kg N/ha. Lower N concentrations would correlate with lower quality pastures at that time of the season, due to reproductive seed heads which contain more structural components. It also suggests that N from soil mineralisation from the legume component of the pasture was not adequate to maintain optimum photosynthesis rates (Peri *et al.* 2002b) and also water use efficiency (Tonmukaykul *et al.* 2009). The influence of low summer rainfall may have also affected N uptake. Rainfall in December was 37 mm which was 75% of the LTM and in February, March and April was 50% less than the LTM. Soil drying may not have occurred in cocksfoot based pastures due to more root length in the top 0.25 m of the soil (Evans 1978) which results in a larger surface area for water and nutrient uptake, hence higher summer N concentrations. When the soil started to dry, the uptake of N may have been limited in ryegrass based pastures. With this explanation, WUE values in RG/Wc pastures were not expected to match that of cocksfoot based pastures. Invasive weed grasses within the RG/Wc plots (barley grass and *Bromus* spp. primarily) were producing similar yields as the cocksfoot based pastures. Dicotyledonous weeds in the RG/Wc pasture contributed 2.2 kg N/ha to the total N yield of 12.7 kg /ha. Estimated values were also calculated based on N% of weeds in RG/Wc plots with N yield results less than 1.5 kg/ha.

CF/Sub pastures out performed RG/Wc pastures with the highest annual N yield from the grass based pastures (Table 4.9). This result emphasises the importance of herbage N concentration on WUE in dryland pastures. Fasi *et al.* (2008) stated that pastures are generally N limited in spring and dry matter production responded to N application at this time compared with other seasons. The primary implication of N deficiency in plants is reduced leaf area. Many species will adjust leaf area to maintain N concentration and photosynthesis. This explains why most results within this study are between 3% and 4% over the course of the season. Therefore, herbage N concentration does not reflect whether pastures would respond and benefit from N fertilizer application.

The herbage quality of feed on offer in dryland farming systems is directly related to the legume component of the pasture (Litherland & Lambert 2007). The increase in water use efficiency of some pastures is indirectly related to each unit of water used producing more dry matter. This is important especially during the crucial spring period. In this study lucerne yielded 426 kg N/ha during its extended spring period until the end of January. All other grass based pastures were being affected by water stress already. Higher values in lucerne and CF/Sub pastures reflect the importance of adequate uptake of soil N and added inputs of N in farming systems. Spring N can influence dry matter production and water use efficiency of pastures (Fasi *et al.* 2008) whether it is readily available in the soil or applied as N fertilizer. This optimises water use in dryland environments where soils have limited soil water storage capacities.

5.7 General Discussion

All the pastures investigated in this study may have a role in dryland farming systems but must be fitted accordingly.

The poor performance of perennial ryegrass and white clover in dryland farming systems indicates that it is not a suitable plant species for this environment (Mills & Moot 2010). Results from the eight years of the ‘MaxClover’ experiment give indications that in a commercial farming system that perennial ryegrass and white clover pastures may have been renewed by Year 5. This is due to the lack of persistence of these species and the level of annual grass and broadleaf weed invasion that occurred. The cocksfoot pastures sown grass component declined over time but at a much slower rate. This will typically continue to decline and will potentially need renewed in the next few years, depending on further weed invasion and production figures. Year to year variability throughout this experiment is due to environmental factors and not management.

Results from this study back up suggestions that alternative species can be used to increase production and persistence. These suggestions are not new and have been in portrayed to dryland farming communities for a number of years.

Despite experimental results, species other than perennial ryegrass and white clover have not been widely adopted over the past decade. However, recently there has been more use of lucerne in dryland farming systems as shown by increased seed sales (Kenny 2010) and farmer comment (Avery *et al.* 2008). There has been a positive response to the incorporation of lucerne by dryland farmers as a result of relevant pastoral research (Moot *et al.* 2003) and technology transfer. Within the research community there was a lot of emphasis on lucerne in the 1980's but several pests and diseases plus inflexible management limited its adoption. These have largely been overcome and there is resurgence in lucerne grazing management. Recent emphasis has also focused on other dryland pasture species and these have also begun to receive farmer attention. Grigg *et al.* (2008) has increased pre-weaning lamb growth rates on hill country in Marlborough through managing subterranean clover correctly. This has allowed a sward clover content of over 50% in spring and an increase from 258 g/head/day in 2001 to 350 g/head/day in 2007. These early adopting farmers have seen profitability increase and are now involved in spreading information to the younger generation. This could benefit within farming communities as farm succession takes place and there is more awareness around technology transfer and positive attitudes towards improving farm systems.

The use of alternative species within dryland farming systems may take more investment to show positive results but long term increases in productivity and pasture persistence may accelerate adoption. Current forage systems need to be re-evaluated to incorporate new pastures or lucerne into them to compliment current practises. To encourage rapid adoption information uptake and transfer are important for dryland farming communities throughout New Zealand. In the absence of independent advisors the agribusiness sector has a role to play in accelerating adoption. Current suspicion between farmers and the agribusiness sector must be overcome to develop transformational change. The follow up for 12 months after sowing is crucial for the success of a pasture or crop. This indicates a need for more effort to support farmers by the agribusiness sector, including agronomists, merchants and sales people.

Without a strong network of support, the key management requirements of alternative pasture species may be misunderstood. The potential loss of confidence in a species, as has occurred for Caucasian clover, can then result, which may take a further generation to overcome. Thus, close alignment between research, extension and on farm application are required to improve the potential for success of specialist dryland pastures.

6 Conclusions

1) Lucerne had the highest annual yield of 12880 kg DM/ha and the highest annual WUE of 23 kg DM/ha/mm. Dryland farmers should maximize the potential of lucerne within dryland farming systems.

2) Of the grass based pastures, CF/Sub pastures produced the highest annual yield of 9460 kg DM/ha/y and had the highest annual WUE of 16 kg DM/ha/mm. Subterranean clover should be used as the main pasture legume within a cocksfoot based pasture to increase dryland pasture production. In summer moist years, the inclusion of white clover may be beneficial.

3) ASW, CRW, Sitona weevil and grass grub were present in all treatments but were not at damaging levels.

4) Farmers should make use of cocksfoot as the main pasture grass on farm for persistence and ASW tolerance, rather than perennial ryegrass.

5) Lucerne had the highest total annual legume component (84%) which resulted in a N yield of 462 kg N/ha/y. This was probably the reason for its high water use efficiency.

6) CF/Sub pastures had a total annual legume component of 18% and produced an annual N yield of 216 kg/ha. Based on the results from this study, dryland farmers could use inorganic nitrogen in spring, to maximise water use efficiency and yield when pastures are nitrogen deficient.

7) Annual weed grasses were 62% of the total dry matter in RG/Wc pastures and contributed 48 kg N/ha/y. These pastures were probably beyond their productive best in Year 5.

8) Stronger relationships within the farmer-agribusiness-research nexus are required for positive results with new pasture species for dryland farming systems.

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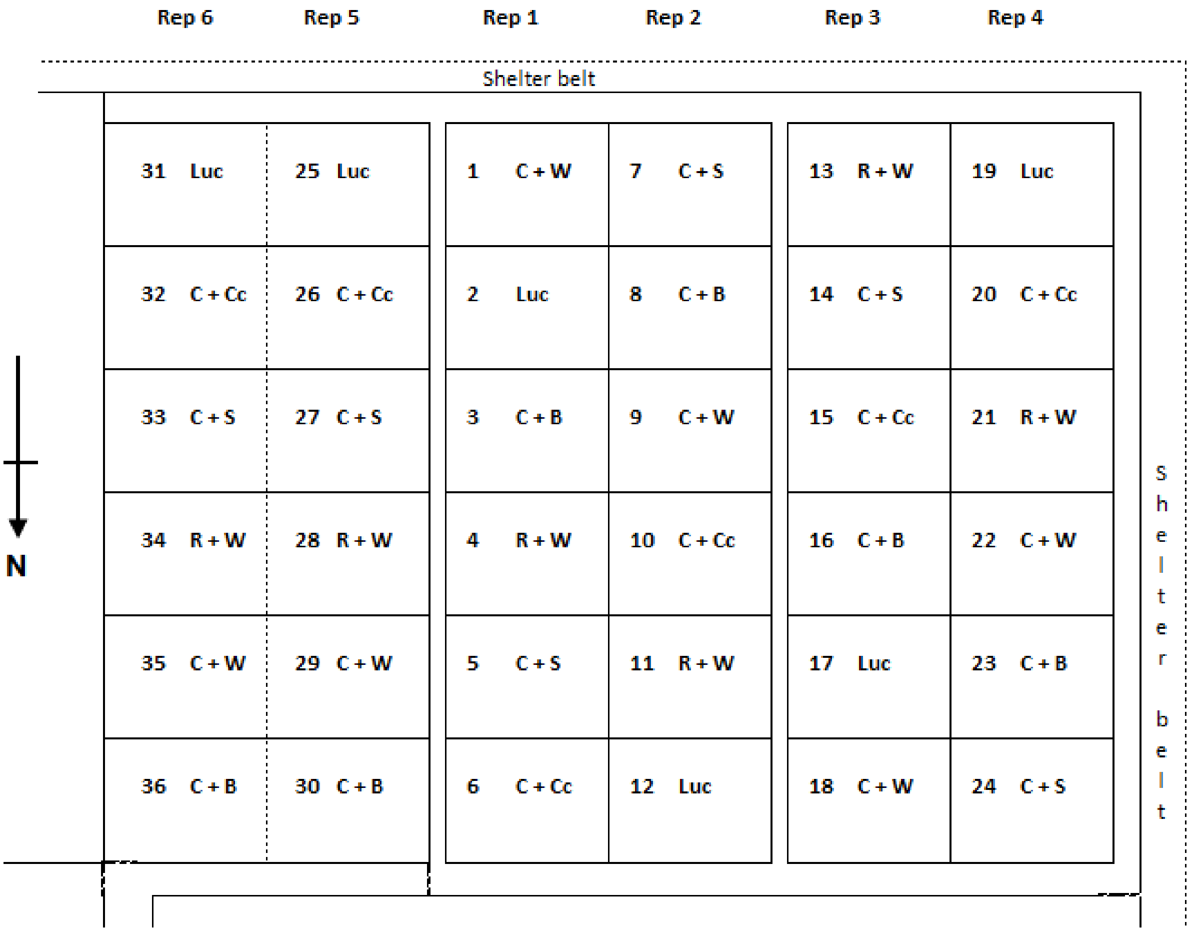
9 Appendices

Appendix 1 Layout of the plots in the Lincoln University ‘MaxClover’ Grazing experiment established in 2002.



Rep 6	Rep 5	Rep 1	Rep 2	Rep 3	Rep 4
31 Luc	25 Luc	1 C + W	7 C + S	13 R + W	19 Luc
32 C + Cc	26 C + Cc	2 Luc	8 C + B	14 C + S	20 C + Cc
33 C + S	27 C + S	3 C + B	9 C + W	15 C + Cc	21 R + W
34 R + W	28 R + W	4 R + W	10 C + Cc	16 C + B	22 C + W
35 C + W	29 C + W	5 C + S	11 R + W	17 Luc	23 C + B
36 C + B	30 C + B	6 C + Cc	12 Luc	18 C + W	24 C + S

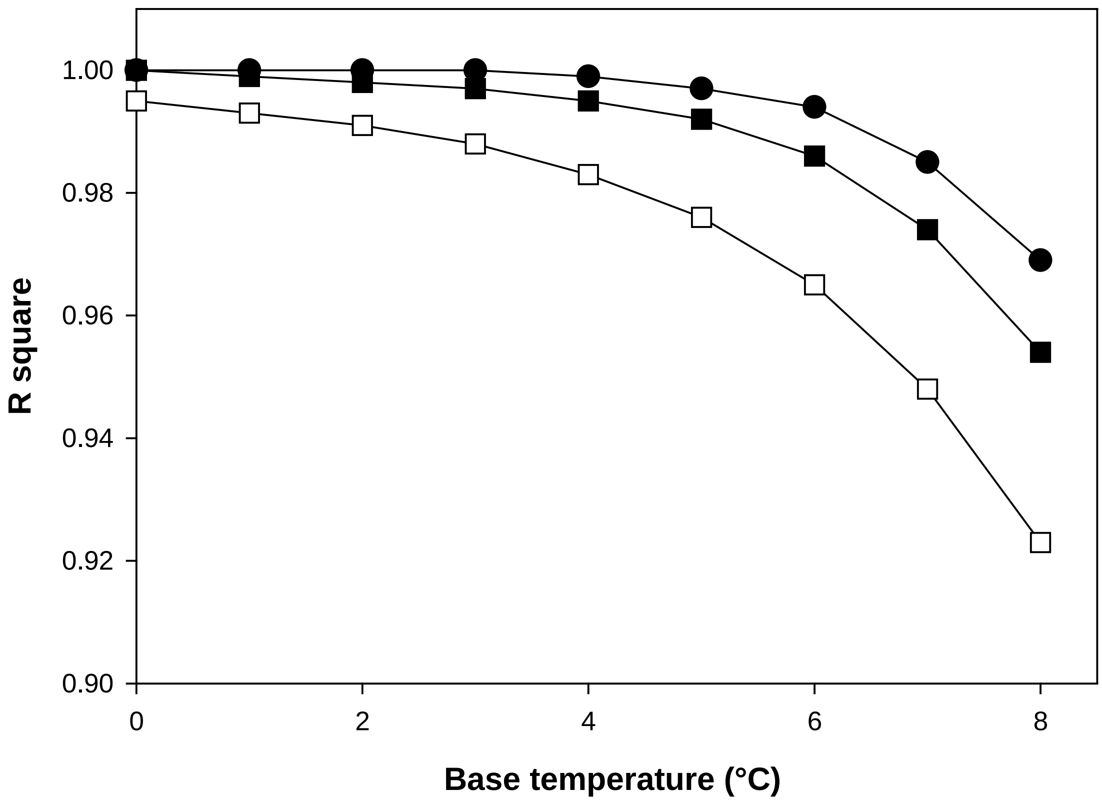
Appendix 2 Values of drained upper limit (DUL) (mm), lower limit (LL) (mm) and plant available water content (PAWC) (mm), of plots from Reps 1, 2, 3 and 5 from 1/7/09 to 30/6/10 at Lincoln University, Canterbury, New Zealand.

Depth (cm)	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6	
	LL	DUL	LL	DUL	LL	DUL	LL	DUL	LL	DUL	LL	DUL
10	6.7	33.2	9.0	32.8	6.6	33.9	7.4	34.2	6.8	33.5	6.4	34.1
25	8.2	31.7	9.0	29.6	7.4	27.4	10.5	31.8	9.6	29.6	7.2	30.7
45	8.7	26.8	6.6	25.2	5.9	20.2	9.4	27.5	10.7	30.9	8.8	26.1
65	6.7	25.1	9.8	29.5	10.6	28.7	8.9	27.6	11.6	28.4	5.5	16.4
85	5.1	23.3	7.9	35.7	10.6	30.6	6.4	22.8	15.0	31.5	5.8	20.6
105	4.8	25.4	6.0	31.2	5.6	21.1	7.4	16.7	8.9	17.1	6.3	13.3
125	5.1	16.4	5.3	25.8	8.1	22.3	8.3	15.1	8.1	14.1	7.0	11.8
145	6.1	10.7	5.3	12.4	20.3	31.4	9.7	24.0	9.7	14.9	8.0	12.2
165	6.2	14.3	5.4	11.5	9.7	15.8	9.2	15.9	11.4	15.7	8.0	11.3
185	6.6	11.9	6.2	11.7	8.6	14.0	9.4	14.7	10.9	15.5	7.8	11.6
205	7.5	11.8	6.3	12.5	9.2	14.5	11.3	17.1	11.8	18.7	8.3	11.5
225	8.2	12.3	6.7	12.8	9.5	13.9	12.3	17.9	9.9	14.8	8.4	11.6
PAWC (mm)	375		431		372		357		323		284	

Depth (cm)	Plot 7		Plot 8		Plot 9		Plot 10		Plot 11		Plot 12	
	LL	DUL	LL	DUL	LL	DUL	LL	DUL	LL	DUL	LL	DUL
10	7.2	33.9	6.5	32.8	5.0	32.0	6.3	34.1	7.2	33.6	6.4	30.3
25	10.4	30.7	9.1	31.0	9.6	30.9	8.8	31.9	10.4	32.9	8.9	28.9
45	12.3	30.9	10.7	31.9	11.3	31.2	9.4	30.1	13.1	30.0	7.9	24.7
65	12.6	27.3	11.1	27.9	11.1	28.9	10.4	28.5	18.2	27.5	8.8	27.8
85	8.9	26.5	13.4	28.8	13.5	30.3	8.1	27.5	26.9	32.0	4.5	15.5
105	6.6	20.6	14.9	29.1	8.1	22.4	7.0	16.6	23.8	35.5	5.0	17.2
125	6.7	13.6	7.9	13.7	6.9	15.3	7.2	14.9	22.9	30.6	6.3	12.1
145	7.4	14.5	8.5	14.5	8.3	15.4	6.6	12.6	7.6	12.0	6.3	12.9
165	7.3	13.6	8.6	13.9	12.7	22.4	9.8	17.2	7.5	11.2	6.5	13.3
185	7.3	13.0	9.2	13.7	7.7	11.5	10.4	16.9	6.8	11.1	6.3	11.4
205	7.6	13.4	8.5	13.3	8.4	12.9	9.6	15.9	5.3	10.0	6.5	11.6
225	8.3	14.8	6.0	8.6	7.8	12.2	9.1	15.4	7.4	10.4	6.3	11.5
PAWC (mm)	346		333		356		365		278		317	

	Plot 13		Plot 14		Plot 15		Plot 16		Plot 17		Plot 18	
Depth (cm)	LL	DUL	LL	DUL	LL	DUL	LL	DUL	LL	DUL	LL	DUL
10	6.0	32.0	6.3	34.0	6.7	33.5	6.6	32.9	7.9	31.5	6.4	33.8
25	6.8	25.6	8.7	30.2	7.8	29.2	7.8	29.3	7.8	25.5	7.6	28.0
45	5.4	20.6	5.3	24.7	7.2	27.5	6.7	24.4	6.5	17.2	5.7	21.1
65	5.1	23.6	5.3	22.0	8.4	24.1	8.1	25.8	8.7	29.7	6.0	29.3
85	5.2	22.0	6.4	23.7	6.6	12.2	6.7	12.0	6.6	13.4	10.9	34.0
105	5.1	20.4	10.0	29.8	7.7	12.7	7.6	14.5	6.0	11.3	8.0	19.1
125	5.6	22.7	18.6	29.6	8.9	14.3	8.4	14.4	5.9	12.1	6.8	12.1
145	5.6	20.4	26.7	33.1	8.6	12.5	9.0	14.6	6.2	11.7	7.1	10.9
165	4.9	14.0	29.3	33.7	7.3	11.3	8.9	13.7	6.7	12.0	6.7	9.6
185	5.2	8.9	22.0	29.2	6.7	10.0	9.3	14.3	6.7	12.0	7.1	9.8
205	5.4	8.6	25.4	31.4	6.5	8.9	8.5	12.7	6.3	10.8	7.5	10.8
225	5.4	8.9	10.9	15.0	6.0	8.6	8.8	12.4	7.1	12.9	8.4	12.7
PAWC (mm)	373		372		267		287		271		329	

	Plot 25		Plot 26		Plot 27		Plot 28		Plot 29		Plot 30	
Depth (cm)	LL	DUL	LL	DUL	LL	DUL	LL	DUL	LL	DUL	LL	DUL
10	4.9	28.6	7.7	32.3	5.6	28.5	8.2	32.0	8.1	31.5	8.2	33.1
25	9.2	29.8	9.2	30.8	8.3	27.0	10.1	27.3	10.3	30.7	10.4	28.9
45	8.8	27.3	8.0	26.7	5.6	15.6	9.4	23.4	10.0	30.1	9.2	26.7
65	9.5	30.6	10.1	29.4	5.6	11.0	11.3	28.0	9.7	27.0	12.4	29.6
85	7.2	28.0	10.4	27.7	6.7	10.5	8.9	20.4	8.1	24.0	11.0	25.0
105	5.6	14.7	6.1	11.5	7.5	11.1	7.2	11.4	8.1	22.1	9.7	15.3
125	5.4	9.3	5.9	8.1	9.4	11.4	7.1	9.4	7.6	12.7	8.3	12.7
145	5.4	9.8	8.2	10.6	8.0	10.7	7.8	10.8	8.1	11.5	9.6	13.4
165	4.8	7.3	9.3	12.4	8.5	10.9	9.2	12.1	8.8	12.3	10.5	13.2
185	5.4	7.8	11.0	13.0	8.4	10.7	9.9	12.7	9.1	11.3	9.9	12.6
205	5.9	7.2	9.7	12.4	5.8	7.1	9.0	11.8	9.8	12.6	8.2	9.9
225	5.6	6.7	9.8	11.2	5.2	6.1	9.7	11.2	9.8	11.4	9.1	11.6
PAWC (mm)	298		278		175		236		299		265	



Appendix 3 **The coefficient of determination (R^2) of the regression of dry matter yield against thermal time using different base temperature from 0 to 8 °C for CF/Sub (●), RG/Wc (■) and Luc (□) using 0.1 m soil temperatures at Lincoln University, Canterbury from 1/07/09 to 30/06/10.**

Appendix 4 The regression equations, standard errors of the coefficients and the coefficients of determination for the regression of accumulated dry matter against thermal time in spring, summer and autumn/winter of six dryland pastures at Lincoln University, Canterbury. Full details of the acronyms are given in Table 3.1.

	Spring X-intercept	
Treatment	Equation	R^2
CF/Sub	$x = 1133 \pm 67.20 \div 5.7 \pm 0.08$	1.00
CF/Bal	$x = 905 \pm 40.40 \div 3.9 \pm 0.05$	1.00
CF/Wc	$x = 568 \pm 183.00 \div 3.1 \pm 0.21$	0.99
CF/Cc	$x = 1195 \pm 5.40 \div 4.8 \pm 0.01$	1.00
RG/Wc	$x = 893 \pm 53.40 \div 4.0 \pm 0.06$	1.00
Luc	$x = 978 \pm 747.00 \div 4.2 \pm 0.46$	0.97

	Spring	
Treatment	Equation	R^2
CF/Sub	$y = 5.7 \pm 0.08x - 1133 \pm 67.20$	1.00
CF/Bal	$y = 3.9 \pm 0.05x - 905 \pm 40.40$	1.00
CF/Wc	$y = 3.1 \pm 0.21x - 568 \pm 183.00$	0.99
CF/Cc	$y = 4.8 \pm 0.01x - 1195 \pm 5.40$	1.00
RG/Wc	$y = 4.0 \pm 0.06x - 893 \pm 53.40$	1.00
Luc	$y = 4.2 \pm 0.46x - 978 \pm 747.00$	0.97

	Summer	
Treatment	Equation	R^2
CF/Sub	$y = 1.0 \pm 0.18x + 5058 \pm 492.00$	0.91
CF/Bal	$y = 0.9 \pm 0.20x + 3094 \pm 539.00$	0.88
CF/Wc	$y = 1.1 \pm 0.30x + 2557 \pm 839.00$	0.80
CF/Cc	$y = 1.1 \pm 0.30x + 3809 \pm 822.00$	0.82
RG/Wc	$y = 0.8 \pm 0.26x + 3517 \pm 715.00$	0.74
Luc	$y = 1.0 \pm 0.16x + 8702 \pm 577.00$	0.95

Appendix 5 The regression equations, standard errors of the coefficients and the coefficients of determination for the regression of accumulated dry matter against accumulated water use in initial and secondary WUE periods of six dryland pastures at Lincoln University, Canterbury. Full details of the acronyms are given in Table 3.1. Regressions forced through the origin in spring but not summer/autumn/winter.

	Initial water use period	
Treatment	Equation	R^2
CF/Sub	$y = 20.0 \pm 1.5x$	0.98
CF/Bal	$y = 13.2 \pm 1.3x$	0.97
CF/Wc	$y = 11.7 \pm 0.5x$	0.99
CF/Cc	$y = 15.2 \pm 1.2x$	0.98
RG/Wc	$y = 12.1 \pm 0.8x$	0.98
Luc	$y = 22.3 \pm 0.5x$	1.0

	Secondary water use period	
Treatment	Equation	R^2
CF/Sub	$y = 8.2 \pm 0.5x + 3236 \pm 257$	0.97
CF/Bal	$y = 8.7 \pm 0.6x + 1320 \pm 325$	0.98
CF/Wc	$y = 7.0 \pm 0.3x + 2009 \pm 189$	0.99
CF/Cc	$y = 6.7 \pm 0.6x + 3538 \pm 338$	0.98
RG/Wc	$y = 4.3 \pm 0.2x + 3267 \pm 97$	1.0
Luc	$y = 13.0 \pm 0.6x + 4722 \pm 348$	1.0

Appendix 6 **The initial period accumulated water use (mm) of six dryland pastures in individual plots, at Lincoln University, Canterbury. Full details of the acronyms are given in Table 3.1. Full details of seasons are given in Section 3.2.**

Treatment	Rep 1	Rep 2	Rep 3	Rep 5	Mean	SEM	Significance
CF/Sub	289	285	355	296	306	15.8	0.001
CF/Bal	306	287	298	287	295		
CF/Wc	455	465	448	456	456		
CF/Cc	416	500	428	433	445		
Rg/Wc	442	423	501	427	448		
Lucerne	436	488	470	538	509		

Appendix 7 **The secondary period accumulated water use (mm) of six dryland pastures in individual plots, at Lincoln University, Canterbury. Full details of the acronyms are given in Table 3.1. Full details of seasons are given in Section 3.2.**

Treatment	Rep 1	Rep 2	Rep 3	Rep 5	Mean	SEM	Significance
CF/Sub	355	383	382	286	351	15.2	0.001
CF/Bal	350	428	334	345	364		
CF/Wc	186	242	238	219	221		
CF/Cc	164	174	198	211	187		
Rg/Wc	206	241	206	174	207		
Lucerne	182	146	137	111	144		