

**Grazing Management and Pasture Production
of Tall Fescue-Legume Mixtures
In Dryland Pastures**

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Pasture production and composition and liveweight gain of sheep grazing tall fescue-clover and perennial ryegrass-clover dryland pastures at Lincoln, Canterbury was examined in four experiments from May 2008 to December 2010. Four objectives were identified to (i) quantify the pasture production, growth, persistence, composition, (ii) pasture nutritive value and liveweight gain of sheep grazed cultivars of tall fescue, white, strawberry and subterranean clover at high and low P and S fertility, to determine the (iii) effect of time of grazing in autumn on subterranean clover growth, and (iv) effect of spring defoliation management on tall fescue cultivars and perennial ryegrass pastures grown with white and strawberry clover.

Experiment 1 examined the interactive effects of tall fescue cultivar (Continental, cultivar Advance, versus Mediterranean, cultivar Flecha), sown clover species (subterranean clover versus a combination of white and strawberry clover) and soil fertility (high P and S fertilizer versus low fertilizer P and S) on annual and seasonal DM production, botanical composition, plant density and morphology. Annual DM production was greater in Advance (7790 kg DM/ha) than Flecha (6871 kg DM/ha) in year 1 and Flecha (8367 kg DM/ha) than Advance (7547 kg DM/ha) in year 2. Annual DM production of the legume component was greater in subterranean clover pastures than perennial clover pastures in both year 1 (945kg DM/ha v 539 kg DM/ha) and year 2 (1457kg DM/ha v 1042 kg DM/ha). Survival of strawberry clover in perennial clover pastures was poor with a low percentage (< 1 % DM) in pasture after 2 years. The percentage of clover in pastures was generally greater in Flecha than Advance. Annual DM production was

greater at high than low fertility in both year 1 (8734kg DM/ha v 7828 kg DM/ha) and year 2 (7134 kg DM/ha v 6834 kg DM/ha). This primarily reflected greater grass growth at high fertility as legume growth was unaffected by soil fertility.

Experiment 2 examined the interactive effects of tall fescue cultivar (Advance versus Flecha) and soil fertility (high P and S fertilizer versus low fertilizer P and S) on pasture nutritive value and liveweight gain of ewes and lambs in spring and ewe hoggets in autumn. Liveweight gain per head of single lambs grazing with lactating ewes (22 ewes/ha) was 284 g/head/day over a 27 day period in spring of year 1. Liveweight gain per head of twin lambs grazing with lactating ewes (25 ewes/ha) was 258 g/head/day over a 60 day period in spring of year 2. Over the total spring period in each year, there was no effect of soil fertility or tall fescue cultivar on liveweight per head or ha of lambs. This occurred despite pasture growth and feed availability being on occasions greater in Flecha than Advance, and at high than low soil fertility. Liveweight gain per head of ewe hoggets (22 ewes/ha) was greater in Flecha (52 g/head/day) than Advance (14 g/head/day) over a 51 day period in autumn of year 1 but greater in Advance (282 g/head/day) than Flecha (197 g/head/day) over a period of 18 days in autumn of year 2. The different cultivar effects between years reflected the availability of feed in response to summer rainfall at the start of the grazing period as well as pasture growth during the grazing period. The clover percentage was average 20% and 31.2% in spring 2008 and 2009, respectively.

Experiment 3 examined the effects of grazing subterranean clover at the spade leaf, three trifoliate and six trifoliate leaf stages in autumn on seedling populations, seedling survival and DM production of subterranean clover when grown with Advance and Flecha tall fescue cultivars. Seedling death during grazing was greater at the spade leaf (43%) than the three leaf or six leaf (14%) stage. However, because seedling populations were initially high (1326 plants m²), this high death with early grazing simply killed seedlings that would have died for other reasons; and seedling numbers at the start of winter were similar among treatments (619 plants m²). Spring clover DM production was greater at the spade leaf (2834 kg DM/ha) than three leaf

(2573 kg DM/ha) or six leaf stage (2648 kg DM/ha), reflecting greater plant size than any difference in plant population. Delaying grazing until after the three leaf stage will enhance seedling survival when seedling populations are low.

Experiment 4 examined DM production, botanical composition, and plant morphology of perennial ryegrass, Advance and Flecha tall fescue pastures grown with strawberry clover and white clover under continuous stocking and rotational grazing in spring. DM production in the establishment phase was greater in perennial ryegrass (1098 kg DM/ha) than Advance (563 kg DM/ha) or Flecha (503 kg DM/ha). In the first full year, DM production was greater in perennial ryegrass (9417 kg DM/ha) and Advance (9928 kg DM/ha) than Flecha (7559 kg DM/ha). Annual DM production of legume was greater in white clover (1638 kg DM/ha) than strawberry clover (670 kg DM/ha). Persistence of strawberry clover was poor with the plant population declining from 145 plants/m² at start to 9 plants/m² after 20 months. Although taproots were larger and lasted longer in strawberry clover than white clover plants, strawberry clover plants had fewer nodal roots, which appeared to limit persistence under grazing. There was no effect of continuous stocking versus rotational grazing on DM production or persistence of white and strawberry clover.

The study showed that pastures based on either Continental or Mediterranean tall fescue cultivars are capable of high DM production in dryland pastures in Canterbury, particularly when grown with subterranean clover. These pastures gave high liveweight gain, which would enable lambs to be finished in spring before the onset of summer dry conditions. Under the conditions of this study, there was little detectable effect of tall fescue cultivar on livestock performance, indicating a role of both types of tall fescue for dryland pastures in Canterbury. Strawberry clover persisted poorly under all grazing management, and without breeding for improved nodal root development or revised grazing management guidelines, will not be a suitable legume for dryland pastures.

Keywords: tall fescue, white clover, strawberry clover, subterranean clover, grazing, *Trifolium repens*, *Trifolium subterraneum*, *Trifolium fragiferum*, *Lolium perenne*, *Festuca arundinacea* Schreb. ;syn. *Schedonorus phoenix* Scop., Seedling population, DM production, LWG.

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List of Abbreviations

Abbreviation	Description	Units
3L	three trifoliolate leaf	
6L	six trifoliolate leaf	
a.s.l.	Above sea level	m
ADF	Acid detergent fibre	%
Adv	Advance	
Aut	Autumn	
C	clover	
CT	Continental tall fescue	
CEC	Cation exchange capacity	
CP	Crude protein	%
DM	Dry matter	Kg/ha
DMD	Dry matter digestibility	%
DOMD	Digestible organic matter in dry matter	%
ADL	Acid detergent lignin	%
F	Fertility	
Fle	Flecha	
HF	High fertility	
kg	Kilogram	kg
LF	Low fertility	
LSD	Least significant difference	
LW	Liveweight	kg/head
LWG	Liveweight gain	g/head/d
ME	Metabolisable energy	MJ/kg
MT	Mediterranean tall fescue	
N	Nitrogen	g/kg
NDF	Neutral detergent fibre	%
NIRS	Near infra-red spectroscopy	
P	Phosphorus	
Per	Perennial	
R ²	Coefficient of determination	
S	Sulphur	
SC	Subterranean clover	
SEM	Standard error of the mean	
SL	Spade leaf	
Spr	Spring	
StC	Strawberry clover	
Sum	Summer	
T	tall fescue	
t	tonne	
TDR	Time domain reflectometry	
TF	Tall fescue	
USA	United States of America	
WC	White clover	
Win	Winter	
WUE	Water use efficiency	

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Chapter 1

General Introduction

1.1 Background Information

Pastures containing a mixture of grasses and legumes form the basis of low cost animal production systems in temperate regions of the world (Caradus *et al.*, 1995). Legumes provide nitrogen for the pasture through nitrogen fixation, and also provide a forage of high feeding value, reflecting both high nutritive value and intake potential (Waghorn and Clark, 2004). There were many studies that showed that the performance of livestock increases as the proportion of clover in the pasture increases (Hyslop *et al.*, 2000). Therefore, the ability to sustain a high proportion of legume in the pasture is an important goal in pastoral systems.

The most commonly sown pasture in New Zealand has been a mixture of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). These species are particularly suitable in summer moist or irrigated pastures, where under the appropriate fertilizer and grazing management regime, they form a productive pasture of high quality. However, in summer dry conditions (<800 mm rainfall) both may fail to thrive and lack persistence. Waller and Sale (2001) reported the similar situation in summer-dry regions of south-eastern Australia. Brock (2006) indicated that white clover needs rainfall of 40 mm/month for persistence and 60 mm/month for good production. Knowles *et al.* (2003) concluded that white clover is generally not tolerant of water deficit conditions, with poor post-drought recovery.

About 2.8 million hectares of land in New Zealand (10.7% of total land area) receives less than 800 mm of rainfall (Brown and Green, 2003). This includes land on the east coast of the South and North Islands as well as north facing hill country. These areas are consistently prone to summer dry conditions where potential evaporation can be double rainfall. The lack of persistence of white clover and ryegrass under these conditions may be a major impediment to

sheep (*Ovis aries*) performance and farm profitability. Thus, alternative grass and legume combinations are sought to provide persistent pastures, of high quality feed. It is particularly important that these pastures grow in the late winter and early spring period in order to feed lactating ewes and their lambs, and to ensure that lambs are finished before the onset of summer dry conditions.

The purpose of this research was to examine production of herbage and sheep performance from pastures of the perennial grass tall fescue (*Festuca arundinacea* Schreb. ;syn. *Schedonorus phoenix* Scop.) growing in combination with different annual and perennial clovers under a range of defoliation regimes in autumn and spring. Therefore, the research hypothesised that the alternative grass and legume combinations with strong late winter and early spring growth, higher legume content were able to provide adequate and high quality feed to lactating ewes and their lambs.

Compared to perennial ryegrass, tall fescue pastures may have better tolerance of hot, dry summer conditions and may have higher growth rates (McCallum *et al.*, 1992). Tall fescue is also noted as being more tolerant of grass grub (*Costelytra zealandica*) and Argentine stem weevil (*Listronotus bonariensis*) attack than perennial ryegrass (Kain *et al.*, 1979; Prestidge *et al.*, 1986). Tall fescue pastures may also have a higher clover content than perennial ryegrass pastures because tall fescue tillers grow more upright so allowing legumes to better coexist in the sward (Exton *et al.*, 1996).

Most of the tall fescue sown in New Zealand to date has been from the summer-active (Continental) group of cultivars that grow vigorously in summer and moderately in winter. More recently, a second winter-active group (Mediterranean) of cultivars has been released on to the New Zealand market. These have less growth in summer but very strong winter and early spring growth and are suggested to be suitable for summer dry conditions where feed in early spring is highly desirable (Charlton and Stewart, 2006). Summer dormancy is one of the more

important traits that grasses have to adapt to environments where there is little, variable, or no summer rainfall (Norton *et al.*, 2006). There is little comparative information on the production of the two groups of cultivars (Minee *et al.*, 2010), the grazing management required for these two groups of cultivars, and how compatible these different cultivars are with annual and perennial clovers. Therefore, this research was proposed to generate the information on the management of tall fescue pastures in combination with perennial clover and annual clovers.

In terms of increasing the legume content of pastures, one potential strategy is to improve the performance of white clover under water stress (Woodfield *et al.*, 1995). The second strategy, used in parallel or as a complement is to replace or complement white clover with other legumes that have improved water deficit tolerance. One alternative legume to white clover for dryland pastures is the annual legume subterranean clover (*Trifolium subterraneum* L.). By flowering and producing seed before the onset of water deficit, subterranean clover may avoid water deficit conditions. It then re-establishes itself after autumn rain. Subterranean clover also has greater cool season growth than white clover, so has the potential to provide feed for ewes and lambs in early spring (Brown *et al.*, 2006). For subterranean clover, crucial times in its life cycle are early spring when it is growing rapidly, late spring when it is flowering and producing seeds, and autumn when it is re-establishing itself (Ates *et al.*, 2006). Key questions at these times are how subterranean clover is affected by competition from grasses and the intensity of grazing management? For example, on one hand a winter-active tall fescue may be more competitive with subterranean clover in early spring. On the other hand, the summer dormancy may provide more space and less competition at the time of re-establishment of the subterranean clover in autumn.

A further legume that has shown some potential for dryland pastures is strawberry clover (*Trifolium fragiferum* L.). The taproot of strawberry clover generally persists longer than that of white clover (Frame, 2000). Moreover, Hofmann *et al.* (2007) indicated strawberry clover

showed greater water deficit resistance in a number of key parameters (higher water status, photosynthesis, transpiration) compared to white clover. However, Hofmann *et al.* (2007) stressed the lack of information on the performance of strawberry clover under grazing and need for field studies to test the use of strawberry clover as a complement or alternative to white clover in grazed pastures.

1.2 Research aim and objectives

The aim of this research was (i) to compare pasture production and sheep performance of dryland pastures that are based on tall fescue grass cultivars growing with annual and perennial legumes, and (ii) to develop grazing management guidelines in spring and autumn that optimise grass-legume mixture pasture production and persistence, and sheep performance. A series of research was conducted to address four main objectives:

1. To quantify pasture production, growth, persistence and composition of winter and summer-active tall fescue pastures growing with white, strawberry and subterranean clover at high and low phosphorus (P) and sulphur (S) fertility.
2. To quantify pasture nutritive value and liveweight gain of sheep grazing winter and summer-active tall fescue pastures growing with white, strawberry and subterranean clover at high and low P and S fertility.
3. To determine the effect of time of grazing in autumn on subterranean clover growth in winter-active and summer-active tall fescue pastures.
4. To quantify the effect of spring defoliation management on winter and summer-active tall fescue and perennial ryegrass pastures grown with white and strawberry clover.

1.3 Thesis structure

The thesis consists of seven chapters and the outline of the thesis structure is shown in Figure 1.1. The first three objectives (1-3) were carried out in a grazing experiment where winter and

summer-active tall fescue were sown in combination with annual and perennial clovers under low and high phosphorus (P) and sulphur (S) fertility. Chapter 3 reports on measurements of pasture production, composition and morphology. Chapter 4 reports on measurements of sheep liveweight gain and pasture nutritive value. Chapter 5 reports on the effects of autumn grazing management on tall fescue and subterranean clover from an experiment conducted within the tall fescue-clover-fertility trial. Objective 4 was carried out in a further experiment to explore spring grazing management effects on tall fescue growing in combination with white and strawberry clover and is reported in Chapter 6. Chapter 7 draws studies together provide general guidelines for the successful use of tall fescue-legume combinations in New Zealand pastures.

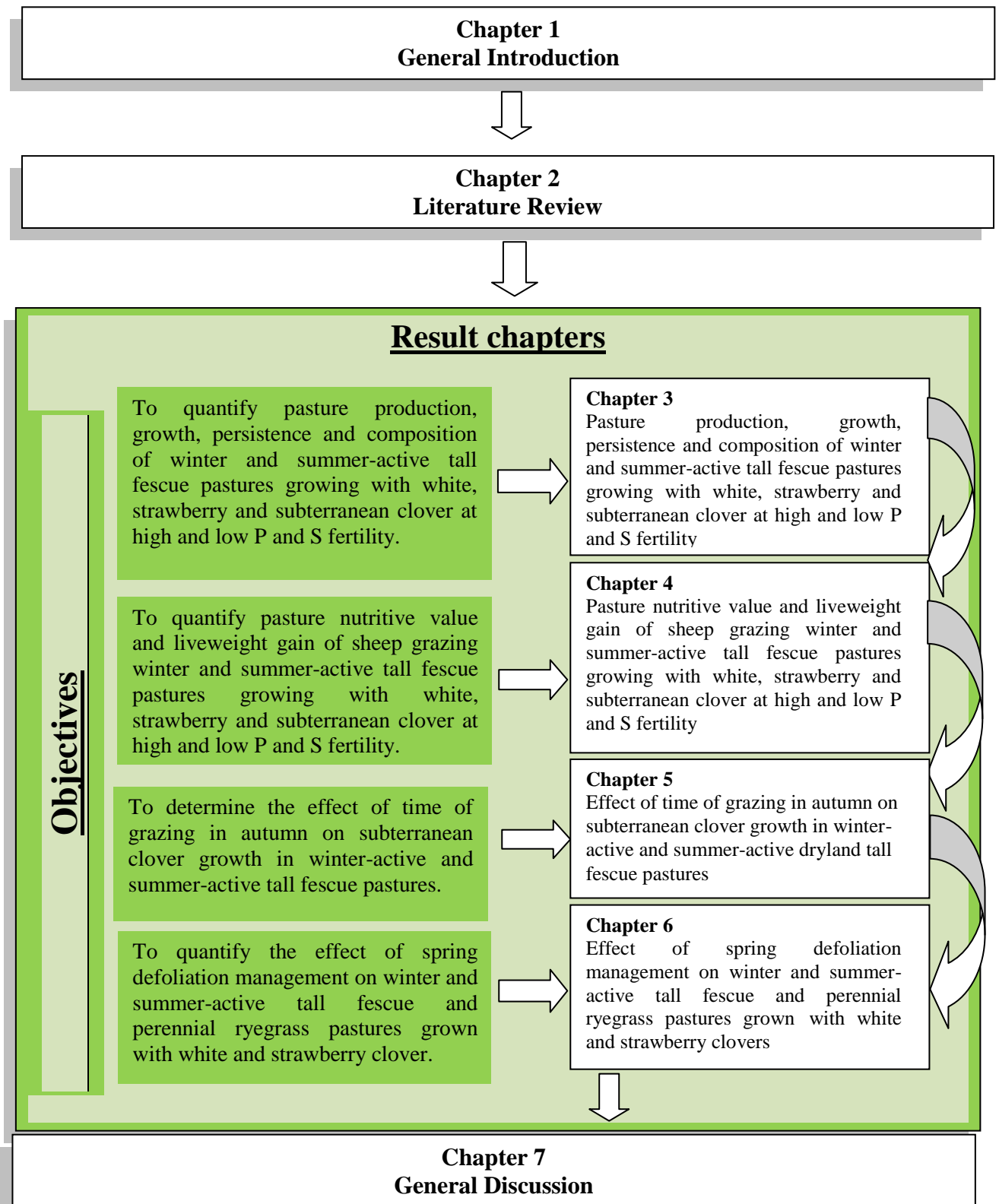


Figure 1.1 diagrammatic representations of the relationship of each chapter to the general aim and main objectives of the research.

Chapter 2

Literature Review

This chapter reviews the literature on (i) perennial and annual clover species and (ii) tall fescue for dryland livestock farming system in temperate environments. Emphasis is placed on response of these species to water stress, grazing management and soil fertility.

2.1 Importance of high legume content in pastures

2.1.1 Nitrogen fixation

The contribution of nitrogen (N) to grazed pasture system via biological N fixation is one of the key reasons that legumes are grown in pastures. Nitrogen is transferred to the grass plant when roots and nodules die, and via animals through urine and dung deposition on the pasture. This improves the dry matter (DM) production of the grass component, and also by increasing the N concentration of the grass makes the grass more preferred by sheep (Edwards *et al.*, 1993). The potential nitrogen fixation rates of white clover are in the range of 600 to 700 kg N/ha/year (Crush, 1987).

However, the presence of mineral N (for example, from N fertilizer) and factors which reduce the abundance of white clover in the pasture (e.g. water deficit, grass competition, pests, disease) result in much lower N fixation rates. Nitrogen fixation rates may range from 17 kg N/ha/year in dry infertile hill pastures to 380 kg N/ha/year in intensively managed summer moist pastures (Crush, 1987). Hoglund and Brock (1987) indicated that in the absence of mineral N, there was a direct relationship between N fixation and legume growth. Thus, to improve N inputs into pasture it is important to increase the legume content of the pasture. Thomas (1992) estimated that legume contents of 20-45% may provide the N requirements of sustainable pastoral systems. But, most of pastures based on white clover contain less than 20% legume (Parsons *et al.*, 2006). In the Winchmore long-term dryland pasture trial located in

Canterbury, New Zealand, clover (mainly subterranean clover) on average made up 30% of the dry matter in the dryland pasture, with variation between years from 14 to 47% (Rickard and McBride, 1986).

2.1.2 Liveweight gain

Legumes are also regarded as high quality forage for livestock in grazed pastures. Hyslop *et al.* (2000) reviewed a series of studies examining liveweight gain of young sheep grazing perennial ryegrass and tall fescue pastures containing different levels of white clover. This summary showed that liveweight gain/head was sensitive to small changes in clover content, rising sharply between 0 and 20% clover content. For tall fescue, liveweight gain/head increased from 100 g/head/day with no clover to 250 g/head/day with 35% clover.

Interestingly, for the same clover content, liveweight gain on tall fescue exceeded that on perennial ryegrass, indicating improved pasture quality of tall fescue relative to the grass. For some species of legumes (e.g. *Lotus* sp.), there are other beneficial effects on nutrition (e.g. presence of condensed tannins and flavanoids). The advantages of these compounds are to increase efficiency of N utilization within the digestive tract (Solter *et al.*, 2007).

The increased animal performance as the clover content of the pasture increases may reflect both higher nutritive value and intake. Compared to perennial grasses such as ryegrass and tall fescue, legumes generally have higher crude protein, readily fermentable carbohydrate and metabolisable energy but lower water soluble carbohydrate, lignin and fibre (Waghorn and Clark, 2004). Also, compared to perennial grasses, the nutritive value of legumes generally declines less with the onset of reproductive development in spring, increasing temperatures and with long regrowth intervals (Waghorn and Clark, 2004). The intake rates of sheep and cattle increases as the proportion of legume in the diet increases (Edwards *et al.* (1993); Penning *et al.* (1991), with this due mostly to greater bite masses. This summary emphasizes the need to

consider factors controlling clover abundance (e.g. grass-clover competition, choice of clover and grass species, grazing management) to improve animal performance.

2.2 Legume species

The benefits of forage legumes species have been outlined in the previous section (e.g. as nitrogen fixation ability and superior nutritive value and voluntary feed intake) (Frame, 2005; Solter *et al.*, 2007). The objective of this section is to outline the attributes and potential of some alternative annual and perennial legumes for dryland pastures. In the text, there is a focus on attributes that may allow the species to persist under water and grazing stress.

2.2.1 White clover (*Trifolium repens* L.)

Among the legume species, white clover is the most commonly sown legume in New Zealand (Frame, 2005). White clover growth peaks in the late spring and early summer period, if soil moisture is not limiting. The plant has a tap root for the first 12 to 18 months (Brock *et al.*, 2000). Once the tap root dies, the plant persists as a series of individual stolons growing independently as plantlets with fine adventitious roots from the stolon nodes (Brock *et al.*, 2000; Thomas, 2003). The low, stoloniferous growth habit allows perenniation amongst grass species in the pasture, and makes this species highly suitable to grazing. (Chapman and Caradus, 1997) reported a close linear relationship between white clover herbage accumulation rate and stolon density in most years.

2.2.2 Strawberry clover (*Trifolium fragiferum* L.)

Strawberry clover was the first non-traditional, perennial legume commercialised in Australia (Nichols *et al.*, 2012). Strawberry clover is a perennial legume that has shown tolerance of a number of stress factors including salinity and water logging (Kemp *et al.*, 1999; Charlton and Stewart, 2006). Nichols *et al.* (2008) reported that strawberry clover produced 2.7 t/ha in the second year of their study on herbage production and persistence of 24 perennial legumes at five sites across southern Australia differed in annual rainfall and extent of salinity and

waterlogging. It shows highest yields in spring and summer, and is capable of cool season growth in mild temperate areas of New Zealand (Frame, 2000). Seed germination and seedling growth of strawberry clover was inadequate at 10°C, with leaf-blade development was similar with white clover at 15°C and 20°C (Olusuyi and Raguse, 1968). Like white clover, it has a stoloniferous growth habit, which may give it a similar ability to white clover to survive in grazed swards. Hofmann *et al.* (2007) reported that strawberry clover displayed water deficit resistance in a number of key parameters including maintenance of leaf size, leaf water status and of photosynthesis rates under water stress. Strawberry clover had similar pattern of water deficit response as white clover, but showed a paraheliotropic response on repeated cycles of water stress on growth and apparent dinitrogen fixation. (Johnson and Raguse, 1985). The taproot of strawberry clover generally persists longer than that of white clover (Frame, 2000). Hofmann *et al.* (2007) stressed the lack of information on the performance of strawberry clover under grazing and need for field studies to test the use of strawberry clover as a complement or alternative to white clover in grazed pastures.

2.2.3 Subterranean clover (*Trifolium subterraneum* L.)

Subterranean clover originates from Mediterranean countries and is a self-generating, winter growing annual pasture legume (Smetham, 1999; Smetham and Sparks, 2003; Frame, 2005). It germinates after rain in autumn, overwinters as a rosette, before forming runners in spring. Flowers are produced in late spring, with seeds often buried into the soil in burrs containing 2-3 seeds (Smetham, 1999). In persisting over summer as seed, subterranean clover avoids summer water deficit, so is best adapted to areas with an annual rainfall less than 700 mm (Kemp *et al.*, 1999). Subterranean clover may provide high quality feed in late winter-early spring (Ates *et al.*, 2008) when the peak period of growth occurs. Yield of the subterranean clover was suppressed less by water stress than that of capeweed. The differing sensitivities of the species

to water stress were attributed to differences in seedling size and growth rates at the onset of drought (Chapman *et al.*, 1984).

Subterranean clover has lower optimum temperature and better winter growth than white clover (Korte *et al.*, 1987), and Turner *et al.* (2001) reported that more than 90% of the seeds germinated and emerged at 12°C. The pattern of response to temperature differed amongst cultivars, with optimum temperatures for growth being higher in Woogenellup and Clare than Tallarook and Yarloop. The cultivar Bacchus Marsh showed little response to temperature. Strain differences in relative growth rate were determined largely by disparities in based on leaf area (E_a) rather than by differences in leaf area: plant weight ratio (Morley, 1958). Subterranean clover was the most tolerant of the annual legumes to acid soil conditions, showing no visible toxicity symptoms and no response to lime in terms of seed yield (Hayes *et al.*, 2008). White clover failed to persist at the very dry sites, but subterranean clover increased in abundance, indicating suitable environments for the establishment and regeneration of clover populations. At less severe sites, subterranean and white clover generally achieved a similar herbage production range (Chapman *et al.*, 1986). Subterranean clover cultivars are classified by flowering time and level of hard seededness. In early flowering cultivars, growth is more pronounced in early spring than late flowering cultivars (Wurst, 2004).

Subterranean clover has a prostrate growth habit, and Moot *et al.* (2003) reported that the growing point of subterranean clover was pulled closer to the soil surface as the seedling develops, conferring some protection from grazing. This finding points towards there being a period in early seedlings growth stage where seedlings may be prone to death via grazing.

2.2.4 Water stress response - legumes

Kemp *et al.* (1999) reported that white clover survives short-term water deficit by senescing leaves, and then regrowing from stolons after the drought. Recovery from long term water deficit may require that plants re-establish themselves from buried seeds (Knowles *et al.*,

2003). However, persistency of white clover is poor if the annual rainfall is less than 800 mm. This was also concluded by Brock (2006) who stated that white clover needs 40 mm/month for persistence and 60 mm/month for good production. Knowles *et al.* (2003) concluded that white clover is generally not tolerant of water deficit conditions, with poor post-drought recovery.

Alternative species may give better water deficit tolerance. For example, subterranean clover copes with water deficit conditions by avoiding summer dry conditions as seeds. Within subterranean clover, sowing cultivars together in mixtures that vary in flowering time may be a useful strategy to exploit and cope with variable spring rainfall. For example, early flowering cultivars exploit winter rainfall and ensure high quality feed. If late spring rainfall occurs, late flowering cultivars may be well placed to exploit this prior to the onset of flowering and subsequent death (Wurst, 2004).

Some initial data suggests that strawberry clover may be more water deficit tolerant than white clover. The taproot of strawberry clover generally persists longer than that of white clover (Frame, 2000). This may result in increased water accession and thus could help towards increased production under dry conditions. A more recent study Hofmann *et al.* (2007) indicated that strawberry clover showed greater water deficit resistance in a number of key parameters (higher water status, photosynthesis, transpiration) compared to white clover.

However, Hofmann *et al.* (2007) stressed that a lack of nodal roots may be a limitation of strawberry clover in grazed pastures. Further, they suggested a need to examine strawberry clover as a complement or alternative legume to white clover. For example, sowing these two stoloniferous legumes together may be useful, with strawberry clover persisting in dry summer conditions. If there is a wet spring and summer, then white clover may be well placed to exploit these conditions. As they have similar growth habit, there is the added advantage that grazing management may not have to be altered differentially for each species.

2.3 Tall fescue (*Festuca arundinacea* Schreb. ;syn. *Schedonorus phoenix* Scop.)

Tall fescue is a deep-rooted, perennial bunchgrass (Stephenson and Posler, 1988) that is productive (Charlton and Stewart, 2006) and adapted to a range of environments (Lazenby, 1997). Its main features are water deficit tolerance (Charlton and Stewart, 2006), heat tolerance and summer growth (Reed, 1996) insect tolerance, clover compatibility (Hay, 1987; Milne *et al.*, 1998), tolerance of wet soils (Reed, 1996), hard frost and insect pest (Kemp *et al.*, 1999) and responsiveness to irrigation (Lowe and Bowdler, 1995). Tall fescue is an out-crossing allohexaploid ($2n = 6x = 42$) grass species extensively used for forage and turf worldwide with better able to tolerate drought than other cool-season grasses, being the most drought-tolerant grass when compared with seven others within the *Lolium*–*Festuca* complex (Ebrahimiyan *et al.*, 2013). Tall fescue has the potential to improve animal production in many situation (Milne *et al.*, 1998), but successful use depends on establishment and management techniques.

The rate of new tiller formation in tall fescue is one-third slower than ryegrass, but its tillers survive three times longer and are much larger (Milne *et al.*, 1998). Tall fescue appeared to have the greatest scope under moisture stress in terms of maintaining productivity and displaying attributes that contribute to persistence (Turner *et al.*, 2012). Leaf axillary buds develop into daughter tillers during development of reproductive stems in spring and will survive only if the reproductive stems are removed before they flower. Some tall fescue plants also have the ability to produce rhizomes and longer spell between grazing in autumn results in more rhizome growth. This has been indicated to increase density in tall fescue pastures (Milne *et al.*, 1998).

2.3.1 Tall fescue types

Cultivars are often split into two group based on their seasonal growth patterns (Charlton and Stewart, 2006). The summer-active (Continental) group contains cultivars (Advance, Vulcan,

Lunibelle, Typhoon) that grow vigorously in summer and moderately in winter. The winter-active (Mediterranean) group contains cultivars (Flecha, Resolute) that have little growth in summer but very strong winter growth and are deemed suitable for summer dry conditions (Charlton and Stewart, 2006). The summer-active group has more general application for New Zealand conditions (Charlton and Stewart, 2006), however there is little published comparative data on production and performance of winter and summer-active groups (Minee *et al.*, 2010).

The summer dormant groups are based on European ecotypes from the Mediterranean basin that are persistent in environments with prolonged and severe summer water deficits. These plants become summer-dormant in response to increasing daylength and probably high temperatures; the process is thought to operate independently of soil moisture (Villiers, 1975; Ofir and Kerem, 1982). Although mechanisms of obligatory summer dormancy in cool-season perennial grasses are not well understood, a complete cessation of growth functions, except for shoot meristems or surviving vegetative structures may occur (Ofir and Kerem, 1982). This may enable grass plants to escape summer water deficit and initiate autumn regrowth in response to decreasing daylength and lower temperatures (Malinowski *et al.*, 2005).

Tall fescue cultivars also vary in their flowering time and establishment rate, with early flowering growing well in August-September but the quality declines earlier than later-flowering types as seedheads develop. All tall fescue cultivars are rated as slow in establishment rate compared to perennial ryegrass, allowing clovers to established and compete with grass plants (Charlton and Stewart, 2006).

2.3.2 Tall fescue endophyte

Tall fescue plants may be infected with the free living symptomless fungal endophyte *Neotyphodium coenophialum*. The endemic wild type endophyte has been shown to be important for the persistence of tall fescue pastures in New Zealand, particularly Northland and Waikato, through the production of alkaloids which reduce damage by insects such as

Argentine stem weevil and black beetle (*Heteronychus arator*) (Breen, 1994; Kemp *et al.*, 1999). Studies from the USA also indicate that tall fescue infected with the endemic wild type endophyte usually express superior growth, water deficit and mineral stress tolerance, and competitiveness than non-infected plants (Malinowski and Belesky, 2000). However, one of the protective alkaloids produced by wild type endophyte, ergovaline, has also been related to the health disorder in grazing animals called fescue toxicity (Bacon *et al.*, 1977).

To resolve this dilemma a non-toxic *Neotyphodium* endophyte AR542 (MaxQ™) – producing just the alkaloid loline - was released onto the USA seed market and has been shown to give similar levels of animal performance to wild type endophyte with no negative effects on livestock (Parish *et al.*, 2003). The same endophyte is marketed in New Zealand as MaxP™. Popay *et al.* (2005) reported from a glasshouse study reduced feeding by adult Argentine stem weevil and black beetle on tall fescue infected with AR542 than nil endophyte tall fescue. They also showed tiller damage on tall fescue in two Northland farms was consistently lower in AR542 than nil endophyte pastures. Further work in dryland Canterbury pastures (Tozer *et al.*, 2007), indicated fewer annual grass weeds in AR542 than nil endophyte tall fescue pastures. Tozer *et al.* (2007) suggested that this was due to the greater competitive ability of infected tall fescue.

2.4 Dry matter production

2.4.1 Ryegrass versus tall fescue

Annual pasture production is mainly determined by winter temperatures, summer rainfall and soil fertility (Valentine and Kemp, 2007). Tall fescue based pastures require high fertility to produce well, but can withstand more extreme environmental conditions where it produces more green leaves in dry summer (Kemp *et al.*, 1999). In a study in unirrigated pastures in the south Taranaki (1058 mm rainfall; (Judd, 1990), phalaris and tall fescue (summer-active cultivar Roa) pastures produced more than old established perennial ryegrass pastures (Table

2). This was explained partly by greater tolerance to grass grub in tall fescue and perennial ryegrass. This study did not, however, compare newly sown ryegrass with newly sown tall fescue. In contrast, White and Knight (2007) showed no difference in dry matter production between tall fescue (cultivar CA, summer-active) and perennial ryegrass in dryland pastures established in the North Otago. They did, however, note a higher clover percentage in general in the tall fescue pastures, a result that confirms the findings of previous studies (Rollo *et al.*, 1998).

Table 2.1 Average seasonal and annual DM production (kg DM/ha) of old ryegrass, phalaris (*Phalaris aquatica*), tall fescue and cocksfoot (*Dactylis glomerata*) (1982-1986)

	Old ryegrass	SE	Maru phalaris	SE	Roa tall fescue	SE	Kara cocksfoot	SE
Winter	1790	(9105)	2080	(91)	1970	(120)	1700	(101)
Spring	5700	(201)	5180	(310)	6170	(61)	4950	(158)
Summer	4820	(291)	6410	(620)	6160	(320)	5250	(409)
Autumn	2240	(459)	3310	(485)	3060	(619)	2660	(477)
Total	14550	(228)	16980	(625)	17460	(455)	14560	(483)

Source: (Judd, 1990)

On a seasonal basis tall fescue produced more than ryegrass particularly in summer (30%) and autumn (37%). This was confirmed by McCallum *et al.* (1992) also working in the Taranaki, who showed that Roa tall fescue (summer-active) was 30-40% more productive over summer and autumn than perennial ryegrass. Rollo *et al.* (1998) also noted greater summer production in dryland pastures of tall fescue at Winchmore (+16%) compared to old perennial ryegrass pastures.

Minnee *et al.* (2010) noted that tall fescue demonstrated more consistent DM production and had greater water use efficiency than tetraploid perennial ryegrass over a three year irrigated experiment in Canterbury and Waikato, and concluded tall fescue is a viable option for dairy pastures.

2.4.2 Winter versus summer active tall fescue

There is little comparable data on the herbage production of winter and summer-active tall fescue cultivars in New Zealand. Minnee *et al.* (2010) reported in the Canterbury region that the Continental tall fescue produced 7.7 t DM/ha/year and Mediterranean tall fescue produced 7.3 t DM/ha/year under conditions of un-irrigated over summer. In a study by Tharmaraj *et al.*

(2008) in Victoria, Australia, pastures based on winter- (Flecha) or summer- (Advance) active tall fescue were compared with a perennial ryegrass pasture (Samson) at three sites (740 to 1000 mm rainfall). The winter-active pasture had little effect on the overall seasonal distribution of forage supply or total annual yield compared with the perennial ryegrass control treatments. In contrast, the summer-active pasture significantly increased herbage accumulation during summer compared with other pasture types (mean of an additional 1.3 t DM/ha during summer). However, this came at a cost of lower winter production (mean 0.8 t DM/ha).

Malinowski *et al.* (2009) defined the winter-active or summer-dormant as the ability of cultivars to tolerate increasing annual temperature, decreasing precipitation, and repeated severe summer water deficits, and found in their study that the most adapted were tall fescue, phalaris and cocksfoot. The summer-dormant cultivars of cocksfoot and tall fescue species were shown to be more persistent than their summer-active counterpart (Hayes *et al.*, 2010), enabling them to dry the soil profile incrementally over a longer period of time, and the study has demonstrated the importance of increased plant persistence on reducing the water content of the soil profile in drought-prone environments (Hayes *et al.*, 2010).

2.4.3 Legume species

Brown *et al.* (2006) investigated pasture and livestock performance of grass-legume pasture mixtures in dryland pastures at Lincoln. In the 2004/05 year, the subterranean clover-cocksfoot and cocksfoot-white clover were the most productive pasture mixtures followed by cocksfoot-balansa clover (*Trifolium michelianum*), ryegrass-white clover and cocksfoot-Caucasian clover (*Trifolium ambiguum*). The cocksfoot subterranean clover pasture was the most productive in 2005/2006. Mills *et al.* (2008) reported that cocksfoot sown with subterranean clover produced yields of 9.9-12.9 t DM/ha/yr which were greater than, or similar to, all other pastures (8.0-12.9 t DM/ha/yr). Of note, was that the cocksfoot-subterranean clover pasture consistently had the highest growth rates in the August to October period – the crucial feed supply time in a dryland

sheep production system. The cocksfoot-subterranean clover pasture also gave the highest stock production in the August to October period. There is no comparable New Zealand data on growth of strawberry clover-grass mixtures compared to white and subterranean clover under dryland conditions.

2.5 Grazing management

Grazing management is the manipulation of grazing animals to accomplish desired results in terms of animal, plant, land or economic responses (Vallentine, 2001). The key tools of grazing management are the frequency and intensity of grazing, and its timing relative to key events such as flowering and seedling establishment. Some of the key effects for tall fescue and strawberry, white and subterranean clover are described below. The successful management of mixtures with legumes and grass depends on the yield performance of the legume component in the mixture, and the nutritional quality of the species growing in a mixture was determined by the legumes rather than by the grass (Gierus *et al.*, 2012).

2.5.1 Tall fescue

For tall fescue, a key management time is spring, as seedhead development leads to poor quality feed that is difficult to remove by grazing (Milne *et al.*, 1998). Stewart and Charlton (2003) stated grazing control in spring should be more frequent than ryegrass, to prevent excessive seedhead development, as stemmy pastures grow poor quality feed. Tall fescue has poor tillering capacity when kept below 30 – 40 mm by regular continuous grazing (Korte *et al.*, 1987).

Kerrisk and Thomson (1990) compared perennial ryegrass with tall fescue (cultivar Roa, summer-active) and phalaris under combinations of three defoliation heights and three defoliation intervals in a mowing trial in Taranaki. Climate had a major influence on the response of the three pastures to defoliation management. In a dry spring, tall fescue produced most from a 15 day cutting interval, while 30 days was best for perennial ryegrass. In a drier

than average summer in Taranaki, 10 day intervals gave greater growth rates in tall fescue and perennial ryegrass than did 15 day or 30 day intervals. A significantly higher pasture growth rates over all seasons in lax defoliation (5.5cm) than hard defoliation (3cm) in ryegrass (15%), tall fescue (20%) and phalaris (21%).

Donaghy *et al.* (2008) conducted a study of the effect of leaf age in tall fescue (cultivar Advance) under rotational grazing in Tasmania, Australia. They showed an increase in leaf yield (DM) up to and including the four leaf stage of regrowth, but that crude protein and metabolisable energy declined with increasing leaf growth stage. They concluded that defoliation at the two leaf stage interval of regrowth maximized herbage quality. Defoliation at the four-leaf stage resulted in 30% higher stubble WSC concentration and 20% higher leaf DM yield than defoliation at the two-leaf stage of regrowth, but compromised herbage quality and allowed water soluble carbohydrate replenishment to pre-defoliation levels and resulted in a satisfactory rate of regrowth.

There is little comparable data on the grazing management requirements of winter and summer-active tall fescue cultivars. Paddock observations in Marlborough indicate that winter-active tall fescue plants (e.g. Flecha) may require higher grazing pressure in early spring to maintain pasture quality and may respond better to continuous stocking than rotational grazing (Moorhead, 2008). A study on nitrogen fertilization, sowing method and grazing management of tall fescue swards determines the grazing management effects on tiller population density: frequent grazing promotes tillering under conditions with adequate N supply, whereas it was impaired under conditions of N deficiency (Scheneiter and Amendola, 2012).

2.5.2 Legumes

In a series of studies, Brock and Fletcher (1993) and Brock *et al.* (2000) examined the effect of continuous stocking versus rotational sheep grazing on white clover populations at Palmerston North, New Zealand. These studies in unirrigated pastures, with rainfall less than 1000mm per

annum, showed that under rotational grazing there were fewer ryegrass tillers and white clover plants than under continuous grazing, and that tillers and clover plants were generally larger. They also showed a differential effect of summer water deficit on white clover performance, with greater loss of clover under rotational grazing. In this context, continuous grazing pre-conditioned pastures for water deficit tolerance by increasing grass tiller density, which allowed greater protection from high temperatures. Under continuous grazing (11,000 -15,000 tillers/m²) soil surface temperatures were considerably lower (40°C) than under rotationally grazed pastures (500-600 tillers/m², 48°C).

Little comparable data is available for strawberry clover in the context of grazing management. Rumball *et al.* (1991) noted the cultivar 'Onward' persisted well under close grazing, but they did not compare with other legume species, or quantify the grazing management. Hull *et al.* (1967) indicated that strawberry clover has been used in mixtures under grazing with Ladino clover, cocksfoot, tall fescue and perennial ryegrass, but did not report specifically on the performance of strawberry clover under grazing.

For subterranean clover, a key stage for grazing management is the time and intensity of grazing in autumn following germination. Thomas (2003) highlighted that once subterranean clover seedlings reach the 4 leaf stage, the hypocotyl draws the base of the cotyledons below the soil surface, and the axillary buds of the spade and first trifoliolate leaf to around soil level. Based on this, Moot *et al.* (2003) suggested that grazing should be delayed until the six leaf stage to avoid seedling loss. Grazing is unlikely to kill seedlings unless the whole seedling is pulled out of the ground. Moot *et al.* (2003) also highlighted that the optimal grazing time may also depend on the level of grass competition and the seedling population density, as these determine degree of defoliation of seedlings and so proneness to grazing.

Frame (2005) stressed that spring grazing management is also important for subterranean clover. In the case of annual legumes, Ates *et al.* (2006) showed that high lamb liveweight

gains can be obtained on subterranean clover pastures, but overgrazing of subterranean clover during spring may result in poor seed production and reduced seedling numbers in the following autumn. The management needs to be adapted to ensure a sufficient resting period for ripening the seeds of subterranean clover (Solter *et al.*, 2007). During the first year after establishment it may be necessary to rest pastures in spring to ensure sufficient seed production and build up seed reserves (Ates *et al.*, 2008). The effect of spring grazing management on subterranean clover seed production and lamb liveweight gain is the subject of a previous study (Ates, 2009) and will not be considered further here.

2.6 Soil fertility

In terms of soil fertility, low nitrogen availability to plants is a common factor limiting pasture production and the acceptability of that herbage to livestock (Lambert *et al.*, 1982; Edwards *et al.*, 1993). The amount of fixed nitrogen that can be contributed to the pastoral system will depend on the extent of legume growth. Water, grazing management and species cultivar has already been discussed as factors which may affect this. Further edaphic factors that may affect this are phosphorous (P) and sulphur (S) levels and soil pH (Edmeades *et al.*, 1984). Compared to grasses, legumes generally have a higher requirement for P and are less tolerant of low P availability (Jackman and Mouat, 1972; Caradus, 1980).

Dodd and Orr (1995) screened 18 annual legumes for their response to P (Olsen P 10 versus 24) in a pot trial. They showed that serradella (*Ornithopus sativus*), hairy birdsfoot trefoil (*Lotus subbiflorus*) and subterranean clover were able to maintain high levels of growth at low P levels relative to their potential at high P, and were thus suited to low P fertility soils. In a further evaluation of perennial legumes (Dodd and Orr, 1995), red clover (*Trifolium pratense*) and strawberry clover exhibited growth rates that were equal to or exceeded those of white clover under conditions of low P availability. Black *et al.* (2007) examined pasture production and liveweight gain from white and Caucasian clover pastures maintained at high (Olsen P =

20) and low (Olsen P = 11) P fertility. They showed higher liveweight gain was greater on high than low fertility pastures (1178 kg ha⁻¹ v 1094 kg ha⁻¹ on Caucasian clover) and (1069 kg ha⁻¹ v 1015 kg ha⁻¹ on white clover). They noted this was mainly due to an increase in herbage production of similar composition and nutritive value, giving a greater number of grazing days at high fertility.

Tall fescue is considered to have a higher requirement for P fertility (Milne *et al.*, 1998), although there is little data from experiments to confirm this. The higher fertility requirements were suggested in a field survey of pastures by Smith *et al.* (1998) where tall fescue was more dominant in pastures of higher P fertility. They also noted that poor establishment may be more crucial than higher fertility for good tall fescue persistence.

2.7 Grass-legume interactions

In evaluating new cultivars of grasses and clover, it is important to consider compatibility between grass and clover species because of the dominant effect that clover can have on livestock performance (Hyslop *et al.*, 2000; Parsons *et al.*, 2006). Of note, is that most evaluations of new cultivars are conducted with monocultures (e.g. NZPBRA forage evaluation trials), consider only dry matter production, and may be conducted with mowing rather than grazing. Such studies yield useful information on performance of cultivars under these conditions, but may fail to detect important effects of grasses species and cultivars on legumes. Several studies have noted different ryegrass cultivars lead to different clover contents in the paddock (Swift *et al.*, 1993).

Other research notes a higher legume content in tall fescue pastures compared to ryegrass pastures (Exton *et al.*, 1996). However, it is not clear whether the compatibility of winter versus summer-active tall fescue with clover varies. On one hand, winter-active tall fescue may promote conditions that are not conducive to subterranean clover compared to summer-active tall fescue. This is because they might be most competitive in early spring when subterranean

clover is also growing most rapidly. Here, competition might also be expected to be greater for early flowering subterranean clover cultivars. On the other hand, because winter- active tall fescue is dormant in summer and early autumn, conditions for subterranean clover germination may be enhanced compared to summer-active tall fescue.

Vazquez de Aldana *et al.* (2012) reported that the greater competitive ability of endophyte inoculated plant related to chemical interactions, with allelopathic activity and secondary metabolites in plants, which may have an effect on the companion species. However, Lewis (1992) concluded that endophyte infection of ryegrass does not appear to increase ryegrass production or to decrease white clover production in the United Kingdom. Omacini *et al.* (2012) stress the necessary of expanding the knowledge about the factors that control desirable and undesirable effects of endophyte on the ecosystem as well as symbiosis persistence.

2.8 Conclusions

The following conclusions can be drawn based on the literature on tall fescue-legumes mixtures in dryland pastures:

- High legume content in pastures is important to fix atmospheric nitrogen and supply the N requirement of pastures and therefore increase the nutritive quality of the herbage and give higher liveweight gain to the livestock.
- There is potential variation in the growth of tall fescue cultivars that may affect pasture composition and livestock performance. Winter-active tall fescue grows more in late winter and early spring and becomes dormant during summer. In contrast, summer-active tall fescue has little growth in cooler months and grows more in late spring and summer.

- The perennial clovers, white and strawberry clover spread via surface stolons which are dependent on nodal roots after the taproot dies. In contrast, subterranean clover germinates in autumn, spreads via runners, produces seed and dies in summer, and will germinate in the following autumn after rain. These differences will require different grazing management requirements to ensure long term persistence and are likely to be affected by competition with grasses.
- Dry matter production of tall fescue was reported to be greater than perennial ryegrass provided that soil fertility was adequate. But there are very few comparisons between tall fescue cultivars and the performance of the tall fescue-legumes mixtures under various grass-legumes combinations, and little available information on performance of winter and summer-active cultivars.
- The best grazing management of tall fescue-legumes mixtures involves maintaining the grass at vegetative stage, maintaining the soil fertility status and to understand the grass-legume interactions in the wider pastoral systems.

Chapter 3

Pasture production, growth, persistence and composition of winter and summer-active tall fescue pastures growing with white, strawberry and subterranean clover at high and low P and S fertility.

3.1 Introduction

The most commonly sown pasture in New Zealand is a mixture of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). While this mixture is suitable for summer-moist or irrigated pastures, they are less persistent and productive in dryland farming systems subject to periodic water stress in the late spring and summer period (Mills and Moot, 2010). Brock (2006) indicated that the shallow rooting species white clover needed rainfall of 40 mm/month for persistence and 60 mm/month for performance; otherwise without irrigation white clover should not be considered. Further, Knowles *et al.* (2003) concluded that white clover is generally not tolerant of water deficit conditions, with poor post-drought recovery. Thus, there is a need to consider and evaluate alternative grass-legume combinations, that are more persistence and productive, under dryland conditions.

The annual legume, subterranean clover (*Trifolium subterraneum* L.), has considerable potential as an alternative to white clover on dryland farms (< 800 mm/annum). Subterranean clover avoids water deficit conditions by growing actively in late winter and spring, flowering and producing seeds before the onset of summer water deficit, and re-establishing from seeds during autumn. Mills and Moot (2010) concluded that in dryland pastures in Canterbury subterranean clover-cocksfoot had greater dry matter production over a seven year period than other mixtures, including perennial ryegrass-white clover.

A further alternative approach to white clover is to use a more water deficit tolerant perennial legume such as strawberry clover. The taproot of strawberry clover generally persists longer than that of white clover (Frame, 2000). Further, Hofmann *et al.* (2007) indicated strawberry clover showed greater water deficit resistance in a number of key parameters, including water status, photosynthesis and transpiration compared to white clover. However, Hofmann *et al.* (2007) indicated that a lack of nodal rooting in strawberry clover may be a limitation on the persistence of strawberry clover and stressed the need to examine the production and persistence of strawberry clover under grazing conditions.

Tall fescue is a deep-rooted, perennial grass that may be a useful alternative to perennial ryegrass under dryland conditions (Stephenson and Posler, 1988; Charlton and Stewart, 2006). Tall fescue is noted for its high heat tolerance leading to improved summer growth (Reed, 1996), and tolerance of a range of insect species such as grass grub, porina (*Wiseana spp.*) (Bourner *et al.*, 1996) and Argentine stem weevil (Popay and Ball, 1998). Tall fescue cultivars have been classified into Continental (summer-active) and Mediterranean (winter-active) types based on their seasonal growth patterns (Stewart and Charlton, 2003; Hand *et al.*, 2010). The summer-active Continental type, has contributed the majority of temperate cultivated germplasm and grows vigorously in summer and moderately in winter (Stewart and Charlton, 2003). Conversely, Mediterranean cultivars grow more strongly in the cool season and have limited summer growth due to dormancy in response to increasing day length and probably high temperatures (Villiers, 1975; Ofir and Kerem, 1982). This may enable grass plants to escape summer water deficit and initiate autumn regrowth in response to decreasing day length and lower temperatures (Malinowski *et al.*, 2005). However, few studies have measured pasture growth of Continental and Mediterranean cultivars under Australasian conditions or considered interactions with associated legumes. The study by Tharmaraj *et al.* (2008) in south-western Victoria, Australia showed that the winter-active cultivar Flecha had similar overall seasonal

distribution of forage supply and total annual yield compared to the control ryegrass-white clover pasture, but that the summer-active cultivar Advance had significantly greater herbage accumulation compared to the perennial ryegrass-white clover pasture during summer.

In evaluating pasture grass species, it is important to consider how the grass and legume species interact in mixtures (Harris *et al.*, 1981). Grass competition plays an important role in regulating establishment, growth and persistence of annual and perennial legumes in mixtures and seasonal patterns of growth of grass may play a key role in this (Cherney *et al.*, 1986). It is possible that Mediterranean tall fescue cultivars, which begin growth earlier in spring, may compete more strongly with annual legumes such as subterranean clover than Continental tall fescue cultivar. However, the establishment of the annual legume may be better in autumn when grown with Mediterranean tall fescue due to the slow growth of grass following dormancy providing greater opportunity for recruitment of new plants. Further, Mediterranean tall fescue may compete less strongly than Continental tall fescue with perennial legumes during water stress periods during summer.

The performance of grass-legume mixtures under dryland conditions is also determined by levels of macronutrients critical for legume growth and persistence, such as phosphorus (P) and sulphur (S) (Smith *et al.*, 1998). Tall fescue is generally regarded as high fertility species (Charlton and Stewart, 2006); however, there is little data on response to P and S fertility under New Zealand condition. White clover is noted for being responsive to both P and S fertility. Dodd and Orr (1995) showed that the annual clover species serradella, hairy bird's-foot trefoil and subterranean clover were able to maintain high levels of growth at low P levels relative to their potential at high P, and were thus suited to low P fertility soils. Further, Dodd and Orr (1995) noted strawberry clover as responsive to P and S as the perennial legume red clover.

This study reports pasture growth and composition over two years for a dryland grass-clover pasture in Canterbury, New Zealand maintained under intensive sheep grazing. The specific

objective of the current study was quantify the interactive effects of tall fescue cultivar (Continental, cultivar Advance, versus Mediterranean, cultivar Flecha), sown clover species (subterranean clover versus a combination of white and strawberry clover) and soil fertility (high P and S fertilizer versus low fertilizer P and S) on annual and seasonal DM production, botanical composition, plant density and plant morphology. The effects on pasture nutritive value and sheep liveweight gain of the same pastures are considered in Chapter 4.

3.2 Materials and Methods

3.2.1 Site description

3.2.1.1 Experimental site

The experiment was conducted from 22 May 2008 to 16 June 2010 at Lincoln University, Canterbury, New Zealand (43°39'S, 172°28'E, 11 m a.s.l.). The soil at the site was a Templeton silt loam (Udic Haplosteps) of variable depth to underlying gravels (c.0.4-1.5 m) across the site (Cox, 1978). The site was flat with small (c. 1 m) changes in topography. The site was bounded by all (8-10 m) poplar shelterbelt trees on the west and north boundaries.

The site had been previously used for an irrigated comparison of white and Caucasian clovers grown with perennial ryegrass under high and low phosphorus (P) and sulphur (S) fertility that was completed in 2001 (Black *et al.*, 2007). The existing pasture at the site was then managed as a dryland (un-irrigated) pasture that was grazed in common by sheep until September 2007. The site was then sprayed with 3 L/ha Roundup Transorb (540 g/L glyphosate) on 22 August 2007, ploughed and sown with triticale (\times *Triticosecale*). The triticale was grazed by sheep and then mown to remove excess residue in January 2008. Plots were left fallow until the area was ploughed on 29 February 2008, Dutch harrowed and rolled on 3 March 2008 before heavy rolling on 10 March 2008. On 11 March 2008, the area was drilled with tall fescue and clover seeds with a cone seeder using 15 cm drill rows.

3.2.1.2 Soil

The soil fertility treatments were imposed on paddocks so as to continue differences in soil fertility that had been established in the treatment design of the previous experiment (Black *et al.*, 2007). Based on soil tests (0-7.5 cm sample depth) taken across high and low fertility paddocks on 5 July 2008 (Table 3.1), fertilizer requirements to maintain the current levels of phosphorus (P) and sulphur (S) with the P fertility target at Olsen P of 18 mg/L for high fertility and Olsen P of 8 mg/L for low fertility treatments, respectively, obtained from OVERSEER computer software (Overseer, 2010).

The low fertility plots received 80 kg/ha of sulphur superphosphate 15 (8.7 % P, 14.7 % S) and the high fertility plots received 190 kg/ha sulphur superphosphate 20 (8.1 % P, 20.5 % S) on 15 August 2008. Soil samples for the second year were taken on 25 July 2009 on an individual plot basis (Table 3.1). The low fertility plots had an average Olsen P of 10 mg/L with low variability (range = 8 - 13 mg/L) across paddocks. The high fertility plots had an average of 16.8 mg/L but with high variability (range = 13 – 21 mg/L). Based on this, the low fertility plots received 60 kg/ha sulphur superphosphate 15 (8.7 % P, 14.7% S) on 31 July 2009. The high fertility plots received variable rates of fertiliser (150, 190, 230 or 300 kg/ha) of sulphur super phosphate depending on the values of Olsen P of the soil test. The soil test for Olsen P in the third year (August 2010) was 17.8 mg/L for high fertility plots (range 14 – 22 mg/L) and 7 mg/L range (5 – 10 mg/L) for low fertility plots.

Table 3.1 Measurements of soil nutrient status (0 -75 mm depth) for low and high fertility soil treatments in July 2008 and 2009.

Description	July 2008		July 2009	
	Low fertility	High fertility	Low fertility	High fertility
pH	5.6	5.7	5.9	5.8
Olsen P (mg/L)	8.1	17.1	10	16.8
Potassium (me/100g)	0.39	0.36	12.1	11.1
Calcium (me/100g)	5.15	5.63	6.1	6.3
Magnesium (me/100g)	0.83	0.82	17.8	17.5
Sodium (me/100g)	0.12	0.12	7.3	7.3
CEC (me/100g)	12	14.1	11.5	11.8
Sulphate-S (mg/kg)	2.8	2.8	3.9	4.3

3.2.2 Treatments and experimental design

The experimental design was 2 x 2 x 2 factorial laid out in four randomized blocks. The treatments were: soil fertility (low (LF) or high (HF) application of superphosphate (P and S)); tall fescue cultivar (Continental Advance (CT), or Mediterranean Flecha (MT)) with endophyte status more than 90%); and clover sown with tall fescue (subterranean clover (SC) or perennial clover mixture (white + strawberry clover (PC))). The eight treatments were allocated at random to eight 0.04 ha paddocks in each block, with each block consisting of a column of eight paddocks. There were raceways between block (column) 1 and 2 and block (column) 3 and 4, with a perimeter raceway. The details of the species used and their sowing rate are shown in Table 3.2. The subterranean clover treatment was a mixture of the cultivar Denmark (classified as late flowering) and cultivar Campeda (classified as mid/late flowering) (Wurst, 2004).

Table 3.2 Species sown and sowing rates in tall fescue x legume species x soil fertility trial.

Pasture treatment	Tall fescue cultivar and sowing rate	Legume
Mediterranean tall fescue-subterranean clover (MT-SC)	Flecha, 20 kg/ha	Denmark subterranean clover, 10 kg/ha Campeda subterranean clover, 10 kg/ha
Mediterranean tall fescue-perennial clover (MT-PC)	Flecha, 20 kg/ha	Nomad white clover, 3 kg/ha La Lucilla strawberry clover, 3 kg/ha
Continental tall fescue - subterranean clover (CT-SC)	Advance, 20 kg/ha	Denmark subterranean clover, 10 kg/ha Campeda subterranean clover, 10 kg/ha
Continental tall fescue - perennial clover (CT-PC)	Advance, 20 kg/ha	Nomad white clover, 3 kg/ha La Lucilla strawberry clover, 3 kg/ha

*LF – low fertility HF – high fertility

The sowing rate suggested to achieve 450 – 500 plant/m of grass and 150 plant/m of white clover (Praat *et al.*, 1996).

3.2.3 Grazing management

Details of grazing management are shown in Table 3.3. All plots were grazed lightly in common on 15 May 2008, with grazing treatments starting in spring 2008. In spring 2008, four groups each made up of 7 Coopworth ewes and their single one week old Coopworth-Suffolk cross lambs were used in the grazing trial. Two groups were allocated to each block, one group grazing LF plots and the other grazing HF plots at the stocking rate of 22 ewes/ha) The grazing started with MT-SC plots first on 11 September 2008 before moving to MT-PC, and then CT-SC, and CT-PC plots. Grazing ceased on 8 October 2008 in all plots in order to allow the subterranean clover to flower and set seed and ensure production in subsequent years. The groups spent on average 2 days per paddock with a rotation length of 16 days. Plots were not grazed again until autumn, with mechanical topping using a ride-on mower carried out in January 2009 to remove residual seedheads. From 1 April 2009 until 22 May 2009, plots were

grazed with 8 groups. Four groups were allocated to each block, which represented one group allocated to each of LF-CT, LF-MT, HF-CT and HF-MF. There were 3 Coopworth ewe hoggets per group for MT (18 sheep/ha) and 4 hoggets per group for CT (25 sheep/ha), reflecting greater pasture mass available at this time in the CT plots. The groups spent on average 2 days per paddock with a rotation length of 8 days.

In spring 2009, 8 groups initially each containing 3 Coopworth ewes and their twin (6) Coopworth-Suffolk cross lambs grazed the trial from 20 August to 9 December 2009. Four groups were allocated to each block, which represented one group allocated to each of LF-CT, LF-MT, HF-CT and HF-MT (stocking rate of 18 ewes/ha). The number of ewes and lambs was reduced to two and four, respectively, from 22 October until 9 December 2009 to enable pasture growth to more closely match animal demand. The groups spent on average 2 days per paddock with a rotation length of 8 days. Plots were not grazed again until autumn 2010. From 6 March until 24 May 2010, plots were grazed with 8 groups, each containing 3 Coopworth ewe hoggets (18 sheep/ha). Four groups were allocated to each block, which represented one group allocated to each of LF-CT, LF-MT, HF-CT and HF-MT. Grazing ceased from 24 March until 2 May 2010 because of the low pasture mass due to summer dry conditions over this period which slowed the growth of grass and clover, where all hoggets were reallocated to another site outside the experimental site. The groups spent on average 2 days per paddock with a rotation length of 8 days (Table 3.3).

Table 3.3 Grazing treatments and grazing schedule of the seasonal grazing periods, class of animals and grazing rotation length of the pasture treatments from 2008 to 2010 in block H17, Lincoln University.

*Perennial and subterranean clover was grazed together in the same grass cultivar and soil treatments

Grass	Fert	Season	Dates	Management	Class	No. of ewes/lambs	Liveweight	No. of group per treatment or block	Graze/plot	Grazing rotation	'Clean-up' grazing
CT+ MT	HF	Spring 2008	11 Sep – 8 Oct	Grazing	Ewe/Lambs	7/7	61 kg	2 mobs	2 days	16 days	15 Sep – 1 Oct
CT+MT	LF		11 Sep – 8 Oct	Grazing	Ewe/Lambs	7/7	67 kg	2 mobs	2 days	16 days	15 Sep – 1 Oct
		Summer 2008	8 Oct - 30 Mar	Spell	-	-					
CT	HF	Autumn 2009	1 Apr – 22 May	Grazing	Hoggets	4	41 kg	2 mobs	2 days	8 days	
MT	HF		1 Apr – 22 May	Grazing	Hoggets	3	40 kg	2 mobs	2 days	8 days	
CT	LF		1 Apr – 22 May	Grazing	Hoggets	4	39 kg	2 mobs	2 days	8 days	
MT	LF		1 Apr – 22 May	Grazing	Hoggets	3	41 kg	2 mobs	2 days	8 days	
		Winter 2009	23 May – 20 Aug	Spell	-	-					
CT	HF	Spring 2009	20 Aug – 9 Dec	Grazing	Ewe/Lambs	2-3/4-6	64 kg	2 mobs	2 days	8 days	
MT	HF		20 Aug – 9 Dec	Grazing	Ewe/Lambs	2-3/4-6	67 kg	2 mobs	2 days	8 days	
CT	LF		20 Aug – 9 Dec	Grazing	Ewe/Lambs	2-3/4-6	62 kg	2 mobs	2 days	8 days	
MT	LF		20 Aug – 9 Dec	Grazing	Ewe/Lambs	2-3/4-6	68 kg	2 mobs	2 days	8 days	
		Summer 2009	9 Dec – 6 Mar	Spell	-	-					
CT	HF	Autumn 2010	6 Mar – 24 Mar	Grazing	Hoggets	3	34 kg	2 mobs	2 days	8 days	
MT	HF	Period 1	6 Mar – 24 Mar	Grazing	Hoggets	3	34 kg	2 mobs	2 days	8 days	
CT	LF		6 Mar – 24 Mar	Grazing	Hoggets	3	35 kg	2 mobs	2 days	8 days	
MT	LF		6 Mar – 24 Mar	Grazing	Hoggets	3	35 kg	2 mobs	2 days	8 days	
		Autumn 2010	25 Mar – 2 May	Spell	-	-					
CT	HF	Autumn 2010	2 May – 24 May	Grazing	Hoggets	3	40 kg	2 mobs	2 days	8 days	
MT	HF	Period 2	2 May – 24 May	Grazing	Hoggets	3	42 kg	2 mobs	2 days	8 days	
CT	LF		2 May – 24 May	Grazing	Hoggets	3	41 kg	2 mobs	2 days	8 days	
MT	LF		2 May – 24 May	Grazing	Hoggets	3	40 kg	2 mobs	2 days	8 days	

3.2.4 Measurements

3.2.4.1 Annual and seasonal pasture growth and botanical composition

Pasture growth was measured in each of the 32 plots over 24 regrowth periods from 22 May 2008 to 16 June 2010 using 1 m x 1.5 m enclosure cages. At the start of each regrowth period, an area was trimmed with a rotary mower to 30 mm above ground level. At the end of each regrowth period (28 days) one 0.2 m² quadrat was cut to 30 mm above ground level using hand shear to measure the actual growth of herbage during that time. All pastures were harvested on the same day. A subsample (about 200 g) of fresh herbage was sorted into sown grass, sown legume, volunteer white clover, unsown species and dead material before drying at 70°C and weighing. The botanical composition on a DM basis was then determined. After cutting, cages were relocated to new pre-mown sites in each plot to exclude grazing sheep.

3.2.4.2 Plant populations and morphology

Plant population and morphology were measured on 30 September 2008, prior to the first grazing. All grass and clover plants were dug up to a depth of 20 cm in two 1-m drill rows in each plot. The samples were washed and counts made of the number of plants of each sown species, tillers per grass plant, growing points per white clover and strawberry plant and runners per subterranean clover plant (Hurst *et al.*, 2000). It was not possible under grazing conditions to distinguish Campeda from Denmark subterranean clover cultivars. Plants were then separated into roots and shoot material bulked for each plot, dried at 70°C to a constant weight, and dry weight of shoots, and roots per plant determined. Plant population and morphology were measured again in spring 2008 (30 Oct 2008), spring 2009 (30 Oct 2009) and winter 2010 (20 June 2010). The plant in this context was classified as a stolon with taproot, or later as the plant fragmented, a separated stolon fragment with nodal roots (Brock *et al.*, 2000). In 2010, the sampling of subterranean clover was delayed until 20 July, as the subterranean clover seedlings were still very small due to the late autumn rain and germination of subterranean clover seeds. For subterranean clover, the sampling

method was modified in the second year so that three 0.25 m x 0.25 m quadrats located at random in each plot were dug out to a depth of 20 cm. This was because subterranean clover plants had spread beyond the drill rows due to reseeding.

3.2.5 Environment

Meteorological data (rainfall, air temperature, solar radiation, wind run, Penman and soil temperatures) was collected from the Broadfield site located 2 km north of the experiment.

The pattern of monthly rainfall is shown in Figure 3.1. Total annual rainfall in 2008 (597 mm) was greater than long term average (512 mm), and similar to long term average in 2009 (585mm). Of note is that rainfall was higher than average from May to June 2008, and less than average from October to December, from July to October 2009, and from December 2009 to May 2010. Of note also is that rainfall was higher than average in January 2009.

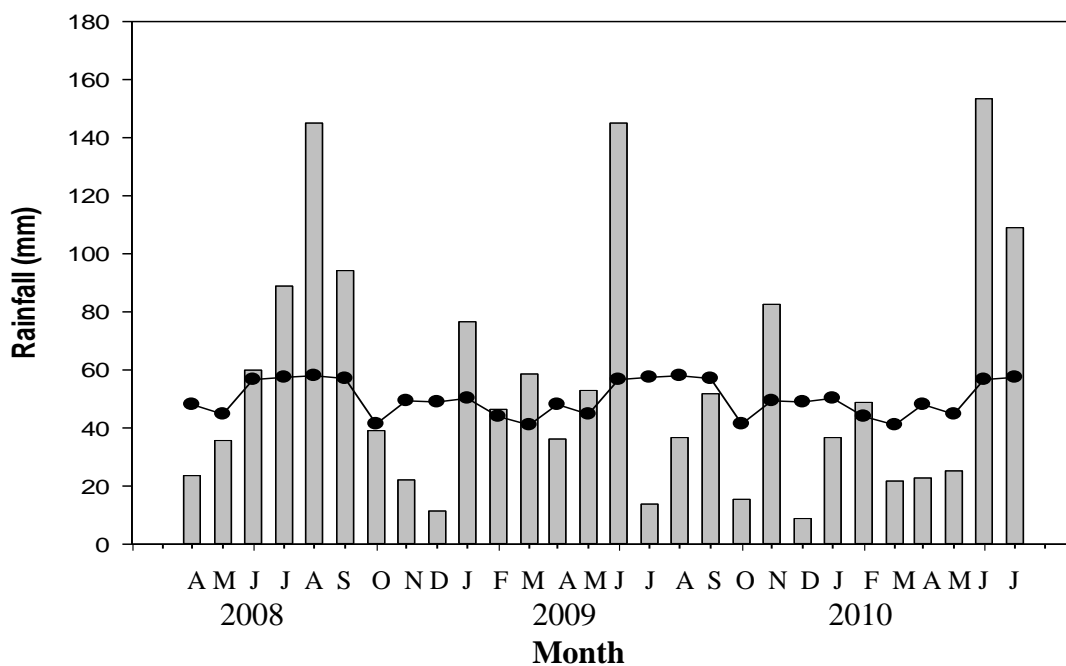


Figure 3.1 Monthly rainfall (mm) during the experimental period (bars) and 30 year long-term average for the site. Data from the Broadfield Meteorologic site located 2 km from experiment.

Soil moisture in the top 20 cm of the soil profile was also measured at 10 days intervals during the cage cut period from 31 Oct 2008 to 16 June 2010 using Time Domain Reflectometry (TDR) rods

inserted to 20 cm depth. Rods were inserted in total of 8 plots of the high fertility (HF) Flecha (MT) and Advance (CT) tall fescue pastures sown with subterranean (SC) and perennial clovers (PC), 2 replicates for each treatment (MT-SC, MT-PC, CT-SC and CT-PC).

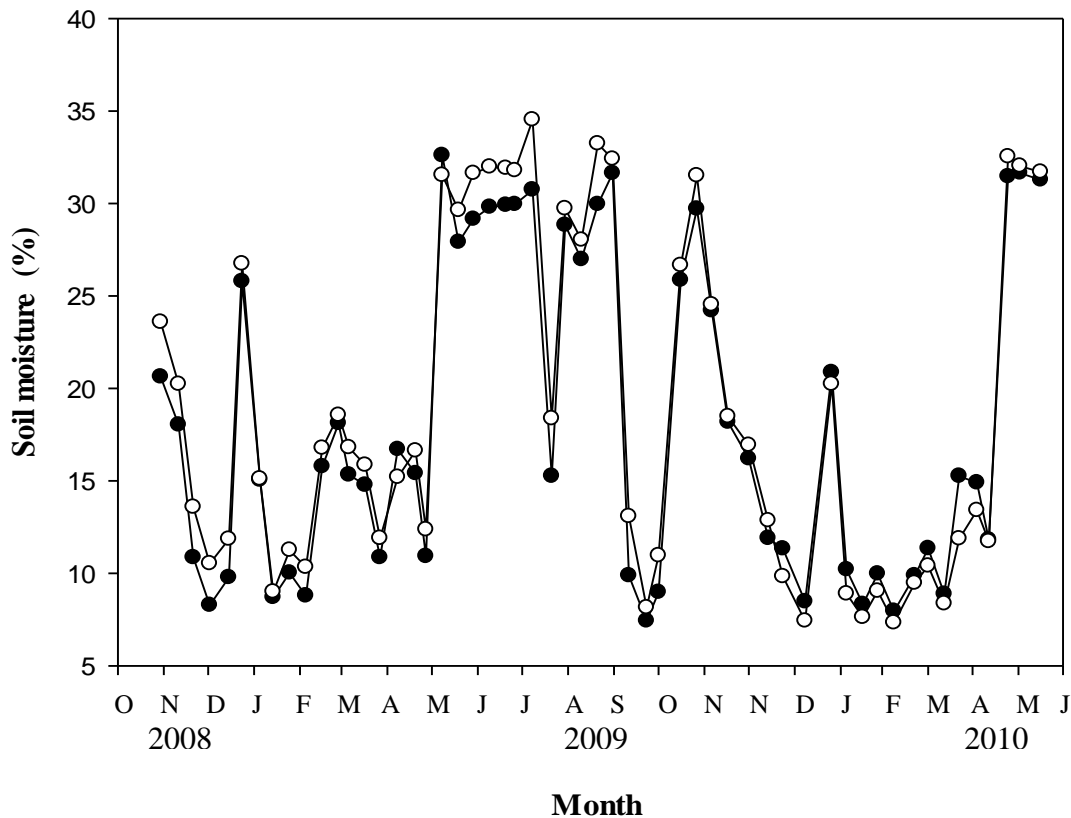


Figure 3.2 Soil moisture (%) at 20 cm depth from CT (○); MT (●) plots from 31 October 2008 to 16 June 2010.

The soil moisture at the experimental area was low (<10%) in early and late summer (December 2008 and February 2009). High soil moisture content in mid summer reflected that rainfall in January 2009 (46.4 mm). The soil moisture remained high through autumn and winter 2009 and dropped in early spring 2009 before increasing again in mid and late spring 2009. The soil moisture remained low in summer 2009, early and mid autumn 2010. The soil moisture increased again in late autumn and early winter 2010. The soil moisture content between treatments was not significantly different throughout the study period, except in June 2009, where the soil moisture in CT plots, was significantly higher than MT plots (LSD 1.8).

3.2.6 Data analysis

Total annual pasture production (1 June to 31 May) (kg DM/ha/yr), pasture growth rate (kg DM/ha/day) and botanical composition (%DM) at each harvest date, and plant population and morphology at each measurement date were analysed by ANOVA of a 2 x 2 x 2 factorial design using GenStat, version 12.2, (VSN International Ltd, 2010). A least significant difference (LSD) test was used to separate treatments means when ANOVA indicated significant differences among treatments. The establishment phase for pasture growth was defined as the period from March to May 2008, Year 1 from June 2008 to May 2009 and year 2 are from June 2009 to May 2010. The data was analysed by ANOVA at each harvest point rather than repeated measures analysis as focus was on differences at each time point.

3.3 Results

3.3.1 Pasture herbage accumulation

Total herbage accumulation averaged 645, 7312 and 7935 kg DM/ha for the establishment phase, and years 1 and 2, respectively (Table 3.4). Total herbage accumulation in the establishment phase and years 1 and 2 was greater ($P < 0.01$) in HF than LF. Total herbage accumulation in year 1 was greater ($P < 0.05$) in CT than MT (7790 v 6871 kg DM/ha) but in year 2 was lower in CT than MT (7547 v 8367 kg DM/ha). Sown grass herbage accumulation was greater ($P < 0.001$) in CT than MF in year 1 and year 2 ($P < 0.001$). Total herbage accumulation was greater ($P < 0.001$) in SC than PC in both year 1 and year 2. Sown clover herbage accumulation was greater ($P < 0.001$) in SC than PC in the establishment phase and in year 1 but not in year 2. Sown clover herbage accumulation was greater ($P < 0.05$) in MT than CT in year 1 (793 v 655 kg DM/ha) and year 2 (1491 v 956 kg DM/ha). In year 2, a significant clover x tall fescue type interaction showed that SC growing at LF (3559 kg DM/ha) had the highest herbage accumulation ($P < 0.05$) compared to other clover-fertility combinations (average 2582 kg DM/ha). Sown grass herbage accumulation was greater

($P < 0.05$) in HF than LF in the establishment phase (637 v 418 kg DM/ha), year 1 (5647 v 4924 kg DM/ha) and year 2 (6071 v 5058 kg DM/ha).

Table 3.4 Total annual and sown species herbage accumulation (kg DM/ha/year) from May 2008 to June 2010 for main effects of tall fescue cultivar (CT, MT), sown clover (PC, SC) and soil fertility (HF, LF). Est. refers to the period from March to May 2008. Year 1 and 2 are for June to May periods. Significance of effects from ANOVA for main effects of tall fescue, clover and soil fertility are shown at the base of the table; *** $P < 0.001$, * $P < 0.05$, NS-not significant

	Total			Clover			Grass		
	Est	Year 1	Year 2	Est	Year 1	Year 2	Est	Year 1	Year 2
Tall fescue									
CT	625	7790	7547	50	655	956	517	5892	5950
MT	664	6871	8367	68	793	1491	534	4710	5114
Clover									
PC	656	6585	7101	24	539	1042	588	4871	5206
SC	633	7965	8681	85	945	1457	465	5594	5785
Soil fertility									
HF	775	7828	8734	62	760	1415	637	5647	6071
LF	516	6834	7180	53	714	1108	418	4924	5058
Significance									
LSD	173.0	256.6	359.2	27.2	147.8	403.8	74.7	281.5	255.6
Tall fescue	NS	*	*	NS	*	***	NS	***	*
Clover	NS	***	***	*	***	NS	*	NS	NS
Soil fertility	***	***	***	NS	NS	NS	***	*	*

Separation of strawberry and white clover in the perennial clover treatment showed that strawberry clover declined in pastures throughout the experiment. In the establishment phase, there was no significant difference between strawberry clover and white clover (12.9 v 11.1 kg DM/ha). The production of strawberry clover in year 1 (125 kg DM/ha) and year 2 (17 kg DM/ha) was less than white clover (414 kg DM/ha in year 1 and 1025 kg DM/ha in year 2).

Pasture growth rates throughout trial are shown in Figure 3.3a. Pasture growth rates were greater ($P < 0.05$) in CT than MT in both the first summer-early autumn (December 2008 to March 2009) and second summer-early autumn (December 2009 to February 2010) periods. Pasture growth rates were greater ($P < 0.05$) in MT than CT during the autumn to winter period of 2009 (Figure 3.3a). SC plots had significantly greater pasture mass than PC for two harvests in spring 2009, and

four harvests in spring-summer 2010 (Figure 3.3b). Soil fertility had a relatively small effect on pasture growth, with significantly greater growth in HF than LF plots on 5 harvests (May and June 2008, July and November 2009, and May 2010), interspersed throughout the measurement period (Figure 3.3c)

There was a significant interaction between sown clover and tall fescue for pasture growth on 15 April 2009, where pasture growth rate was higher in MT-PC than MT-SC and CT with SC and PC (Table 3.5). There was also a significant interaction between soil fertility and clover on 14 July 2009. Pasture growth was greater in SC than PC but only at high fertility. On 9 March 2010, pasture growth rate was greater in the PC than SC but only at HF (Table 3.6).

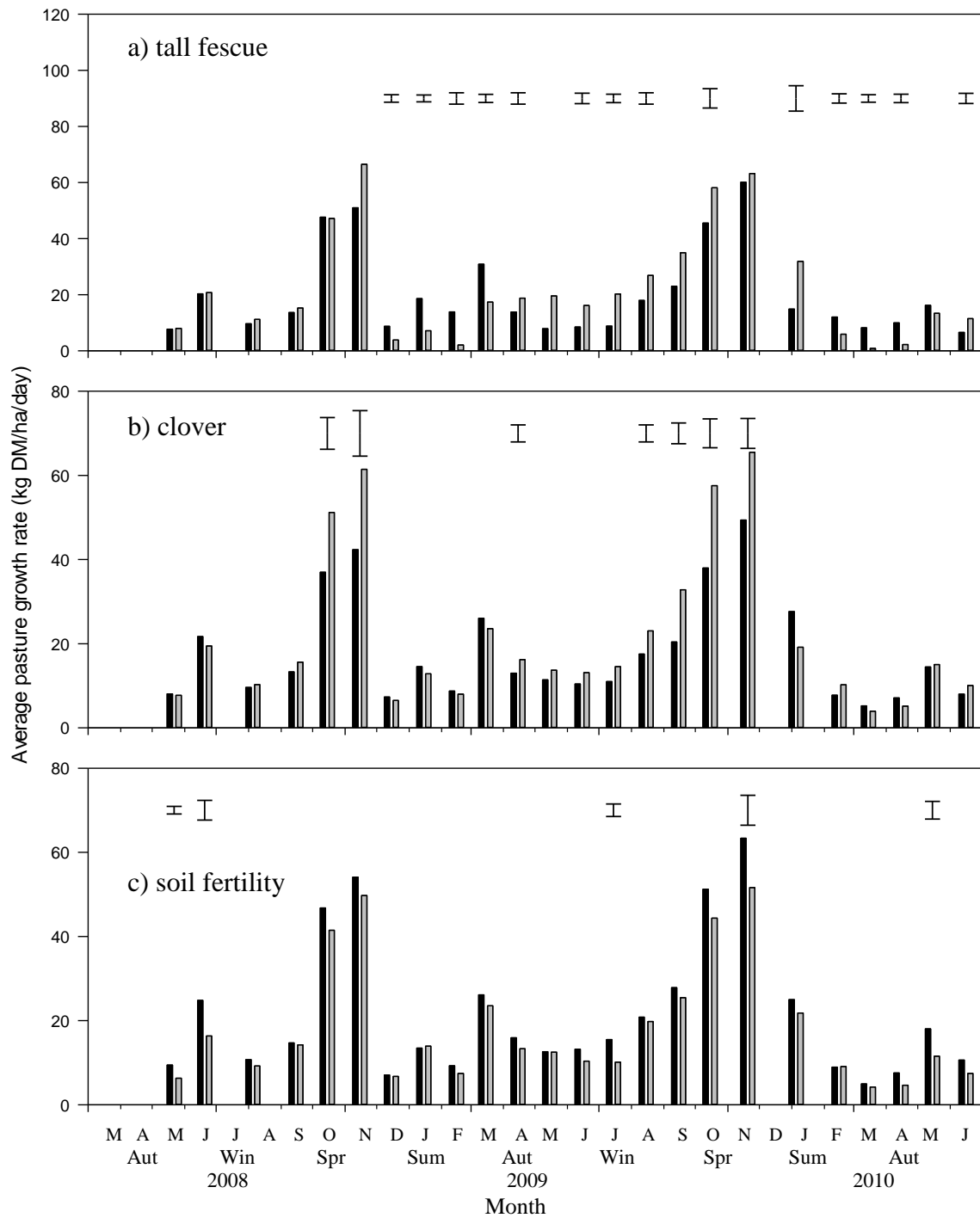


Figure 3.3 Average pasture growth rates (kg DM/ha/day) from May 2008 to June 2010 for main effects of a) tall fescue cultivar (CT ; MT), b) sown clover species (SC ; PC), and c) soil fertility (HF ; LF). Bars indicate LSD ($P = 0.05$) for main effects where significant effects were detected from ANOVA.

3.3.2 Percentage of sown clover

The percentage of clover was in general greater in CT than MT plots over the 2 year period, with significant treatments effect on nine occasions (Figure 3.4). The percentage of clover in the year 1 was greater ($P<0.05$) in SC than PC pastures in all harvests from late winter 2008 to summer 2008 (December). The pattern of higher percentage of clover in SC compared to PC in spring, and PC than SC in autumn was repeated in the year 2.

The dominant sown perennial clover was white clover. Strawberry clover reached a maximum abundance of 5.5 % on 9 January 2009 then declined and throughout the second year there was less than 1 % in pasture harvested with the remainder (up to 38.5 %) being white clover. The percentage of clover was greater ($P<0.05$) in LF than HF plots on four occasions (July and September 2008, September 2009 and May 2010) and in HF than LF plots of two occasions (October and November 2009).

There was a significant interaction between sown clover and tall fescue for the percentage clover on 10 February 2009 and 15 May 2010, where the percentage of clover was higher ($P<0.05$) in PC-MT but there was no effect of clover in CT (Table 3.5).

There was a significant interaction between soil fertility and sown grass for the percentage clover on 8 February 2010, where the percentage of clover was higher ($P<0.05$) in MT-LF than in CT-LF but not different between cultivars at HF (Table 3.6).

There was a significant interaction ($P<0.05$) between soil fertility and sown clover, for the percentage of clover on 26 August 2008, 10 June 2009 and 16 September 2009. The percentage of clover was greater in SC than PC at LF but not at HF (Table 3.6).

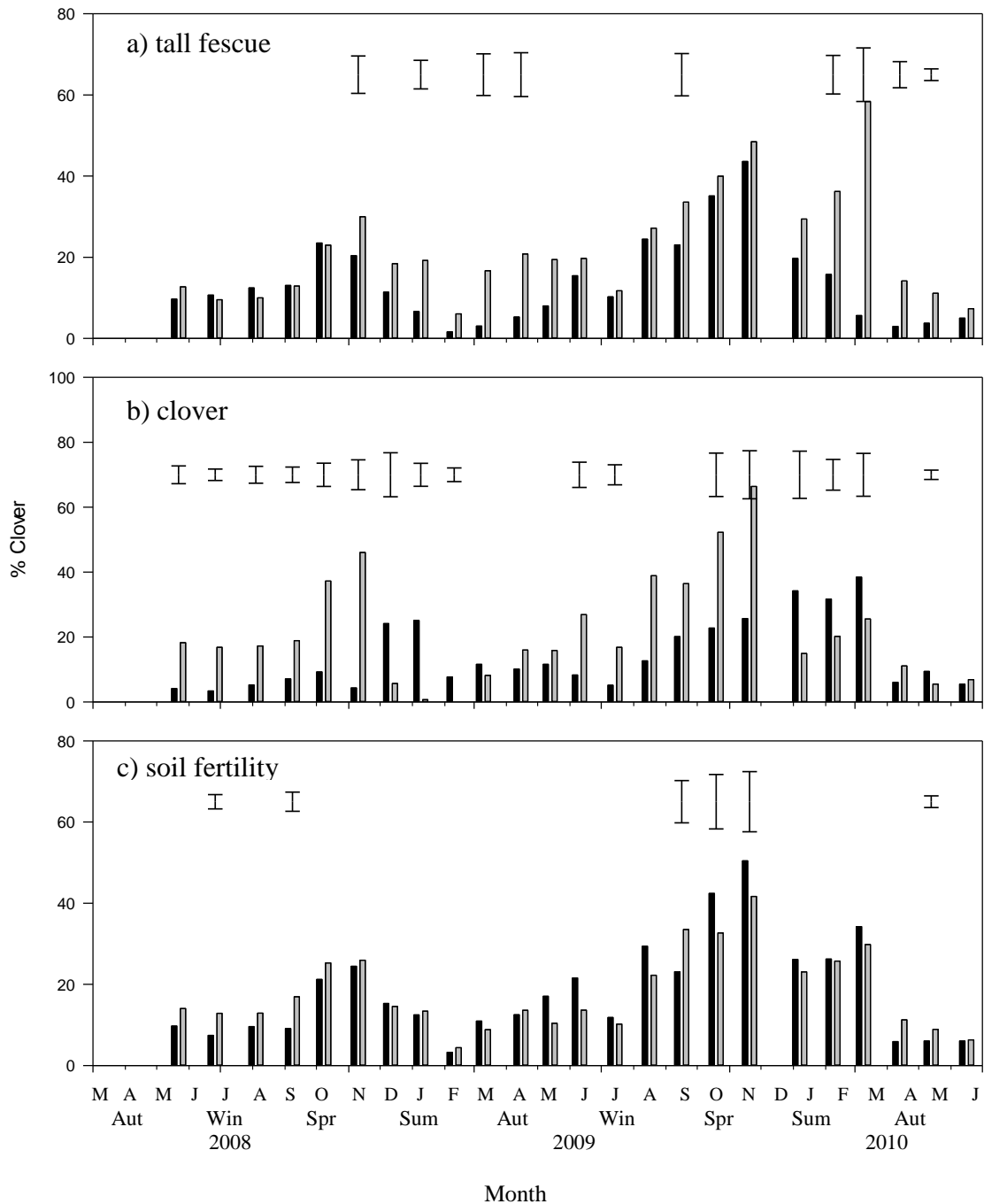


Figure 3.4 The percentage of clover content (%) on dryweight basis from May 2008 to June 2010 for main effects of a) tall fescue cultivar (CT ■; MT □), b) sown clover species (SC □; PC ■) and c) soil fertility (HF ■; LF □). Bars indicate LSD (P=0.05) for main effects where significant effects were detected from ANOVA.

3.3.3 Percentage of sown grass

There was a consistent pattern of a higher percentage of grass in CT than MT throughout the trial, with this effect significant on 10 occasions. The difference was pronounced from November 2009 to June 2010. The percentage of grass was higher ($P < 0.05$) in PC than SC at most pastures

harvests from late winter to December 2008. The effect switched from January to March 2009, with a higher ($P < 0.05$) percentage of grass in SC than PC. The pattern was repeated in the second year. There was little effect of soil fertility on the percentage of grass (Figure 3.5).

There was a significant interaction between sown clover and tall fescue on 9 January 2009 and 10 February 2009 for the percentage of grass. The percentage of grass was higher in PC than SC in MT pastures but not different in CT pastures (Table 3.5).

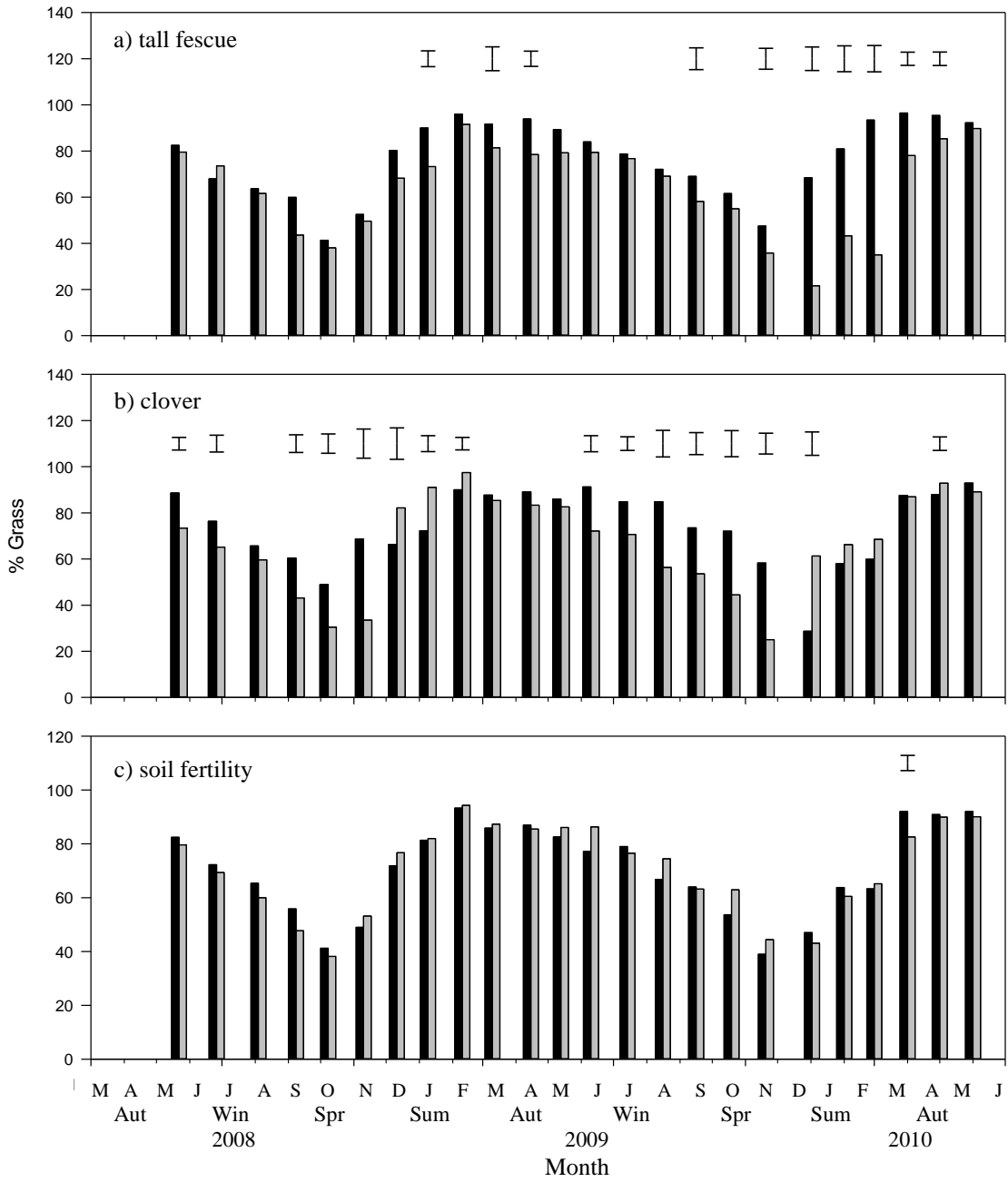


Figure 3.5 The percentage of grass content (%) from May 2008 to June 2010 for main effects of a) tall fescue cultivar (CT ■; MT □), b) sown clover species (SC □; PC ■), and c) soil fertility (HF ■; LF □). Bars indicate LSD (P=0.05) for main effects where a significant effect was detected from ANOVA.

3.3.4 Percentage of weed species

The percentage of weed species, mostly grass such as annual poa (*Poa annua*), barley grass (*Hordeum sp*) and broad-leafed weed such as yarrow (*Achillea sp.*), dandelion (*Taraxacum officinale*), broad-leaved dock (*Rumex obtusifolus*), spurrey (*Spergula avensis*) and plantain (*Plantago sp.*) in the plots is shown in Figure 3.4. The general patterns showed a high weed percentage (>20%) in the period after establishment. Thereafter, the percentage of weeds species remained low (<10%), with slight increases in spring (c. 10%) reflecting growth of annual grass weeds. The percentage of weed was higher ($P<0.05$) in MT than CT in August 2008, November 2008 and November 2009 and SC than PC in November 2008 and 2009.

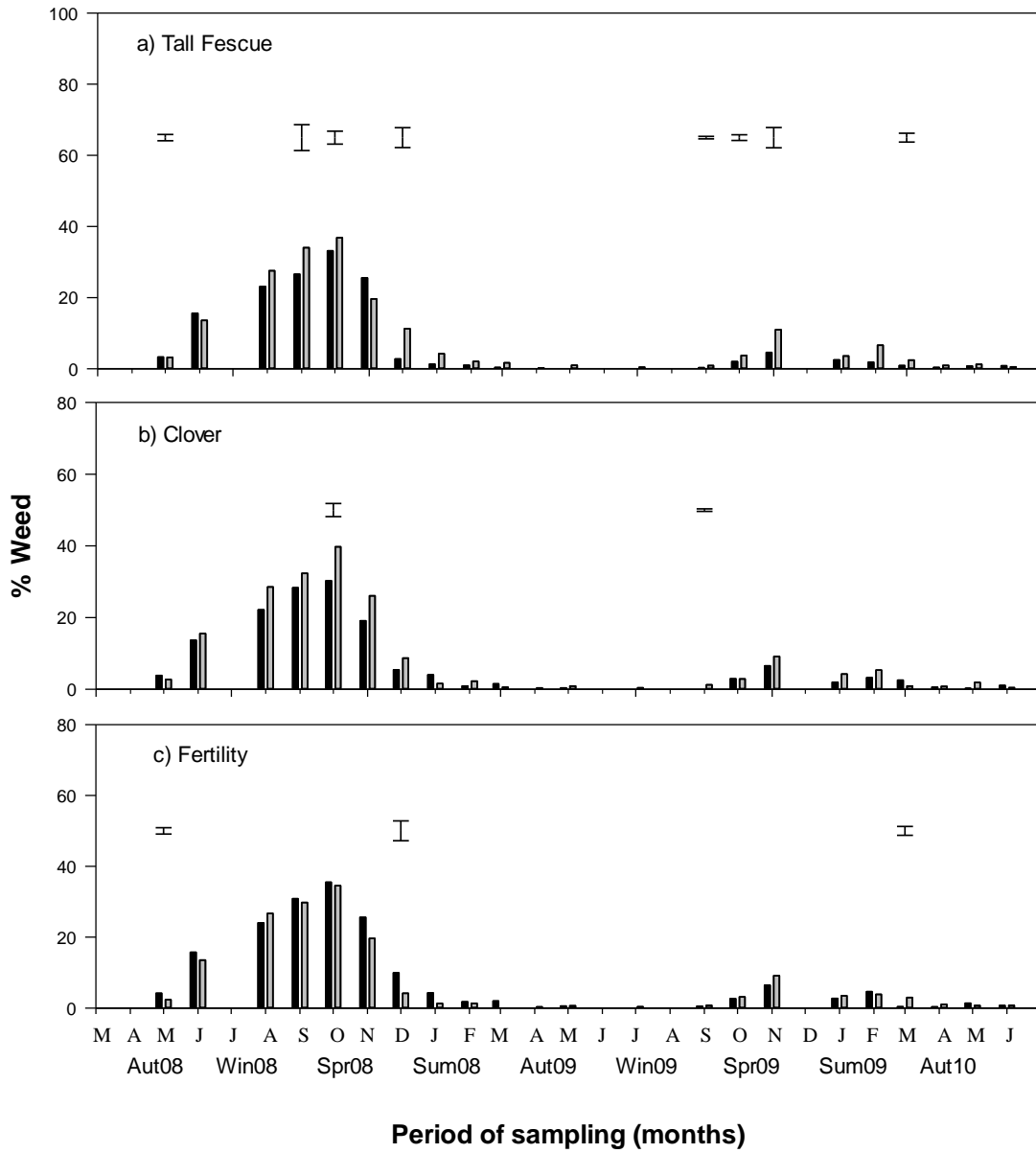


Figure 3.6 The percentage of weed (%) from May 2008 to June 2010 for main effects of a) tall fescue cultivar (CT ■; MT □), b) sown clover species (SC □; PC ■), and c) soil fertility (HF ■; LF □). Bars indicate LSD (P=0.05) for main effects where significant effects were detected from ANOVA.

Table 3.5 Interaction between tall fescue and sown clover for pasture growth (kg DM/ha/day), and percentage grass, clover and weed on dates where interaction was significant. Means within row followed by different letters are significantly different according to LSD test.

	CT		MT		LSD	P value
	SC	PC	SC	PC		
Pasture growth						
15/04/09	13.7a	14.0a	18.8b	12.0a	4.01	0.018
Grass						
09/01/09	93.4a	86.7a	88.8 a	57.8b	9.72	0.001
10/02/09	96.5a	95.5a	98.5a	84.5b	7.66	0.020
Clover						
10/02/09	2.6a	3.2a	0.2a	12. 1b	5.98	0.011
15/05/10	3. 5a	4.1a	7.6a	14. 8b	4.11	0.029

Table 3.6 Interaction between fertility and sown grass for percentage of grass, clover and weed on dates where interaction was significant. Means within row followed by different letters are significantly different according to LSD test.

	LF		HF		LSD	P value
	CT	MT	CT	MT		
Clover						
08/02/10	30.6b	41.8b	21.9a	9.6a	13.41	0.018
13/5/10	4.1a	13.7b	3.5a	8.6a	4.11	0.029

Table 3.7 Interaction between fertility and sown clover for pasture growth, and percentage grass, clover and weed on dates where interaction was significant. Means within row followed by different letters are significantly different according to LSD test.

	LF		HF		LSD	P value
	SC	PC	SC	PC		
Pasture growth						
14/07/09	9.4a	10. 8a	19.7b	11.2a	5.75	0.020
09/03/10	5.0ab	3.4a	2.9a	7.0b	3.82	0.037
Clover						
26/08/08	21.2c	3.0a	12.3b	2.1a	4.96	0.027
10/06/09	23.5b	5.5a	12.2a	13.8a	10.93	0.015
16/09/09	45.0b	21.9a	17.1a	21.7a	14.73	0.012
Weed						
22/05/08	3.8b	0.9a	3.8b	4.6b	2.56	0.046

3.3.5 Plant population and morphology

3.3.5.1 Subterranean clover

The subterranean clover (SC) population through the trial is shown in Figure 3.7. The SC population averaged 240 plants/m² at the first measurement in spring 2008, declining to an average of 146 plants/m² one month later. The plant population averaged 292 plants/m² in spring 2009, but increased markedly to an average of 2063 plants/m² in July 2010. There was no significant effect of tall fescue cultivar or soil fertility on the number of SC seedlings at any date (Figure 3.7).

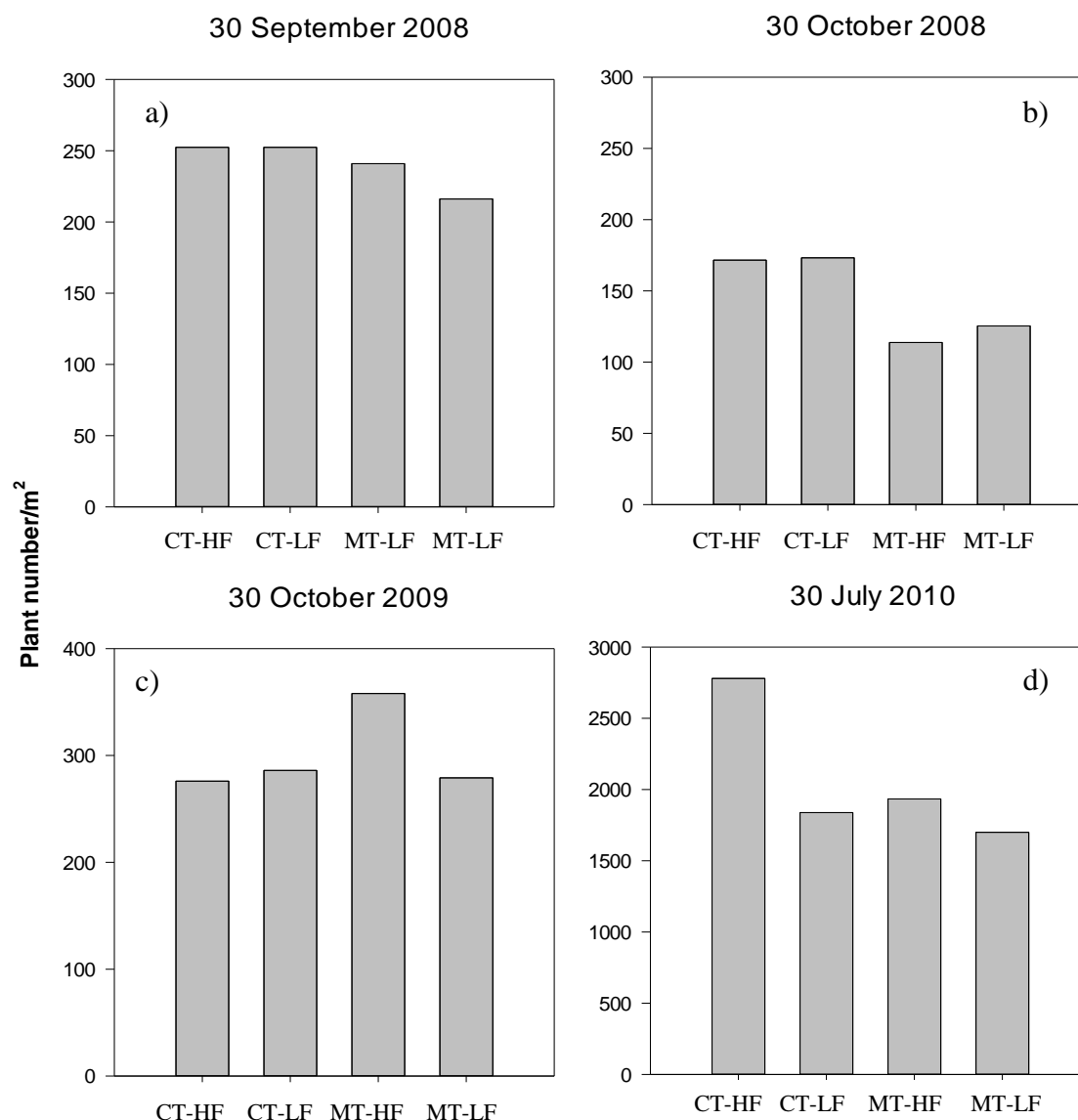


Figure 3.7 Number of subterranean clover plants per m² in September 2008 (a) October 2008 (b), October 2009 (c) and July 2010 (d). CT-HF – Advance high fertility, CT-LF – Advance low fertility, MT-HF-Flecha high fertility, MT-LF-Flecha low fertility.

Subterranean clover plants tended to be heavier in MT than CT at each sampling date (significant at $P = 0.12$, $P = 0.09$, $P = 0.07$, $P = 0.09$, for 30 September 2008, 30 October 2008, 30 October 2009, and 30 July 2010, respectively (Figure 3.8). MT-HF plants were heavier than all other treatments in July 2010 (significant interaction, $P < 0.05$).

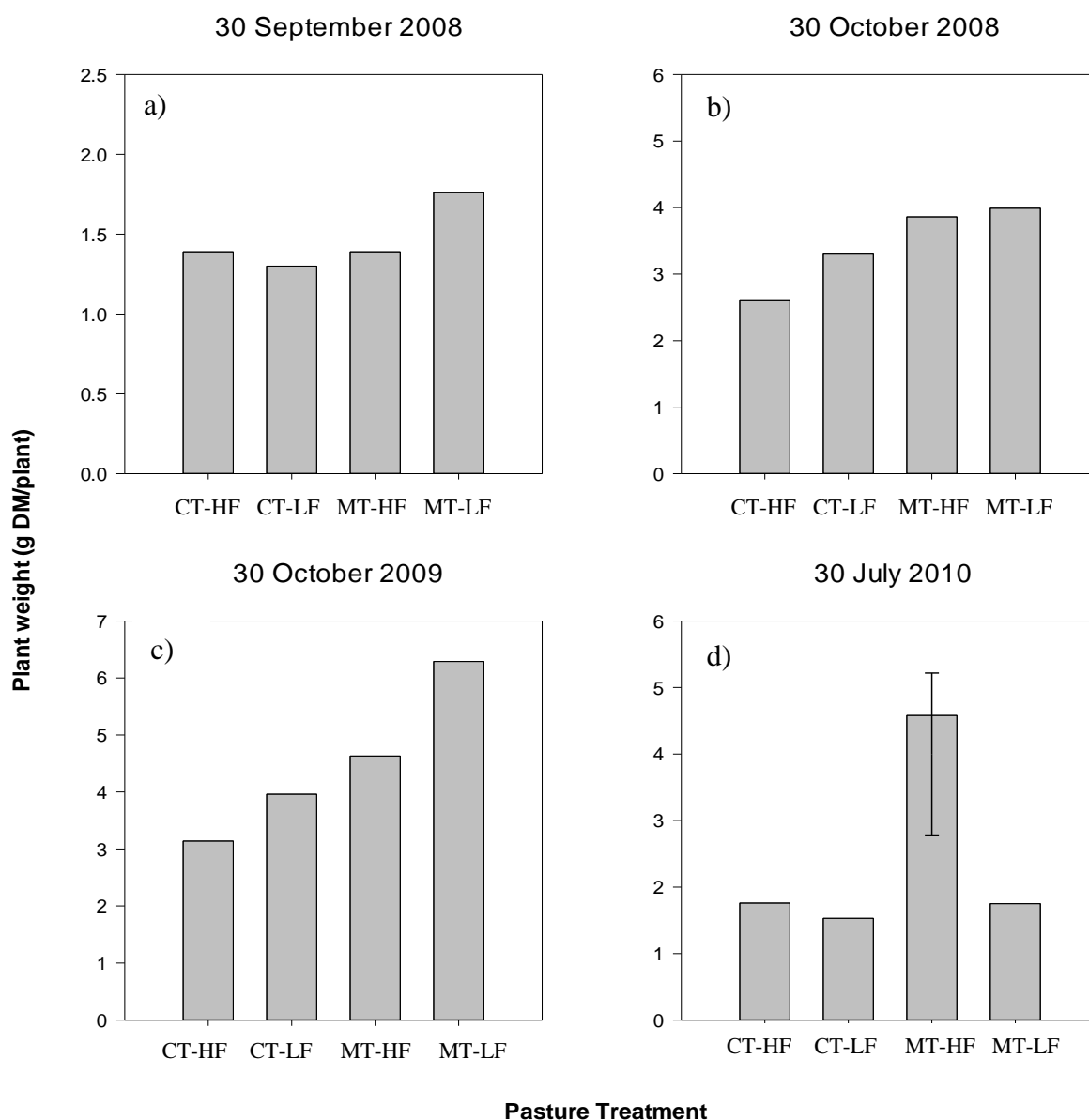


Figure 3.8 Dry weight of subterranean clover plants (g DM/plant) in September 2008 (a) October 2008 (b), October 2009 (c) and July 2010 (d). CT-HF – Advance high fertility, CT-LF – Advance low fertility, MT-HF-Flecha high fertility, MT-LF-Flecha low fertility. Error bar shows LSD for main effect of tall fescue and fertility significant at $P < 0.05$.

3.3.5.2 Perennial clover

Figures 3.9 and 3.10 show white clover and strawberry clover plant populations, dry weight and taproot and nodal root development over time in combinations of MT and CT. The number of strawberry clover per plants decreased from an average of 85 plants/m² at the start to an average 3 plants/m² at the final measurement 22 months later. The number of white clover plants averaged 122 plants/m² at the first harvest and increased to 240 plants/m² at final harvest. This increase reflected the fragmentation of white clover plants into individual units.

In autumn (27 April 2009) the number of strawberry clover plants was greater in the LF than HF plots ($P < 0.05$). In October 2008, there were more white clover plants in MT than CT but only in LF plots (Figure 3.9b).

The number of stolons per plants of both strawberry and white clover increased over time ($P < 0.05$), but to greater degree in white clover. The number of stolons per plant was not significantly different between treatments at any time (Figure 3.10).

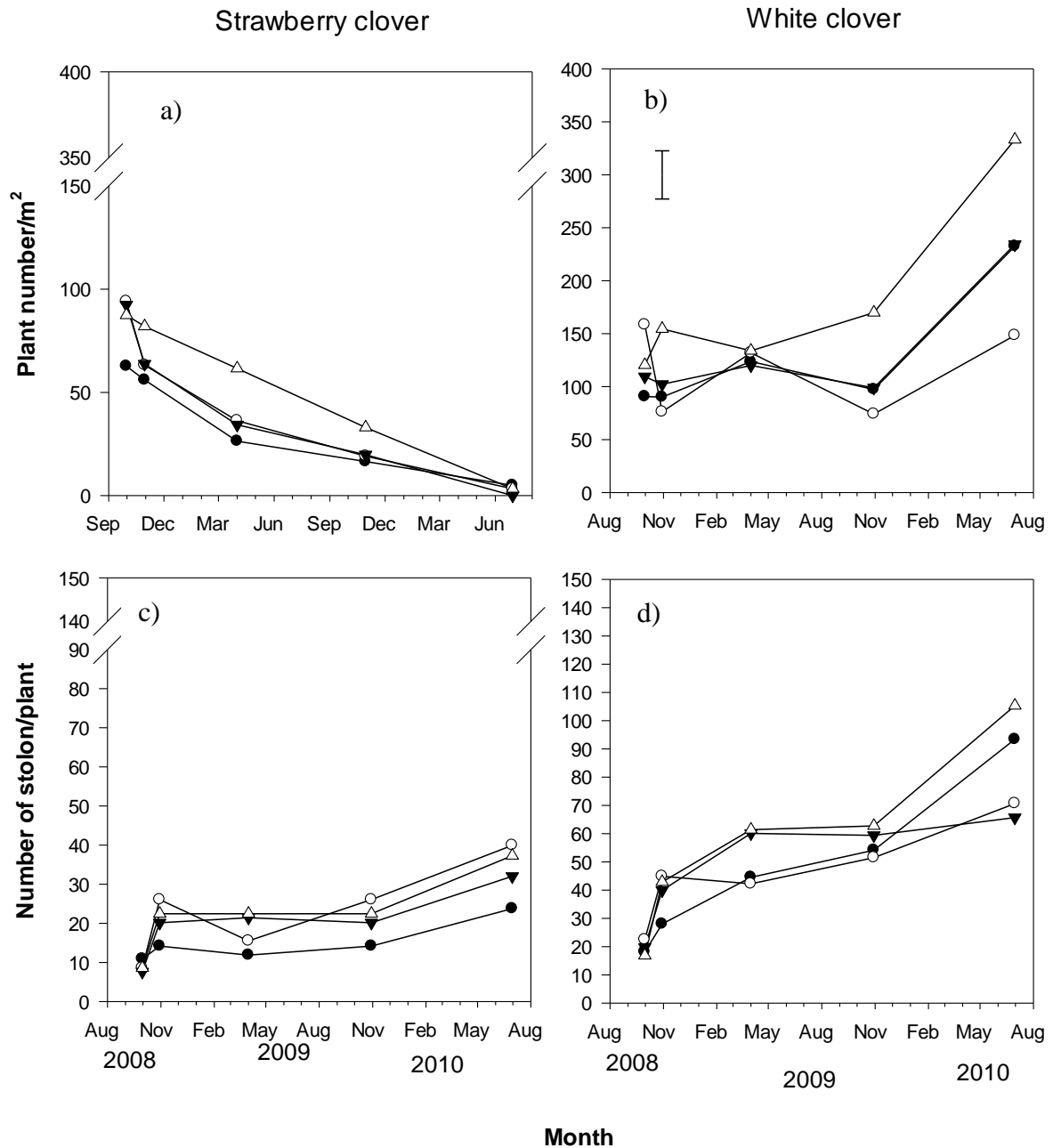


Figure 3.9 The number of plants (a, b) and number of stolon per plant (c, d) of white and strawberry clover measured on 30 September 2008, 30 October 2008, 27 April 2009 and 30 October 2009 and 30 June 2010 the treatments Advance (HF, ●; LF, ○), and MF (HF, ▼; LF, Δ). Error bars show the LSD of significant at $P < 0.05$.

The taproot diameter at the initial measurement was similar (3.0 mm) between white and strawberry clover. The diameter increased in strawberry clover by the second (6 mm) and third sampling (11 mm), but remained constant in white clover (c. 2.5mm).

The number of nodal roots per plant was 2 to 3 times higher in white clover than strawberry clover at all five sampling dates. The number of nodal root of white clover was higher ($P < 0.05$) in MT than CT. There was no significant effect on the number of nodal roots of strawberry clover of tall fescue cultivar and soil fertility. Taproot death over time was higher in white clover than strawberry clover. Most plants lost taproots in white clover but taproots in strawberry clover were retained after 24 months (Figure 3.10).

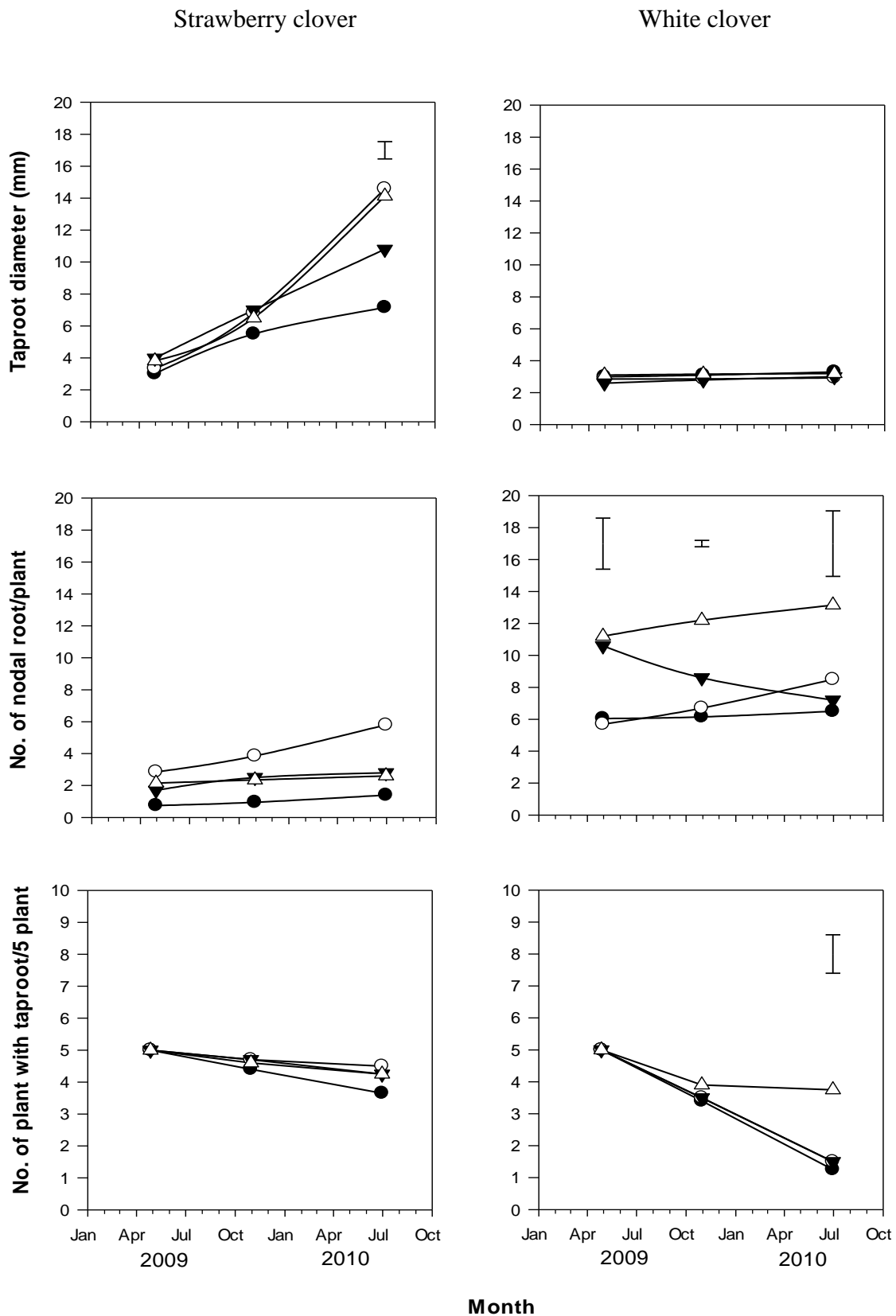


Figure 3.10 Taproot diameter, nodal root number and the number of plant out of five with taproot of strawberry (left) and white (right) clover sampled on 27 April 2009, 30 October 2009 and 30 June 2010 of the treatments CT (HF, ●; LF, ○), and MT (HF, ▼; LF, △). Error bars show the LSD of significant at P<0.05.

3.4 Discussion

3.4.1 Effect of tall fescue cultivar on DM pasture production and botanical composition

Total annual DM production was higher in CT than MT in year 1, but in MT than CT in year 2. Climate data showed that the rainfall during summer 2008 was higher than summer 2009 (181 v 107mm). This would have favoured the summer active CT which was growing at this time compared to the dormant MT. On a seasonal basis, MT had lower growth rate during summer and autumn, but more DM was produced by MT in winter and spring than CT. Tharmaraj *et al.* (2008) working in south east Victoria, found that the winter-active pasture (Flecha) had little effect on the overall seasonal distribution of forage supply or total annual yield compared with perennial ryegrass control treatments. Under conditions of partial irrigation in Canterbury, Minee *et al.* (2010) found that Mediterranean (Advance) and Continental (Resolute II) tall fescue cultivars produced a similar amount in the first two years, but that Mediterranean tall fescue had failed by the third year producing 3.8 t DM/ha less than Continental cultivar.

Tall fescue cultivar also affected the growth of sown clover species. On an annual basis more sown clover was observed on MT in both years and on seasonal basis, where MT dormant in summer and autumn, so less competition between grass and clover seedlings. These patterns may reflect interactions with growth pattern of tall fescue, where MT was less competitive due to slow growth following dormancy. Although growth of MT was greater in late winter and early spring than CT, particularly in the second spring, there was little apparent negative effect on clover DM production. On most occasions the percentage of clover was greater in MT than CT, and more total clover DM was grown in MT. Therefore, there was little evidence to support the hypothesis that Flecha through greater early spring growth may compromise the growth of subterranean clover.

For SC alone, annual DM production was 793 and 1491 kg DM/ha/y in MT (year 1, year 2) and (655 and 956 kg DM/ha/y) in CT. This increase in growth of SC was not due to greater

establishment of SC in MT in autumn, which might be expected to occur with dormancy and more open pasture, as seedling populations were generally higher in CT between cultivar. Rather it appeared to reflect larger seedling size in MT, perhaps due to less interspecific competition at establishment from delayed growth of MT. This was particularly pronounced in MF- HF in the second year. The results demonstrate how subterranean clover plant size, in addition, to plant population is an important determinant of DM production of this species.

3.4.2 Effects of sown clover on DM production and botanical composition

Total DM production was markedly higher with SC than PC, in year 1 (7350 v 6740 kg DM/ha) and in year 2 (8929 v 7350 kg DM/ha). This reflected primarily greater legume growth (1484 kg DM/ha in year 1, 2499 kg DM/ha in year 2) The increased legume growth reflected greater growth of SC throughout winter and spring. In summer, where SC died, the production of PC was higher than SC. However, the additional growth of PC at this time was not able to compensate for the lower spring production and total DM production was less. There was also tentative evidence that the growth of SC and associated N inputs boosted grass growth, annual grass production was 723 kg DM/ha (year 1) and 579 kg DM/ha (year 2) higher in SC than PC pasture.

These findings are in agreement with the study of Mills and Moot (2010) at the same site who found that cocksfoot pastures with subterranean produced 11.2 t DM/ha/y 2007/08 and 9.8 t DM/ha in 2008/09, which was 24% in 2007/08 and 40% in 2008/09 more than all other grass-based pastures. Ates *et al.* (2010) showed that cocksfoot-subterranean clover pastures out-yielded pasture without subterranean clover on dry stony soil by 45%.

Among the PC, there was more white clover than strawberry clover in year 1 and in year 2 with strawberry clover nearly absent in year 2. This indicates that strawberry clover did not persist under the intensive sheep grazing regime in this experiment, which made plants prone to grazing. The morphological measurements indicate that this may be due to a lack of nodal rooting, as it is

one of the key characteristics of legume persistence described by Thomas and Hay (2010). Although strawberry clover retained a longer taproot than white clover, the surviving plants had few nodal roots. This result indicates that strawberry clover is less persistent under the current grazing management, which may therefore need to be altered to improve production and persistence. This is considered further in Chapter 6.

Subterranean clover is dependent on flowering, seed production and subsequent recruitment for long term persistence. In this study, grazing was lax in the first spring to allow flowering and promote seed production (Ates *et al.*, 2008). This lax grazing promoted populations of 292 per m² of plants in the second spring, which was in line with the number suggested by Smetham and Sparks (2003) for high subterranean clover production in mixed pasture. Further flowering in the second spring created very high seedlings populations in the third year (2063/m²) demonstrating the ability to increase SC populations even under intensive grazing management. Further strategies to increase SC populations through autumn grazing management are considered in Chapter 5.

3.4.3 Effects of soil fertility on DM production and botanical composition

Differentiation fertilizer application maintained Olsen P values at 16 and 10 in HF and LF plots, respectively. This resulted in an extra total pasture production of 994 kg DM/ha in year 1 and 1554 kg DM/ha in year 2. This was in agreement with Campillo *et al.* (2005) who reported that pasture productivity of perennial ryegrass-legume and biological nitrogen fixation improved by liming and macronutrients (N, P, K, Mg, S) and micronutrients fertilisation. Black (2007) working at the same site at this study also showed that high fertility irrigated ryegrass white clover and ryegrass-Caucasian clover had greater DM yields than low fertility pastures yields by 1.25 t DM/ha/year. In the current study, the greater total DM production was primarily due to greater grass DM production at HF than LF (5859 v 4991 kg DM/ha), as there was little difference in the DM production of the legume (1088 v 911 kg DM/ha), with soil fertility,

particularly in first year. Tall fescue based pastures are noted as requiring high fertility of P and S to produce well (Kemp *et al.*, 1999), and from farm survey studies tall fescue becomes more dominant in pastures of higher P fertility (Smith *et al.*, 1998). The DM production of clover was higher in HF than LF. The explanation for the lack of a consistent effect of soil fertility on legume DM production may be related to grass dominance suppressing the development of clover in HF compared to LF (Dear and Virgona (1996).

3.5 Conclusions

The following main conclusions can be drawn from this chapter.

- Total annual DM production was greater at high fertility reflecting increased growth of tall fescue compared with less impact of soil fertility on clover.
- The effect of tall fescue cultivars on total DM yield was variable with summer-active Continental tall fescue out yielding winter-active Mediterranean tall fescue in a wet year and winter-active Mediterranean tall fescue out yielding summer-active Continental tall fescue in dry year. Mediterranean tall fescue become summer-dormant in response to increasing daylength and high temperature, but summer-active Continental tall fescue grow when soil moisture available.
- Subterranean clover pastures produced more than perennial clover pastures, due to both greater legume and grass production. Subterranean clover is a more suitable legume for dryland pastures than a combination of perennial clover.
- Persistence of strawberry clover was poor with few plants surviving two years under intensive sheep grazing.

Chapter 4

Pasture nutritive value and liveweight gain of sheep grazing winter and summer-active tall fescue pastures growing with white, strawberry and subterranean clover at high and low P and S fertility

4.1 Introduction

In dryland pastures in Canterbury, New Zealand, where soil moisture deficits are typical in summer (Mills *et al.*, 2008), alternative grass and legume combinations are sought to provide persistent pastures. It is particularly important that these pastures produce high quality feed in the late winter and early spring period in order to feed lactating ewes and their lambs. This ensures that lamb growth rates are high and that lambs are finished before the onset of summer dry conditions (Bywater *et al.*, 2011). This enables feed demand to be reduced and risks associated with dryland farms to be managed more effectively (Bywater *et al.*, 2011). Furthermore, it is important that pastures are able to support grazing in autumn prior to mating of ewes, so promoting high reproductive performance (Bywater *et al.*, 2011).

In grazing studies in dryland pastures, (Mills *et al.*, 2008) has shown the importance of the annual legume subterranean clover in promoting high lamb growth rates in cocksfoot based pastures in early spring. Further, Ates *et al.* (2008) growth rates of greater than 300g/head/day for twin suckling lambs on subterranean clover-cocksfoot based pastures. These results were attributed to the greater feeding value (nutritive value and DM intake) of subterranean clover-cocksfoot pastures. An alternative approach to promote high feeding value in early spring is to use a grass species or cultivars such as winter-active Mediterranean tall fescue with greater cool season activity than perennial ryegrass or summer-active Continental tall fescue cultivars. While

some studies have measured pasture production of Continental and Mediterranean tall fescue (Minee *et al.*, 2010), there is little data on livestock performance.

The objective of this research was to quantify the interactive effects of tall fescue cultivar and soil fertility on;

(1) Pasture nutritive value and liveweight gain of ewes and lambs in spring.

(2) Pasture nutritive and hogget liveweight gain in autumn.

4.2 Material and methods

4.2.1 Experimental site and design

The experimental site used for this experiment was the same as the site used in the pasture production experiment (Chapter 3). Details of general management are included in that section. Additional measurements are described here.

4.2.2 Grazing management

Sheep liveweight gain trials were conducted in spring 2008 and 2009, and autumn 2009 and 2010. Details of grazing treatments are given in Table 3.3.

4.2.2.1 Spring

In spring 2008, four groups each made up of 7 Coopworth ewes and their single one week old Coopworth-Suffolk cross lambs were used in the grazing trial. Two groups were allocated to each block, one group grazing LF plots and the other grazing HF plots at the stocking rate of 22 ewes/ha) The grazing started with MT-SC plots first on 11 September 2008 before moving to MT- PC, and then CT-SC, and CT- PC plots. Grazing ceased on 8 October 2008 in all plots in order to allow the SC to flower and set seed and ensure production in subsequent years. The groups spent on average 2 days per paddock with a rotation length of 16 days. Plots were not grazed again until autumn, with mechanical topping using a ride-on mower carried out in January 2009 to remove residual seedheads.

In spring 2009, 8 groups initially each containing 3 Coopworth ewes and their twin lambs (6) grazed the trial from 20 August to 9 December 2009. Four groups were allocated to each block, which represented one group grazing LF- CT and LF-MF plots and HF- CT and HF-MT in each block (18 ewes/ha). The number of ewes and lamb was reduced to two and four, respectively from 22 October until 9 December 2009 to enable pasture growth to more closely match animal demand. The groups spent on average 2 days per paddock with a rotation length of 8 days. Plots were not grazed again until autumn 2010.

4.2.2.2 Autumn

The autumn grazing trial was carried out in autumn 2009 and 2010 using hoggets. The autumn 2009 grazing trial started from 1 April 2009 until 22 May 2009, plots were grazed with 8 groups. Four groups were allocated to each block, which represented one group allocated to each of LF-CT, LF-MT, HF-CT and HF-MT. There were 3 Coopworth ewe hoggets per group for MT (18 sheep/ha) and 4 hoggets per group for CT (25 sheep/ha), reflecting greater pasture mass available at this time in the CT plots. The groups spent on average 2 days per paddock with a rotation length of 8 days.

The autumn 2010 grazing trial was started from 6 March until 24 May 2010, plots were grazed with 8 groups, each containing 3 Coopworth ewe hoggets (18 sheep/ha). Four groups were allocated to each block, which represented one group allocated to each of LF-CT, LF-MT, HF-CT and HF-MT. Grazing ceased from 24 March until 2 May 2010 because of the low pasture mass due to summer dry conditions over this period which slowed the growth of grass and clover, where all hoggets were reallocated to another site outside the experimental plots. The groups spent on average 2 days per paddock with a rotation length of 8 days (Table 4.1).

Table 4.1 Measurement period for sheep grazing the swards from 2008 to 2010.

	Spring 2008	Autumn 2009	Spring 2009	Autumn 2010-1	Autumn 2010-2
Start date	11 September	1 April	20 August	6 March	2 May
Finish date	8 October	22 May	9 December	24 March	24 May
Duration (d)	27	51	111	18	22

4.2.3 Measurements

4.2.3.1 Herbage mass

Pre- and post-grazing herbage mass (kg DM/ha) was measured using a calibrated raising plate meter (Jenquip, New Zealand), prior to and after grazing each plot. On each occasion, a total of 50 raising plate meter readings per plot were taken in a zigzag pattern across each plot. The average meter reading was recorded and converted to herbage mass using a calibration equation. The meter reading was calibrated against herbage mass for each treatment on three occasions with one calibration for each season using the double sampling method described by Hodgson *et al.* (1999). Table 4.2 shows calibration curves for each cultivar in spring and autumn.

Table 4.2 Calibration of Raising plate meter

Pasture type	Season	equation	r ²
Advance	Spring	kg DM/ha = 112.5RPM(cm)	0.78
Flecha	Spring	kg DM/ha = 155.5RPM(cm)	0.70
Advance	Autumn	kg DM/ha = 94.5RPM(cm)	0.63
Flecha	Autumn	kg DM/ha = 108.4RPM(cm)	0.64

4.2.3.2 Botanical composition

Botanical composition was measured prior to sheep being introduced into each plot in spring. In autumn samples were collected once per month on all 32 paddocks. Around 10 samples (representative of what the animal is eating) were sampled to obtain a bulked sample of around 500 g fresh weight. Samples were bulked across treatments for each complete grazing rotation (e.g. 8 days if on four paddock rotation). Botanical composition of the bulked sample was then calculated by separating a sub-sample of around 200 pieces into grass, legumes, weeds and dead material before drying at 70°C and weighing. The botanical composition on a DM basis was then determined.

4.2.3.3 Nutritive value

Dried pasture samples collected for botanical composition were retained for chemical analyses. The samples were bulked according to their respective plots for the whole grazing trial period and milled to pass through a 1-mm sieve of centrifugal grinder (Retsch ZM 200) for chemical analysis. Ground samples were then analysed for crude protein (CP), digestible organic matter (DOMD%), acid detergent fibre (ADF%) and neutral detergent fibre (NDF%) by near infra-red spectroscopy using a calibrated NIRS-Foss NIR Systems 5000 Rapid Content Analyser (Adesogan *et al.*, 2000). Crude protein content of pasture on offer was calculated by $N\% \times 6.25$ and metabolisable energy (ME) (MJ kg/DM) content was calculated by $DOMD \times 0.16$ (Nicol, 1989).

4.2.3.4 Liveweight gain

All sheep (ewes and lambs) were weighed unfasted during the spring grazing trial, as the fasted live weight was not suitable for lactating ewes and lambs. To minimise body fill effects, ewes and lambs were weighed at the same time (around 9.00 am) on each occasion. Fasted live weight (after overnight fast) was recorded in all autumn grazing trial animals. When grazing periods (e.g. in spring) exceed 30 days, interim measurements at 30 days were taken. Live weight gain (g/head/d) was calculated for each measurement period. Grazing days was calculated as the total number of ewes + lambs per plot multiplied by the number of days each plot was grazed, and converted to grazing days per hectare. Live weight gain hectare was calculated for each treatment group by multiplying grazing days in each measurement period by live weight gain per head in the corresponding period.

4.2.4 Statistical analysis

Liveweight gain per head per day (g/head/d) and per ha per day (kg/ha/d), pasture mass, botanical composition and pasture nutritive value data were analysed with either soil fertility or soil fertility and tall fescue as factors depending on season and the number of treatment mobs. Mean liveweight gain per head averaged across each treatment was used as the response variable

rather than individual sheep. Pasture mass and botanical composition data in spring 2009 were grouped by month for statistical analysis. Where ANOVA was significant, means were separated by least significant difference (LSD) at $P < 0.05$.

4.3 Results

4.3.1 Pre- and post-grazing pasture mass

Pre-grazing pasture mass averaged 783 kg DM/ha over the 27 day period in spring 2008 and was greater ($P < 0.001$) in MT (998 kg DM/ha) than CT (580 kg DM/ha) and in HF (922 kg DM/ha) than LF (657 kg DM/ha) ($P < 0.05$). Post-grazing pasture mass was greater ($P < 0.05$) in HF (581 kg DM/ha) than LF (417 kg DM/ha), and in MT (606 kg DM/ha) than CT (392 kg DM/ha).

Pre-grazing pasture mass in spring 2009 was higher ($P < 0.001$) in MF (564 kg DM/ha) than CT (436 kg DM/ha) throughout the grazing period (Figure 4.1). Post-grazing pasture mass was also greater in MT (470 kg DM/ha) than CT (335 kg DM/ha) throughout spring 2009 and was higher ($P < 0.05$) in HF than LF in November-December 2009.

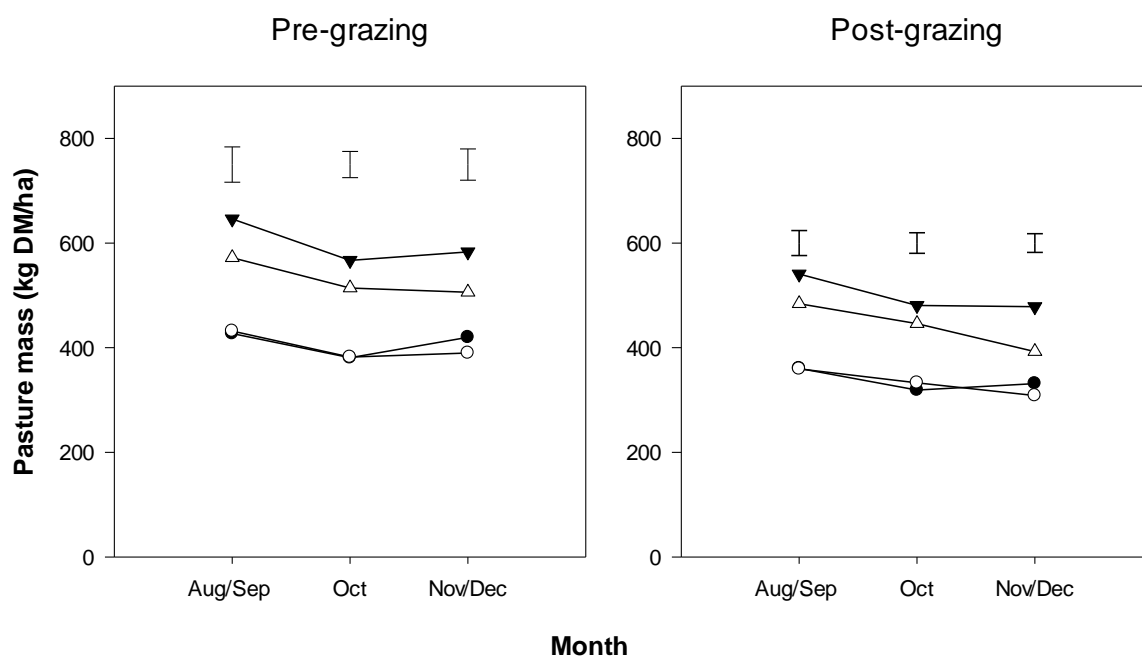


Figure 4.1 Pre-grazing and post-grazing pasture mass over 111 day period from to 20 August to 9 December in spring 2009 in Advance plots at HF (●) and LF (○) and MT plots at HF (▼) and LF (Δ). Bars represent LSD for main effect at each date.

Pre-grazing pasture mass over the 51 day period from 1 April to 22 May in autumn 2009 was in MT than CT in May 2009. Post-grazing pasture mass was greater ($P<0.001$) in MT than CT in May, and in PC than SC ($P<0.05$) in April and May 2009 (Figure 4.2).

Pre-grazing and post-grazing pasture mass of autumn 2010 was higher ($P<0.001$) in MT than CT in February, March, May and June 2010. Pre-grazing pasture mass was higher ($P<0.05$) in PC than SC in February 2010, and pre- and post-grazing pasture mass were greater ($P<0.05$) in HF than LF in March 2010.

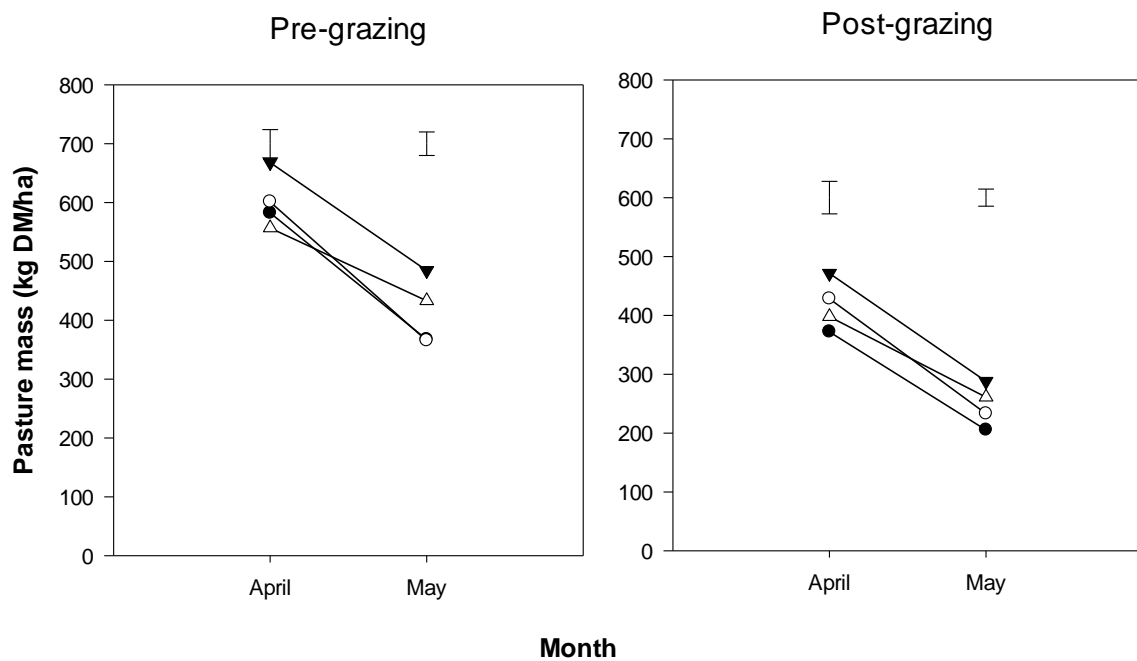


Figure 4.2 Pre-grazing and post-grazing pasture mass over 51 day period for 1 April to 22 May in autumn 2009 in CT-HF (●), CT-LF (○) and MF-HF (▼), MT-LF (△) plots. Bars represent LSD for main effects of soil fertility and tall fescue ($P<0.05$).

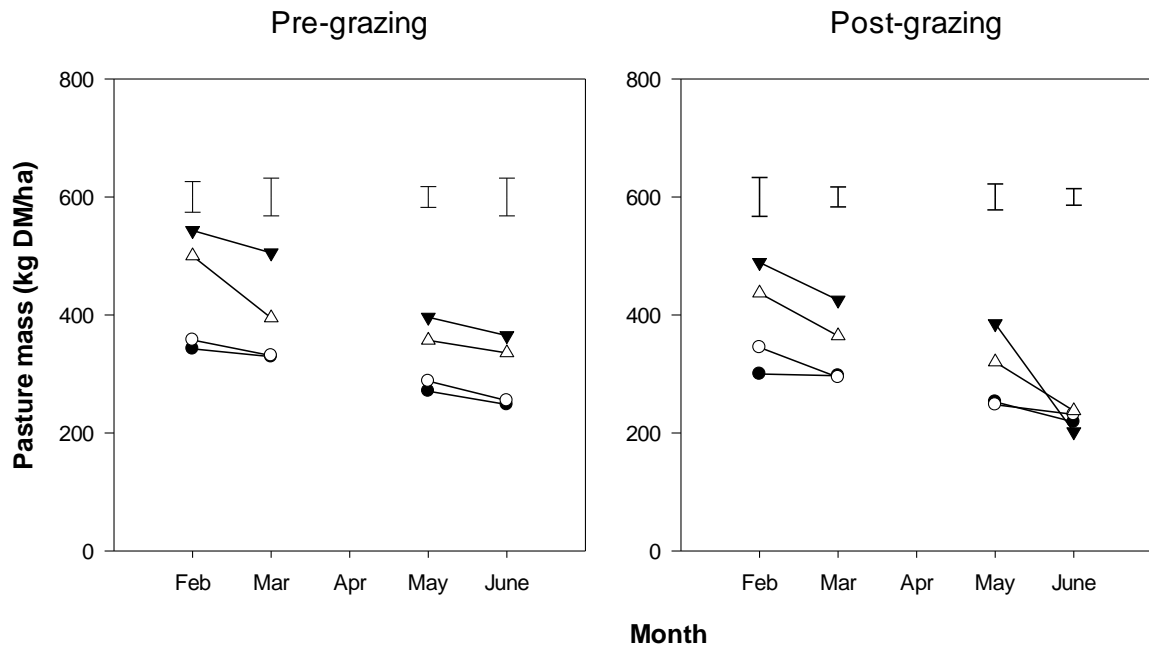


Figure 4.3 Pre-grazing and post-grazing pasture mass in autumn 2010 in CT-HF (●), CT-LF (○) and MT-HF (▼), MT-LF (△) plots. Bars represent LSD for main effects at each date. ($P < 0.05$).

4.3.2 Botanical composition

4.3.2.1 Spring grazing

The clover content of the pasture averaged 20% in 2008 and was greater ($P < 0.05$) at LF (22.8%) than HF (19.9%) plots and in CT (24.6%) than MT in 2008. The clover content of pasture in spring 2009 increased over the grazing period from 20 August to 9 December 2009. The clover content of the pasture averaged 31.2%, with 32.9% in HF and 29.5% in LF plots. The clover content was higher in ($P < 0.05$) MT than CT on August/September and October 2009 (Figure 4.4).

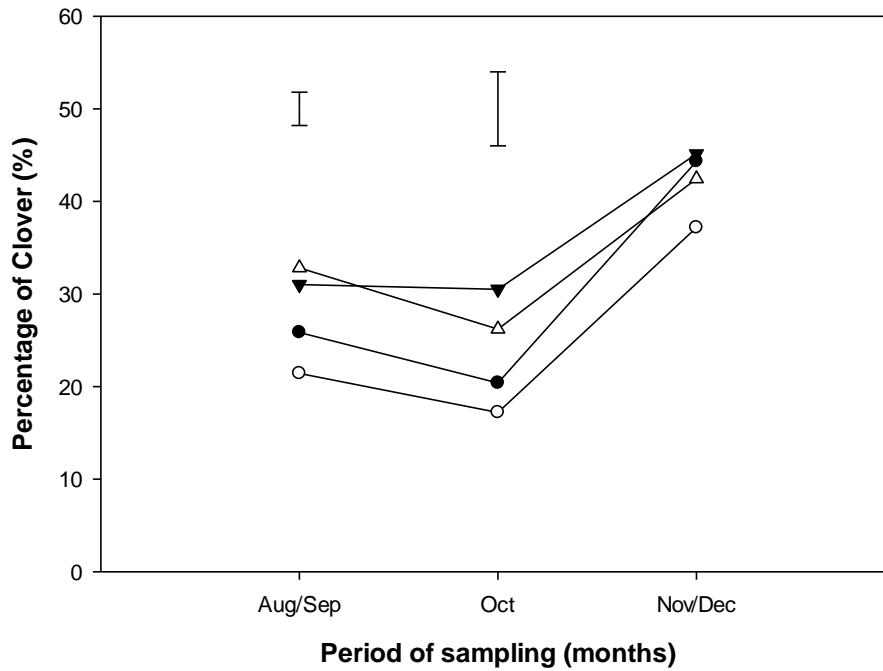


Figure 4.4 Botanical composition of the herbage for high and low fertility in spring 2009 grazing trial for the treatments of CT-HF (●), CT-LF (○), MT-HF (▼) and MT-LF (△). Bars represent LSD for main effects of the above the periods when ANOVA was significant ($P < 0.05$).

4.3.2.2 Autumn grazing

In 2009, the percentage of clover in the pasture on offer was low ($< 20\%$) and was unaffected by tall fescue or soil fertility (Figure 4.5a). The percentage of clover in March 2010, was higher ($P < 0.05$) in MT due to lack of growth of MT (Figure 4.5 b). However, the clover percentage in CT plots remained low. By May 2010, the percentage of clover in MT plots had dropped to similar levels to CT (Figure 4.5b).

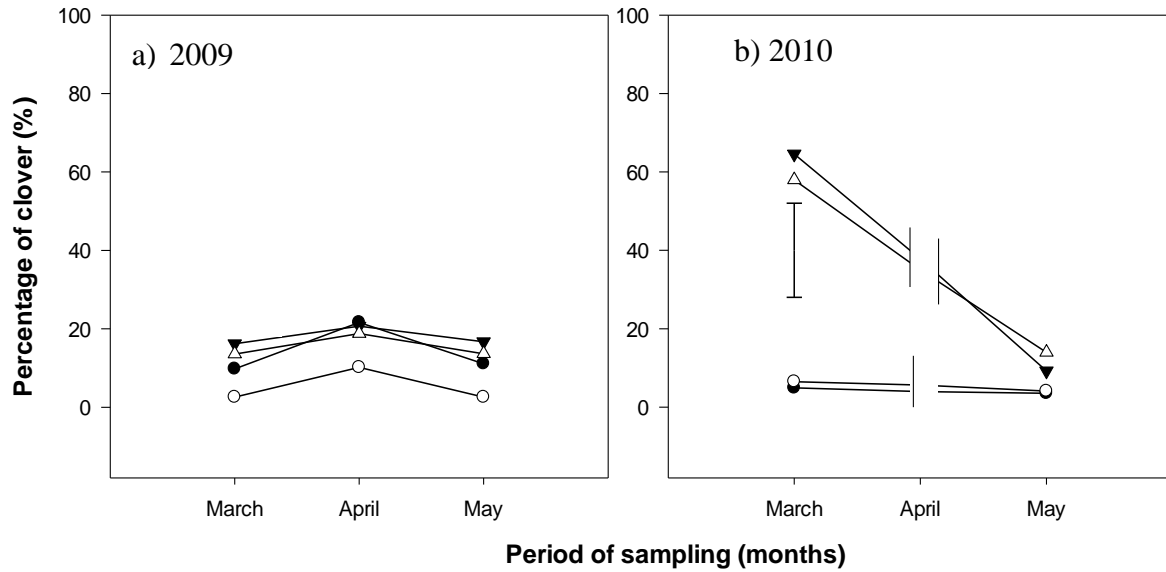


Figure 4.5 Botanical composition of the herbage in autumn 2009 and 2010 for the treatments of CT-HF (●), CT-LF (○), and MT-HF (▼) and MT-LF (△). Bars represent LSD for main effects of the above the periods when ANOVA was significant ($P < 0.05$).

4.3.3 Nutritive value

The nutritive value of the pasture in each grazing season is shown in Table 4.3 – 4.7. The values are averages across the entire grazing period in each season. In spring 2008, ADF and NDF and ME were higher ($P < 0.001$) in CT than MT. ADF and NDF were also higher in PC than SC, and at HF than LF (Table 4.3). There were significant interactions ($P < 0.001$) between clover type and tall fescue cultivars, where CT- PC were the highest in ADF and NDF, and MT- PC was the highest in ME. The protein content was higher ($P < 0.001$) in CT than MT, in PC than SC in LF than HF. There were interactions between clover and tall fescue cultivar, where SC at HF had higher protein content than the other treatment (Table 4.3).

Table 4.3 The nutritive value of the pre-grazing pasture sample during the spring 2008 grazing trial (11 September – 8 October 2008) for main effects of tall fescue, clover and soil fertility. Significance of ANOVA for main effects and interaction are shown at base of table.

	ADF(%)	NDF(%)	ME (MJ/kg DM)	CP (%)
Tall fescue				
CT	27.4	50.8	10.8	17.2
MT	24.8	46.1	12.1	11.3
Clover				
PC	26.6	48.5	11.4	13.8
SC	25.6	46.8	11.5	14.7
Fertility				
HF	26.7	48.9	11.3	13.9
LF	25.5	46.3	11.5	14.6
Significance				
Tall fescue	***	***	***	***
Clover	***	***	NS	*
Fertility	***	***	NS	*
Fescue x Clover	***	***	***	NS
LSD (main effect)	0.455	0.921	0.085	0.587

Significance: * P<0.001, * P<0.05, NS - not significant**

The nutritive value of the pasture in 2009 (12.3 MJ/kg DM ME) was on average higher than 2008 although it was collected for longer time period into late spring. Nutritive value did not differ between treatments in spring 2008 except that the ME of pasture was greater (P<0.05) in PC than SC.

Table 4.4 The nutritive value of the herbage sample during the spring 2009 grazing trial (20 August – 10 December 2009) for main effects of tall fescue, clover and soil fertility. Significance of ANOVA for main effects and interaction are shown at base of table.

	ADF(%)	NDF(%)	ME (MJ/kg DM)	CP(%)
Tall fescue				
CT	20.3	38.7	12.2	19.2
MT	21.1	39.6	12.3	18.8
Clover				
PC	20.9	40	12.4	18.8
SC	20.5	37.4	12.2	19.3
Fertility				
HF	21.1	39	12.3	18.9
LF	20.4	38.4	12.2	19.1
Significance				
Tall fescue		NS	NS	
Clover		***	*	
Fertility		NS	NS	
LSD (main effect)		1.135	0.133	

Significance: * P<0.001, * P<0.05, NS - not significant**

In autumn 2009, ADF was higher ($P<0.05$) in CT than MT and PC than SC (Table 4.5). The ME content of pasture on offer was higher ($P<0.05$) in HF than LF and in CT than MT (Table 4.5). The CP content was higher ($P<0.001$) in MT than CT and in SC than PC (Table 4.5). The CP content of the pasture in autumn 2010 was greater in MT than CT.

Table 4.5 The nutritive value of the herbage sample during the autumn 2009 grazing trial for main effects of tall fescue, clover and soil fertility. Significance of ANOVA for main effects and interaction are shown at base of table.

	ADF(%)	NDF(%)	ME (MJ/kg DM)	CP(%)
Tall fescue				
CT	21.1	42.2	12.6	13.4
MT	21.6	41.5	12.1	16.9
Clover				
PC	22.2	41.6	12.4	13.3
SC	20.5	38.8	12.3	17.1
Fertility				
HF	21.4	42.1	12.4	15.3
LF	21.4	41.6	12.2	15.2
Significance				
Tall fescue	*	NS	***	***
Clover	***	***	NS	***
Fertility	NS	NS	*	NS
LSD (main effect)	0.723	1.296	0.135	1.040

Significance: * $P<0.001$, * $P<0.05$, NS - not significant**

Table 4.6 The nutritive value of the herbage sample during the autumn 2010 grazing trial for main effects of tall fescue, clover and soil fertility. Significance of ANOVA for main effects and interaction are shown at base of table.

	ADF(%)	NDF(%)	ME (MJ/kg DM)	CP(%)
Tall fescue				
CT	22.5	44.8	12.2	14.4
MT	22.3	47.1	12.2	17.2
Clover				
PC	22.4	46.2	12.2	16.0
SC	22.4	45.7	12.2	16.2
Fertility				
HF	22.9	46.4	12.0	15.6
LF	22.0	45.5	12.4	16.0
Significance				
Tall fescue				***
Clover				NS
Fertility				NS
LSD (main effect)				1.426

Significance: * P<0.001, * P<0.05, NS - not significant**

4.3.4 Sheep liveweight gain (LWG)

The LWG/head/day and LWG/ha/day of lambs in spring 2008 was not significant between HF and LF (Table 4.7). The LWG/head/day of ewes was greater ($P<0.001$) in HF than LF. The average LWG/head/day of lambs over the entire period in spring 2009, averaged 209 g/head and was not significantly different between treatments (Table 4.7). However, LWG/hd/d was greater ($P<0.05$) over period from 22 October to 23 November in HF (297 g/d) than LF (213 g/d). The LWG/hd/d of ewes over the entire period of spring 2009 was greater ($P<0.05$) in CT than MT (Table 4.7). The LW gain/hd/d of ewes was greater ($P<0.05$) in LF than HF from 21 September to 22 October but in HF than LF from 22 October to 23 November.

Table 4.7 Liveweight gain/head/day (g) of lambs and ewes in spring 2008 and 2009 grazing Advance and Flecha at low and high fertility. Significance of main effects of tall fescue (T), soil fertility (F) and interaction (T X F) from ANOVA are shown. (P<0.05)

	LF		HF		Significance			LSD	
	CT	MT	CT	MT	T	F	TXF	Main effect	TXF
Lamb									
Spring 2008	292		275		-	NS	-		
Spring 2009									
20/8 - 21/9	306.2	314.6	321.1	314.1	NS	NS	NS		
21/9 – 22/10	220.9	198.3	208.1	182.3	NS	NS	NS		
22/10 – 23/11	266.4	177.3	289.8	180.5	*	NS	NS		
23/11 – 9/12	93.7	57.8	39.12	212.9	NS	NS	NS		
Average	195	217	200	227	NS	NS	NS		
Final liveweight (kg)	30.3	31.6	30.3	32.9					
Ewes									
Spring 2008	18		48			***		38.5	
Spring 2009									
20/8 - 21/9	47	-94	105	-8	NS	NS	NS		
21/9 – 22/10	73	113	44	-8	NS	*	NS	68.7	97.1
22/10 – 23/11	219	207	332	262	NS	*	NS	70.9	100.3
23/11 – 9/12	55	-31	47	63	NS	NS	NS		
Average	98.5	48.8	137.0	77.3	*	NS	NS	38.43	54.34
Final liveweight (kg)	74.6	73	79.4	73.4					
Grazing days 2008	569	588	569	588					
Grazing days 2009	1781	1781	1781	1781					

Significance: * P<0.001 *P<0.05 NS – not significant**

The LWG/ha in spring 2008 was not significantly different between LF and HF (Table 4.8). In spring 2009, LW gain/ha/d was greater (P<0.05) in MT than CT in the third month (22 October to 23 November 2009), but over the entire period of spring LW gain/ha was unaffected by tall fescue or soil fertility (Table 4.8).

Table 4.8 Liveweight (kg/ha/d) of lambs in spring 2008 and 2009 grazing Advance and Flecha at low and high soil fertility. Significance of main effects of tall fescue (T), soil fertility (F) and interaction (T X F) from ANOVA are shown.

Lamb	LF		HF		Significance			LSD	
	CT	MT	CT	MT	T	F	TXF	Main effect	TXF.
Spring 2008	6.3		6.0		NS	NS			
Spring 2009									
20/8 - 21/9	11.4	10.7	11.2	11.4	NS	NS	NS		
21/9 - 22/10	7.4	8.3	6.8	7.8	NS	NS	NS		
22/10 - 23/11	4.4	5.7	4.5	7.3	*	NS	NS	1.04	1.49
23/11 - 9/12	1.5	2.4	3.1	1.0	NS	NS	NS		
Average	6.1	6.8	6.3	7.1	NS	NS	NS		
Grazing days/ha 2008	569	588	569	588	NS	NS			
Grazing days/ha 2009	1781	1781	1781	1781	NS	NS			

Significance: * P<0.001, * P<0.05, NS - not significant**

In autumn 2009, LWG/hd/d and LWG/ha was greater (P<0.001) in MT than CT (Table 4.9). The LWG/hd/d and LWG/ha/d of ewe hoggets in autumn 2010 was greater (P<0.05) in CT than MT from 6 March to 24 March but unaffected by tall fescue cultivar or soil fertility from 2 May to 24 May.

Table 4.9 Liveweight gain/head/day (kg/hd/d) and liveweight gain/ha/day (kg/ha/d) of hoggets in autumn 2009 and 2010 grazing trial. Significance of main effects of tall fescue (T), soil fertility (F) and interaction (T X F) from ANOVA are shown

	LF		HF		Significance			LSD	
	CT	MT	CT	MT	T	F	TXF	Main eff.	TXF
LWG/head/day (g)	22.1	61.1	7.4	43.1	***	NS	NS	16.3	
LWG/ha (kg/ha/d)	1.1	3.1	0.4	2.2	***	NS	NS	0.82	
Grazing days/ha	1050	700	1050	700					
LWG/head/day (g)									
6 March - 24 March	280.0	214.0	285.0	180.0	*	NS	NS	0.06	
2 May - 24 May	35.0	-39.0	67.0	11.0	NS	NS	NS	0.08	
LWG/ha (kg/ha/d)									
6 March - 24 March	5.24	4.01	5.35	3.37	*	NS	NS	1.12	
2 May - 24 May	0.65	-0.74	1.25	0.20	NS	NS	NS		

Significance: * P<0.001, * P<0.05, NS - not significant**

4.4 Discussion

4.4.1 Pasture nutritive value

A notable feature was the consistently high quality of pastures as indicated by the ME exceeding 10.8 MJ ME/kg throughout both spring and autumn. Tall fescue is noted in some studies to have low nutritive value (Thomas and Wilson, 1979), and pasture quality may decline in dryland systems reflecting the development of reproductive material of grass in spring when feed supply exceeds demand (Litherland and Lambert, 2007). However, at the high stocking rates used here (18-22 ewes/ha), there was little opportunity for reproductive development and pasture quality remained high. A similar conclusion was reached in the study of Bywater *et al.* (2011) where the ME of pasture in a dryland sheep system in Canterbury remained high c. 11.5 MJ ME/kg DM due to high ewe stocking rates controlling development of grass seedheads in spring. This led to high lamb growth rates (300 g/d) with lambs ready for slaughter early in the season before the onset of summer dry conditions.

4.4.2 Spring liveweight gain

The liveweight gain/hd of sucking lambs averaged 283 g/d for single lambs over a 27 day period in spring 2008 and averaged 247 g/d for twin lambs over 111 day period in spring 2009. These growth rates were achieved at high stocking rates (22 ewes/ha in 2008, 18 ewe/ha in 2009) relative to the 10 – 14 ewes/ha typical of dryland farms in Canterbury in spring. These liveweight gain values are less than the 307 g/day reported by Ates *et al.* (2006) for twin lambs stocked at 20 ewes/ha on tall fescue (cv. Advance) –subterranean clover dry pastures and the 374 g/d achieved by Ates *et al.* (2008) for cocksfoot-subterranean clover pastures. The values are similar to the 251 g/d reported by Nicol *et al.* (2010) for weaned lambs in intensive, irrigated lamb finishing systems on ryegrass-white clover pastures. The current research, and studies of Ates *et al.* (2008), indicate the potential of achieving high lamb growth rates in spring if quality and quantity of pasture remain high.

It is noteworthy that the experimental design used for grazing management meant the grazing treatments were imposed at the soil fertility and tall fescue cultivar level, and SC and PC were grazed in common within these treatments as part of rotation. This may have reduced the liveweight gain/hd achieved relative to the potential. This is because the clover content of SC pastures was substantially higher than the PC pastures (Chapter 3). Studies have shown a strong positive relationship between legume content and liveweight gain/hd (Hyslop *et al.*, 2000), leading to the expectation of growth rates exceeding 300 g/hd/day if pastures based solely on subterranean clover had been used, rather than combination of annual and perennial clovers.

In spring 2009, liveweight gain declined throughout spring from 314 g/d in September to 202 g/d in October, before increasing for the final month (229 g/d). This result probably reflects declining feed allowance throughout spring due to increasing feed demand of lambs. Even though plots were progressively destocked over spring (18 ewes/ha in September to 12 ewes/ha in December) to reflect decreasing pasture growth (Chapter 3), both pre- and post-grazing pasture mass declined. It is unlikely that declining feed quality contributed to lower liveweight gain as the percentage of clover in the grazed horizon, a good indicator of diet quality, increased throughout spring. Furthermore, ME values averaged across spring remained high (12.3 MJ/kg ME). The decline in liveweight gain/hd reported here, and elsewhere throughout spring (Ates, 2009), emphasizes the value of achieving high liveweight gain/d (>300 g/d) in early spring, to allow flexibility of strategies (slaughter and destocking) in response to variable risk around feed supply in spring (Bywater *et al.*, 2011).

There was limited impact of P and S soil fertility on liveweight gain/hd over the entire period of spring in 2008 and 2009. Black *et al.* (2007) also noted a limited effect of soil fertility on liveweight gain/hd in a study conducted with irrigated pastures at same site, with high fertility leading to greater liveweight gain per head in one year of three. In the current study, pasture growth rate was on occasions greater at HF than LF. Further pre- and post-grazing pasture mass were in general greater at HF. However, this did not appear to be significant enough to create

differences in intake and liveweight gain when both HF and LF pastures were stocked at high stocking rates. Also, there was little effect of soil fertility on the ME content of pasture or botanical composition, so hence little expectation of differences in liveweight gain due to differences in pasture quality, and in general there was more clover at HF.

When effects of tall fescue cultivar on liveweight gain were tested using separate mobs in the second spring, there was little difference between MT and CT. The liveweight gain/hd was similar over the total spring period, with only the cultivar effect being significant in third period (22 October to 23 November 2009) with higher liveweight gain/hd in MT than CT. The lack of consistent cultivar effect occurred despite greater pre- and post-grazing residuals and a higher clover percentage in MT than CT. In a similar fashion to soil fertility the lack of an effect of tall fescue cultivar on liveweight gain/hd of lambs may reflect that differences were not large enough to generate differences in liveweight gain/hd. To capture benefits of the greater early spring growth of MT may require an early or differential start to spring grazing than the 20 August 2008 and 11 September 2009 used in this study.

There was negligible effect of soil fertility or tall fescue cultivar on liveweight gain/ha of lambs. This contrasts with the study of Black *et al.* (2007) who noted greater liveweight gain/ha at high fertility primarily due to more grazing days and higher overall average stocking rate. The limited effect of soil fertility and cultivar reflects small differences in liveweight gain/hd due to treatments. Despite some differences emerging in post-grazing residuals, these were small, and plots were destocked over spring in a similar manner across treatments, hence resulting in small differences in average stocking rates or grazing days over the spring period. If a larger grazing experiment had been conducted with more sheep, changes in stocking rate associated with removal of single sheep from a plot may have enabled finer control over stocking rate.

4.4.3 Liveweight gain/head in autumn

The liveweight gain/head of hoggets in autumn averaged 33.4 g/d in 2009, and 240 g/d and 38 g/d for the first and second periods in autumn 2010, respectively. These values are substantially lower than average of 283 g/d for sucking lambs in spring in this study but higher than those reported by Ates *et al.* (2006) for hoggets on dryland pastures in autumn. Most of the autumn values are lower than those reported for hoggets (176 g/d) in intensive lamb finishing systems under irrigation (Nicol *et al.*, 2010). Together, these data highlight the difficulty of achieving consistently high liveweight gain of livestock in autumn, on grass based systems on dryland farms. (Lattanzi *et al.*, 2007) reported that Mediterranean tall fescue was an option for increasing the carrying capacity of temperate-humid systems based on direct grazing during the critical period of low temperatures, helping to smooth annual forage supply.

There were contrasting effects between years of tall fescue cultivar on liveweight gain/head and liveweight gain/ha of hoggets in autumn. In autumn 2009, liveweight gain/head and liveweight/ha were greater in MT than CT, whereas in autumn 2010, liveweight gain/head and liveweight gain/ha were greater in CT than MT. These patterns appear to reflect feed availability at start of grazing period and growth during the period in response to summer rainfall. In 2009, pre-grazing pasture mass and pasture growth (Figure 3.3, Chapter 3) were greater in MT than CT during trial period, which appeared to negate the greater ME (Table 4.5) of Advance pastures. In contrast, in autumn 2010, despite higher pre-grazing pasture mass in MT, pasture growth was greater in CT throughout the trial period (Figure 3.3). Further, rainfall was insufficient to sustain pasture growth, and all pastures were required to be destocked in May 2010.

4.5 Conclusions

The following main conclusions can be drawn from this chapter.

- Winter-active (Mediterranean) or summer-active (Continental) tall fescue in combination with annual and perennial clovers under high stocking rates in spring provided high quality pastures that gave growth rates of single and twin lambs in excess of 300 g/d in the first part of spring, indicating the percentage of clover was the key factor.
- Soil fertility and tall fescue cultivar had limited impact on lamb growth rates in spring, under the grazing management conditions imposed.
- Liveweight gain in autumn was variable across years, with effects highly dependent on summer rainfall and patterns of growth of cultivars.

Chapter 5

Effect of time of grazing in autumn on subterranean clover growth in winter-active and summer-active dryland tall fescue pastures

5.1 Introduction

Subterranean clover (*Trifolium subterraneum* L.) is an important annual legume in dryland pastures because of its the ability to produce high dry matter production of high nutritive value in the late winter – early spring period (Mills and Moot, 2010). This allows sheep farmers to maximise liveweight gain so that stock can be sold in prime condition before the onset of summer dry conditions (Mills and Moot, 2010). Production of subterranean clover in spring is dependent on the re-establishment of populations of subterranean clover each autumn and survival of these through spring (Ates *et al.*, 2006). Several studies have examined the subterranean clover populations required for maximum DM production in dryland pastures (Prioul and Silsbury, 1982; Smetham and Jack, 1995). Smetham (2003) stated that populations of 500 to 1000 seedlings/m² were required for the successful production of subterranean clover in mixed pastures in spring and paddocks not reaching this level should be targeted for renovation. Ates *et al.* (2006) showed that use laxer grazing management (e.g. low or high stocking rate) or closing paddocks early in spring to increased flower and seed production and recruitment the following year was a suitable strategy to increase seedling populations. An alternative management tool proposed is to manipulate grazing in autumn so as to increase seedling survival. Moot *et al.* (2003) and Thomas (2003) provided indirect evidence that the tolerance to grazing and so survival of seedlings may be related to the leaf stage at which they are grazed. They outlined that once seedlings reach the four-leaf stage, the hypocotyl is drawn to the base of the cotyledons below the soil level, and the axillary buds of the spade and first trifoliolate leaf to around soil level. In this position, it is hypothesized that growing points are unlikely to be

removed by grazing unless the whole seedling is pulled out of the ground (Moot *et al.*, 2003). They suggested that delaying grazing to at least the six trifoliate leaf stage will enhance survival. However, there have been no direct field tests of this criterion and how it relates to other seedling mortality factors, such as competition with other seedlings and associated grasses is not clear. For example, delaying grazing of mixed pasture with subterranean clover may result in greater death through intra-specific seedling competition and competition with associated grasses which overtop the seedlings.

The objective of this study was to investigate the effects of grazing subterranean clover at the spade leaf, three trifoliate and six trifoliate leaf stage in autumn on seedling populations, seedling survival and DM production of subterranean clover when grown with winter and summer-active tall fescue cultivars.

5.2 Material and methods

5.2.1 Experimental site and design

The experiment was conducted in the soil fertility x subterranean clover x tall fescue experiment described in Chapters 3 and 4. For this experiment, the 16 plots, each 27.9 x 14.5 m (0.04 ha), sown with subterranean clover were used. This represented four replicates of the factorial combination of soil fertility (HF and LF) and tall fescue cultivar (MT and CT). Each plot was further subdivided into three sub-plots, each 9.3 x 14.5 m which were randomly allocated to be grazed at the spade leaf (SL), three trifoliate (3L) and six trifoliate (6L) leaf stage.

The grazing treatments were carried out from 24 February to 6 May 2009. This followed the emergence of subterranean clover seedlings in January 2009 after 45.4 mm of rainfall on 20 December 2008 and 35.8 mm on 18 January 2009. Measurements were concluded in November 2009 when subterranean clover died in early summer after flowering.

For grazing, two hoggets were fenced into the allocated sub-plot. The grazing started when approximately 50% of the seedlings population had reached the designated leaf stage (Table 5.1). This was done by visual estimation of 10 seedlings from each sub-plot to check leaf stage. The pre- and post-grazing masses at each grazing time determined by 50 rising plate meter measurements per plot are shown in Table 5.1. The average meter reading was recorded and converted to herbage mass using a calibration equation. The meter reading was calibrated against herbage mass for each treatment using the double sampling method as described in Chapter 3 (Hodgson *et al.*, 1999).

Table 5.1 Date of grazing, pre-grazing and post-grazing pasture mass of spade leaf (SL), three trifoliate (3L) and six trifoliate (6L) leaf stage treatments of subterranean clover seedlings.

Treatments	Date graze	Pre-graze pasture mass (kg DM/ha)	Post-graze pasture mass (kg DM/ha)
SL	24 February 2009	500	350
3L	17 March 2009	800	400
6L	20 April 2009	890	402

After the leaf stage grazing treatments were completed in April, all fences of the sub-plots were removed and all plots were grazed in common. For this plots were grazed with eight groups, four assigned to the HF plots and four assigned to the LF plots (Chapter 3).

5.3 Measurements

5.3.1.1 Number of seedlings

The number of seedlings in two permanent 0.1 m² quadrats in each of three grazing sub-plots was counted before and after grazing at each leaf stage grazing treatment in autumn 2009. Seedlings were then counted again in each permanent quadrat on 6 May 2009.

5.3.1.2 Pasture production and botanical composition

An enclosure cage was placed on each sub-plot on 13 May 2009, trimmed and monitored until 20 November 2009 when all subterranean clover plants were dead after producing seeds in late spring and early summer. At the start of each regrowth period, an area was trimmed with a rotary mower to 30 mm above ground level. At the end of each regrowth period (28 days) one 0.2 m² quadrat was cut to 30 mm above ground level using hand shear. All pastures were harvested on the same day. A subsample (about 200 g) of fresh herbage was sorted into sown grass, sown legume, volunteer white clover, unsown species and dead material before drying at 70°C and weighing. The botanical composition on a DM basis was then determined. After cutting, cages were relocated at new pre-mown sites to exclude grazing sheep.

5.3.1.3 Clover morphology

On 27 June 2009, the subterranean clover plants from one randomly placed 0.1 m² quadrat in each plot were dug out and counted. Plants were washed, separated into root and shoot material, oven-dried at 70°C for 48 h, and dry weight of shoots and roots per plant determined.

5.3.2 Data analysis

The number of seedlings pre and post-grazing, seedling survival and DM production were analysed by ANOVA of a split plot design with soil fertility x tall fescue interaction as whole plot factor and leaf stage as the sub plot factor.

5.4 Results

5.4.1 Number of seedlings

The number of seedlings and seedling death are presented in Table 5.2. There were more ($P < 0.001$) seedlings pre-grazing in the SL than 3L and 6L leaf stage treatments. This reflected mortality of seedlings that died for reasons other than grazing over the period 24 February to 20 April (Table 5.2). Seedling death was higher ($P < 0.001$) during grazing in the SL than 3L and 6L leaf stage treatments (Table 5.2), with nearly half seedlings dying at SL, 14% at 3L stage, and few (5%) at 6L. A combination of lower death at later leaf stages but fewer seedlings pre-grazing contributed to seedling populations being similar post-grazing in the three leaf stage treatments (Table 5.2). There were no significant main effects of soil fertility or tall fescue cultivar on seedling populations on seedling survival from grazing until May 6. Seedling populations in May 6 were greatest in 3L stage treatment.

Table 5.2 Main effects of leaf stage tall fescue cultivar and soil fertility on seedling populations per m² (pre-and post-grazing), % death during first grazing, seedling populations per m² in May, and % death from grazing till 6 May 2009. Significant effects of ANOVA are shown at the base of table. Leaf stage means within a column followed by different subscripts are significantly different according to LSD test (P=0.05) following a significant ANOVA.

Grazing time	Seedling populations			Seedling populations	
	Pre-graze	Post-graze	% death first grazing	May 6	% death 6 May 2009
Leaf stage					
SL	1326 _a	761 _a	43 _a	594 _b	22
3L	1046 _a	907 _a	14 _b	710 _a	22
6L	839 _b	804 _a	5 _c	552 _b	31
Soil fertility					
LF	1088	853	19	645	24
HF	1052	795	22	592	26
Tall Fescue					
CT	1018	792	18	593	25
MT	1123	855	20	643	25
Significance					
Leaf stage	***	NS	***	*	NS
Fertility	NS	NS	NS	NS	NS
Tall fescue	NS	NS	NS	NS	NS
LS x TF	NS	NS	NS	NS	NS
LSD					
Leaf stage	175.3		7.48	110.7	
Tall fescue and Soil fertility					

Significance: * P<0.001, * P<0.05, NS - not significant**

5.4.2 Pasture production and botanical composition

Pasture growth rate was significantly higher in SL than 3L in May 2009 but unaffected by leaf stage for the rest of measurement period. Pasture growth rate was higher (P<0.05) at HF than LF in July, September, October and November 2009 in MT than CT from June to August 2009 (Fig 5.1).

For plants sampled in June, the number of runners and leaves per plant was greater (P<0.05) in 3L than SL or 6L (Table 5.5). Root length (P<0.05) and runner weight (P<0.001) were greater at the SL than 3L or 6L.

Table 5.3 The effect of leaf stage, soil fertility and tall fescue, on the number of runners and leaves/plants, root diameter and length, and weight of runners and root/plant sampled on 27 June 2009. Significant effects of ANOVA are shown at the base of table. Leaf stage means within a column followed by different subscripts are significantly different according to LSD test (P=0.05) following a significant ANOVA.

	Number/plant		Roots (mm)		Weight (gm)	
	Runners	Leaves	diameter	length	Runners	Roots
Leaf stage						
SL	3.2 _b	104.5 _b	1.9 _a	9.6 _a	1.1 _a	0.4 _a
3L	4.1 _a	125.5 _a	1.8 _a	9.0 _b	1.0 _a	0.3 _b
6L	3.7 _b	97.0 _b	1.8 _a	8.2 _c	0.5 _b	0.2 _b
Soil fertility						
LF	3.5	103.3	1.8	9.0	0.8	0.3
HF	3.8	114.7	1.9	8.8	0.9	0.3
Tall fescue						
CT	3.8	108.7	1.8	8.8	0.8	0.3
MT	3.5	109.3	1.9	9.0	0.9	0.3
Significance						
Leaf stage	*	*	NS	*	***	***
Soil fertility	NS	NS	NS	NS	NS	NS
Tall fescue	NS	NS	NS	NS	NS	NS
LSD						
Leaf stage	0.72	18.08		0.91	0.26	0.06
Tall fescue and Soil fertility						

Significance: * P<0.001, * P<0.05, NS - not significant**

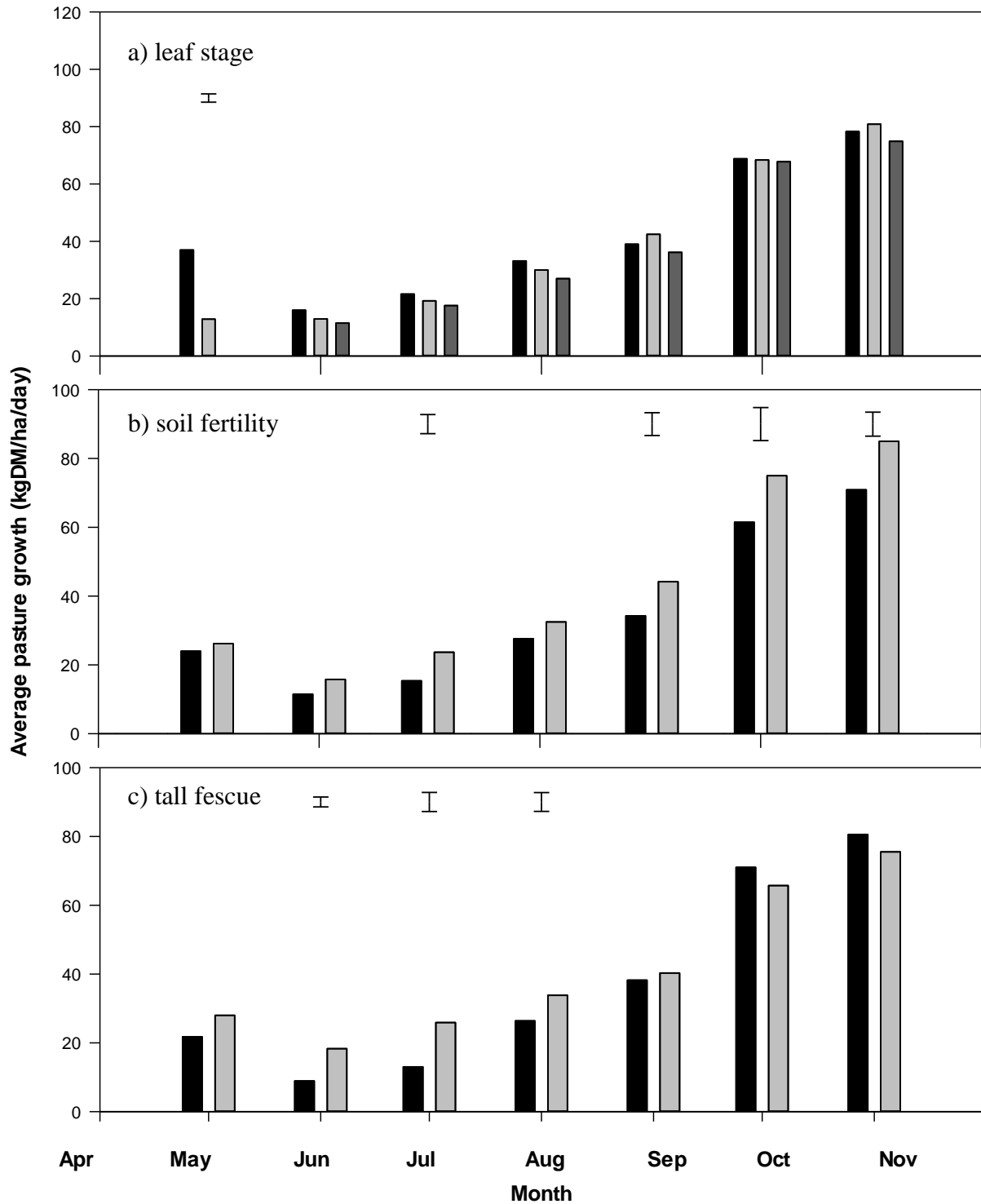


Figure 5.1 Pasture growth (kg DM/ha/day) for the treatments of a) leaf stage of subterranean clover (SL, ■; 3L, □; 6L, ▨) b) high and low fertility (HF, □; LF, ■), and c) tall fescue cultivars (CT, ■; MT, ▨). Bars indicate LSD (P=0.05) for where main effects of each treatment are significant (P<0.05).

There was an interaction between tall fescue cultivar and fertility (P<0.05) in August and November 2009 for pasture growth rate. CT had greater growth rate than MT in HF plots only (Table 5.3).

Table 5.4 Interaction between tall fescue and soil fertility) for pasture growth rate (kg DM/ha/day) for 16 August and 20 November 2009.

Date	HF		LF		LSD	P value
	CT	MT	CT	MT		
16 August 2009	27.3	17.5	27.9	29.5	6.61	0.023
20 November 2009	80.2	60.9	68.9	63.2	8.57	0.032

The accumulated grass DM production in winter 2009 was greater in MT than CT ($P < 0.001$) and was greater in HF than LF ($P < 0.05$) in winter and spring 2009 (Table 5.4). The accumulated clover DM production in winter was higher in SL than 3L or 6L, in MT than CT ($P < 0.001$) and in HF than LF ($P < 0.05$). Accumulated clover DM production in spring was higher in SL than 3L or 6L, and at HF than LF (Table 5.4).

Table 5.5 Accumulated DM production of grass and clover (kg DM/ha) in winter and spring of three different leaf stages of subterranean clover, low and high fertility, and Flecha and Advance tall fescue. Significant effects of ANOVA are shown at the base of table. Leaf stage means within a column followed by different subscripts are significantly different according to LSD test (P=0.05) following a significant ANOVA.

	Grass		Clover	
	Winter	Spring	Winter	Spring
Leaf stage				
SL	1795 _a	5168 _a	660 _a	2834 _a
3L	1766 _a	5342 _a	499 _b	2573 _b
6L	1763 _a	5088 _a	420 _b	2648 _{ab}
Tall fescue				
CT	1358	5317	365	2622
MT	2191	5082	688	2748
Soil fertility				
HF	2018	5727	613	2826
LF	1532	4671	440	2544
Significance				
Leaf stage	NS	NS	*	*
Tall fescue	***	NS	***	NS
Soil fertility	*	***	*	*
LSD				
Leaf Stage			98	205.5
Tall Fescue and Soil fertility	334.3	409	122.8	207.8

Significance: ** P<0.001, * P<0.05, NS - not significant

5.5 Discussion

5.5.1 Effects of grazing on seedling survival

Seedling death during grazing at the spade leaf stage (43%) was high compared to 3L (14%) and 6L stage (5%). This finding confirms the comments made by Moot *et al.* (2003) that the seedling survival will be enhanced if grazing is delayed beyond four leaf stage, by which time the axillary buds of first trifoliate leaf are drawn to ground level. This is the first field test of this theory.

Despite MT being more open and sparse at the SL stage than CT due to dormancy, seedling survival during grazing was unaffected by cultivar. This indicates that grass structure did not make seedlings more prone to grazing at the early leaf stage or that greater cover in CT offered protection to seedlings. Selective grazing can occur, with sheep preferring a diet comprising 70-85% clover and 15-30% grass (Cosgrove *et al.*, 1999). However, it is plausible that due to the low mass in both MT and CT, there would opportunities for selection in both cultivars.

Despite high mortality during grazing, seedling numbers were similar post grazing. This was because of death of seedlings between SL (24 February 2009) and 6L (20 April 2009). Over this period seedling numbers declined from 1326 to 839 seedling/m² in the absence of grazing. It appears that grazing early killed seedlings that would have died for other reasons (e.g. interspecific competition). It is notable seedling populations were high in this study. Under these conditions, early grazing may not be important in determining seedling populations. However, if seedling populations were lower, grazing at SL is likely to substantially reduce seedling numbers. Ates *et al.* (2008) stated that 500 seedling m² was important for high production and populations in this study exceeding this. Therefore, in deciding which paddock to graze relative to leaf stage, farmers would benefit from knowledge of plant populations.

Under the high seedlings populations in this study, accumulated clover DM production was greater in both winter and spring in the SL than 3L and 6L stages. This result did not appear to reflect increased seedling numbers as this was the highest in the 3L stage at the start of winter and not different between SL and 6L. A more likely explanation for the difference is that the seedlings were bigger in SL. Despite plants grazed at the SL stage having the fewest runners per plant, they had the greatest runner weight and root weight. The increase in size is likely to reflect reduced competition as grass height was reduced by early grazing, and indicates the dominant role that time of grazing plays in determining plant size.

5.6 Conclusions

The following main conclusions can be drawn from this chapter.

- Grazing at spade leaf and three trifoliate leaf stage of subterranean clover will increase seedling death and reduce seedling numbers, compared to six trifoliate leaf stage. Delaying grazing to six trifoliate leaf stage increases seedling survival during grazing when seedling numbers are low.
- If the seedling populations are high ($>500/m^2$) grazing at spade leaf and three trifoliate stage will not detrimentally affect final seedlings populations. At this stage grazing will provide valuable feed resource and may boost winter and spring clover production due to a compensatory increase in seedling size.

Chapter 6

Effect of spring defoliation management on winter and summer-active tall fescue and perennial ryegrass pastures grown with white and strawberry clover

6.1 Introduction

Perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens*) have been the most commonly sown pasture mixture in New Zealand. This mixture forms a productive pasture of high quality in summer moist or irrigated pastures, under the appropriate fertilizer and grazing management regime. However, in summer dry conditions (<800 mm rainfall), both may fail to thrive and lack persistence, as these pastures have not tolerant of water deficit conditions regions (Goh and Bruce, 2005), and have poor post-water deficit recovery (Knowles *et al.*, 2003).

The perennial legume, strawberry clover, has been advocated by Hofmann *et al.* (2007) as possible alternative to white clove, and showed that strawberry clover had greater water deficit resistance compared to white clover in a number of key parameters. However, in Chapter 3, it was shown strawberry clover persisted poorly compared to white clover under intense sheep grazing. This effect was attributed to limited nodal root development, perhaps due to competition with grasses. Previous work (Black and Lucas, 2000) has shown that that for slow establishing species such as Caucasian clover a good strategy to ensure establishment of populations is to reduce interspecific competition with grass by sowing clover first as a monoculture and then later drilling grass. Whether, this would increase the nodal root development of strawberry clover remains unclear.

Grazing management severity and frequency in spring may also be important in determining persistence and production of legumes. Spring is a crucial time as both populations of clover and grass plants are changing rapidly during this period (Brock and Caradus, 1996). In this period, grazing management has been noted to have a large effect on the size of plants, but has little effect on plant structure (Brock, 1988). Brock *et al.* (2000) noted that continuous stocking with sheep in spring favoured the retention of larger sized white clover plants being recruited from fragmenting taprooted plants compared to rotational grazing. This was due to less competition for light between grass and clover at a time when the clover population structure is shifting toward smaller plants (Edwards and Chapman, 2011). Whether this pattern is similar for strawberry clover is not known. Further, Brock and Kim (1994) concluded that grazing management was an important factor affecting post drought recovery of white clover with better under continuous stocking due to dense grass populations providing shelter from direct solar radiation during water deficit stress. The objectives of this chapter were;

- 1) To quantify DM production and botanical composition of perennial ryegrass, winter-active and summer-active tall fescue pastures grown with strawberry clover and white clover.
- 2) To quantify the effect of rotational grazing versus continuous stocking in spring on strawberry clover and white clover populations, plant morphology, and population.
- 3) To compare the morphology and population of strawberry and white clover plants when sown in monoculture and clover-grass mixtures.

6.2 Material and methods

6.2.1 Experimental site and design

The experiment was conducted at Lincoln University, Canterbury, New Zealand (43°39'S, 172°28'E, 11 m above sea level) over 20 months from February 2009 to December 2010. The soil type is a Templeton silt loam (Udic Haplosteps) of variable depth to underlying gravels (c.0.4-1.5 m) across the site (Cox, 1978). The experimental design was two replicates of 3 x 2 x 2 factorial laid out in a split plot design. The main plots were factorial combinations of two grazing treatments with sheep in spring (continuous stocking (CS) in spring versus rotational grazing (RS) in spring) x three grass species (perennial ryegrass (PRG), and tall fescue cultivars, Advance (CT) and Flecha (MT)). The main plots were 12 x 35 m and each main plot was split into two sub-plots and allocated to be sown with either white clover (WC) or strawberry clover (StC). The size of sub-plots was 35 m x 6 m. Strawberry clover and white clover plots were grazed in common together. The trial plots were sown on 8 December 2008. Sowing rates were 20 kg/ha of CT and MT (Max P endophyte), 15 kg/ha PRG (cultivar Extreme, AR37 endophyte), and 3 kg/ha of StC and WC. The sowing rate was according to the recommendation by the seed supplier to achieve the same number of seed/ha. Tall fescue and strawberry clover cultivars were the same as those used Chapter 3. At the north and south end of the experimental site, four plots each 10 x 10 m was sown with strawberry clover monocultures at 3 kg seed/ha.

The whole area was fertilised with 30% sulphur superphosphate at the rate 760 kg/ha on 10 March 2008, and the site was then sprayed with Roundup 360 (360 g/l glyphosate) at the rate of 3 litres per ha on 17 July 2008. The trial site was ploughed on 20 August 2008, top-worked with a rota-crumbler on 6 October 2008, and Dutch harrowed and rolled on 1 December 2008. On 8 December 2008, the area was drilled with tall fescue and ryegrass, and clover seeds with a cone-seeder in 15 cm drill rows. On 20 January 2009, the area was sprayed with Pulsar (200g/L bentazone) at the rate of 5 l/ha as general broadleaf weeds control.

6.2.2 Grazing management

The plots were lightly grazed in common with sheep depending on pasture availability (at least once a month) during the first nine months after establishment to ensure effective establishment of all pasture. In spring (15 August) 2009, grazing management treatments began.

The continuous stocking (CS) treatment was a put and take system with Coopworth (hoggets (40 – 45 kg liveweight) to maintain a pasture mass between 400 – 600 kg DM/ha. As the plots were small, the grazing management of the continuous stocking treatment was not a ‘true’ continuous stocking. Rather, a three paddock shift was used in which two sheep grazed in one of the CS paddocks in each block for two days before moving to another in the same replicate, thus giving a six day return time. This was expected to give similar defoliation intervals to the mean of seven days observed by Clarke *et al.* (1984) for continuous stocked pastures.

The rotational grazing (RS) treatment was to a residual of 400 kg DM/ha, with plots grazed at a 14 day interval in spring (15 August – 15 December). This rotation length was chosen due to the fact that tall fescue needs to be grazed frequently to keep the grass low and to avoid the formation of seedhead (Tozer *et al.*, 2007). Sufficient sheep (3 to 5) were placed in a paddock to ensure that pasture mass was reduced to desired post grazing residual over a 1 day period.

For both treatments, a 21 day interval was used for the rest of the year, as the growth rate slowed down, as recommended by Saul and Chapman (2002). The pure strawberry clover swards together with pure perennial ryegrass swards in the raceway of the plots were grazed by continuous stocking with hoggets when not used to graze in the experimental plots. Pasture mass in this area was maintained in a similar mass to CS experimental plot.

6.2.3 Climate data

The climate data (rainfall and air temperature) were collected from the Broadfield weather station located 2 km north of the site for the duration from 1 February 2009 to 30 November 2010. The

annual rainfall was lower in 2009 (540 mm) than in 2010 (648 mm). On average, 48% of the total annual rainfall occurred during winter and spring. The winter (June – August) of 2010 was wetter (256 mm) than the winter of 2009 (72 mm). The highest rainfall of the year occurred in May with 145 mm in May 2009 and 153 mm in May 2010 (Figure 6.1).

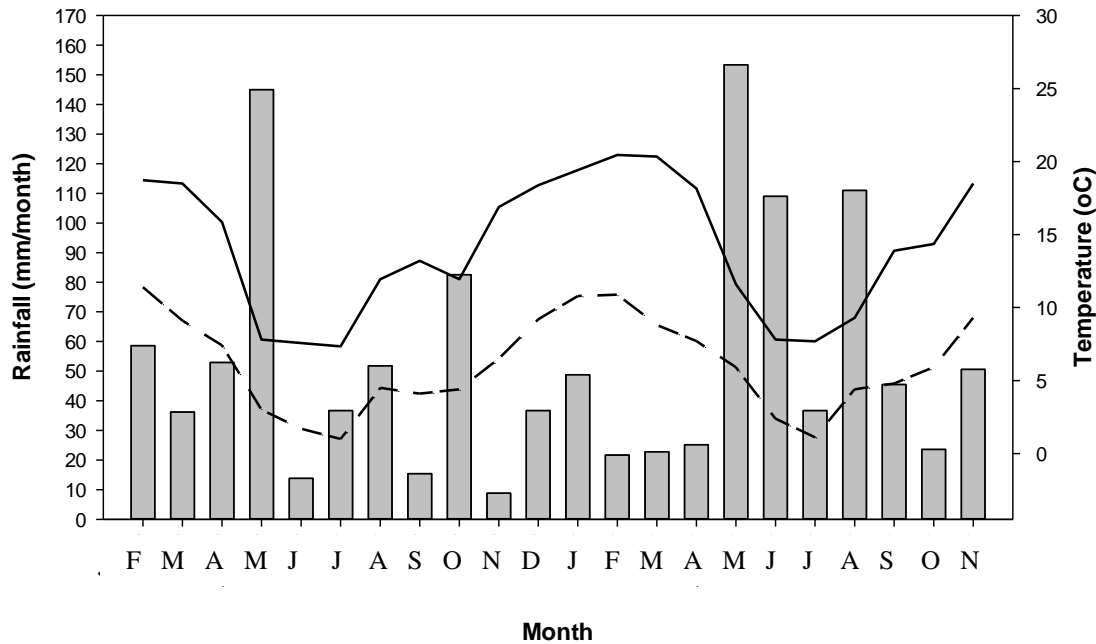


Figure 6.1 Monthly rainfall (bars), maximum (—) and minimum (---) air temperature measured by Broadfield Weather station situated 2 km from the experimental plots.

6.2.4 Measurements

6.2.5 Pasture production and composition

Pasture growth was measured in each pasture over 20 regrowth periods from 3 February 2009 to 19 November 2010 using enclosure cages. At the start of each regrowth period, an area was trimmed with a rotary mower to 3 cm above ground level. At the end of each regrowth period (28 days) one 0.2 m²/quadrat was cut to of 1 cm. All pastures were harvested on the same day. Sub-samples of fresh herbage (about 200 g) were taken to determine botanical composition (Cayley and Bird, 1996). The samples were sorted into sown grass, sown legume, volunteer white clover,

unsown species and dead material. The herbage was dried at 70°C until a constant weight, weighed and botanical composition on a DM basis determined. After cutting, cages (1 m x 1.5 m) were relocated at new pre-mown sites to exclude grazing sheep.

6.2.5.1 Pasture morphology

The grass and clover morphology and plant population was measured on 3 February 2009 prior to the first grazing. All grass and clover plants were dug up to a depth of 20 cm in two 1-m drill rows in each plot. The samples were washed and the number of plants counted. Counts were made of the number of nodal roots and stolons per plant, and measurements made presence of taproot, taproot diameter, tap root length and nodal root length. Plants were then separated into roots and shoot material bulked for each plot, dried at 70°C and dry weight of shoots and roots determine. Plant population and morphology were measured again in the autumn 2009 (23 April 2009), spring 2009 (23 September 2009), autumn 2010 (23 April 2010) and spring 2010 (30 November 2010). The minimum sample size for the pasture morphology measurement was five plants per sub-plot. If these were not found in the 1 m drill row, the additional plants were collected at random from each plot. The plant in this context was classified as a stolon with taproot, or later as the plant fragmented, a separated stolon fragment with nodal roots (Brock *et al.*, 2000).

6.2.5.2 Comparative monoculture and grass-clover mixtures plant morphology

The strawberry clover plants sown as monocultures were also sampled on 23 April and 30 November 2010 for comparative analysis of the clover plant morphology between mixtures and monoculture. A minimum of 5 strawberry clover plants were sampled from each of the four replicates in the pure swards and CT plots. Plants were measured in the same way as described in section 6.2.4.2, with additional measurements of taproot death, taproot diameter, taproot length, number of nodal root, nodal root diameter, and number of second branch of nodal root, length of stolon, stolon diameter, leaf size and petiole length.

6.2.6 Statistical analysis

DM production, botanical composition and morphology data were analysed by ANOVA of a split plot design where grass species x grazing management was the main plot factor and clover species the sub-plot factor. For DM production, the establishment phase was from 8 December 2008 to 3 February 2009, Year 1 was from 3 February 2009 to 15 January 2010, and the Year 2 was from 15 January 2010 to 19 November 2010 (less than 1 year duration). The comparative analysis of the clover plants in monoculture and mixtures was carried out using a t-test, by comparing clover shoot and root parameters. Where ANOVA was significant, means were separated by least significant difference (LSD, $P < 0.05$).

6.3 Results

6.3.1 Pasture DM production

Total DM production averaged 722, 8968 and 4391 kg DM/ha for the establishment phase, and years 1 and 2, respectively (Table 6.1). Total DM accumulation in the establishment phase was over 500 kg DM/ha greater for PRG than tall fescue (CT and MT) (Table 6.1). In year 1, total pasture DM accumulation was greater ($P < 0.05$) in CT and PRG than MT (Table 6.2), and for WC than StC. There was no difference in total pasture DM production between CS and RS pastures.

Sown grass DM accumulation was approximately 600 kg DM/ha greater in PRG than the two tall fescue cultivars in the establishment phase (Table 6.2) and year 1. Sown grass DM accumulation was 1000 kg DM/ha higher in WC than StC in year 1 (Table 6.2).

Table 6.1 DM pasture production, clover DM production and grass DM production (kg DM/ha) for main effects of grass cultivars, sown clover and spring grazing. EST (8 Dec 2008 –3 Feb 2009); Year 1 (3 Feb 2009 – 15 Jan 2010); Year 2 (15 Jan 2010 - 19 Nov 2010). Grass cultivar means within a column followed by different subscripts are significantly different according to LSD test (P=0.05) following a significant ANOVA. There was no interaction between treatments. The codes used in the table are at the base of the table.

	Total DM Production			Clover DM production			Grass DM production		
	EST	Yr1	Yr 2	EST	Yr1	Yr2	EST	Yr1	Yr2
WC	725	9475	2443	105	1638	146	621	7019	2234
StC	717	8462	2384	76	670	128	641	7222	2095
LSD	160.5	824.0	355.8	91.6	631.5	205.6	194.7	1108.3	467.5
P value	NS	0.024	NS	NS	0.009	NS	NS	NS	NS
CT	563 _b	9928 _a	2253 _a	133 _a	1621 _a	106 _a	430 _b	7141 _b	2086 _a
MT	503 _b	7559 _b	2454 _a	84 _a	1237 _a	247 _a	419 _b	5732 _c	2097 _a
PRG	1098 _a	9417 _a	2533 _a	54 _a	604 _a	59 _a	1044 _a	8488 _a	2451 _a
LSD	35.2	1454.8					158.9	1357.4	
P value	0.014	0.019	NS	NS	NS	NS	0.001	0.009	NS
CS	752	8959	2561	89	1090	187	663	6993	2327
RS	691	8977	2265	92	1218	87	599	7248	2095
LSD									
P value	NS	NS	NS	NS	NS	NS	NS	NS	NS
NS									

Significance: * P<0.01 *P<0.05 NS- not significant**

EST – Establishment, Yr1 – year 1, Yr2 – year 2,

6.3.2 Pasture growth rate.

Figure 6.2 shows the pattern of pasture growth over the 20 month period of trial. The pasture growth rate was higher (P<0.05) in PRG at first harvest (establishment phase). The growth rate of the pasture in autumn (March to May 2009) and winter (June to August 2009) was not significantly different due to the slowdown in growth rate for all pasture grasses and clovers. However, in spring 2009 (October 2009), the pasture growth rate was significantly higher (P<0.05) in RS than CS plots in September 2009.

In early summer (December 2009), there was no significant difference between treatments. However, in mid-summer (January 2010) there was significantly higher ($P < 0.05$) pasture growth rate in CT and PRG plots than MT plots as Flecha had become dormant. In early autumn of the second year (March and April 2010), pasture growth rate was higher ($P < 0.05$) in CT and PRG compared with MT. Growth rates were low in winter, and there was no significant difference between treatments in all treatments (< 20 kg DM/ha). There was no interaction between treatments for DM pasture production.

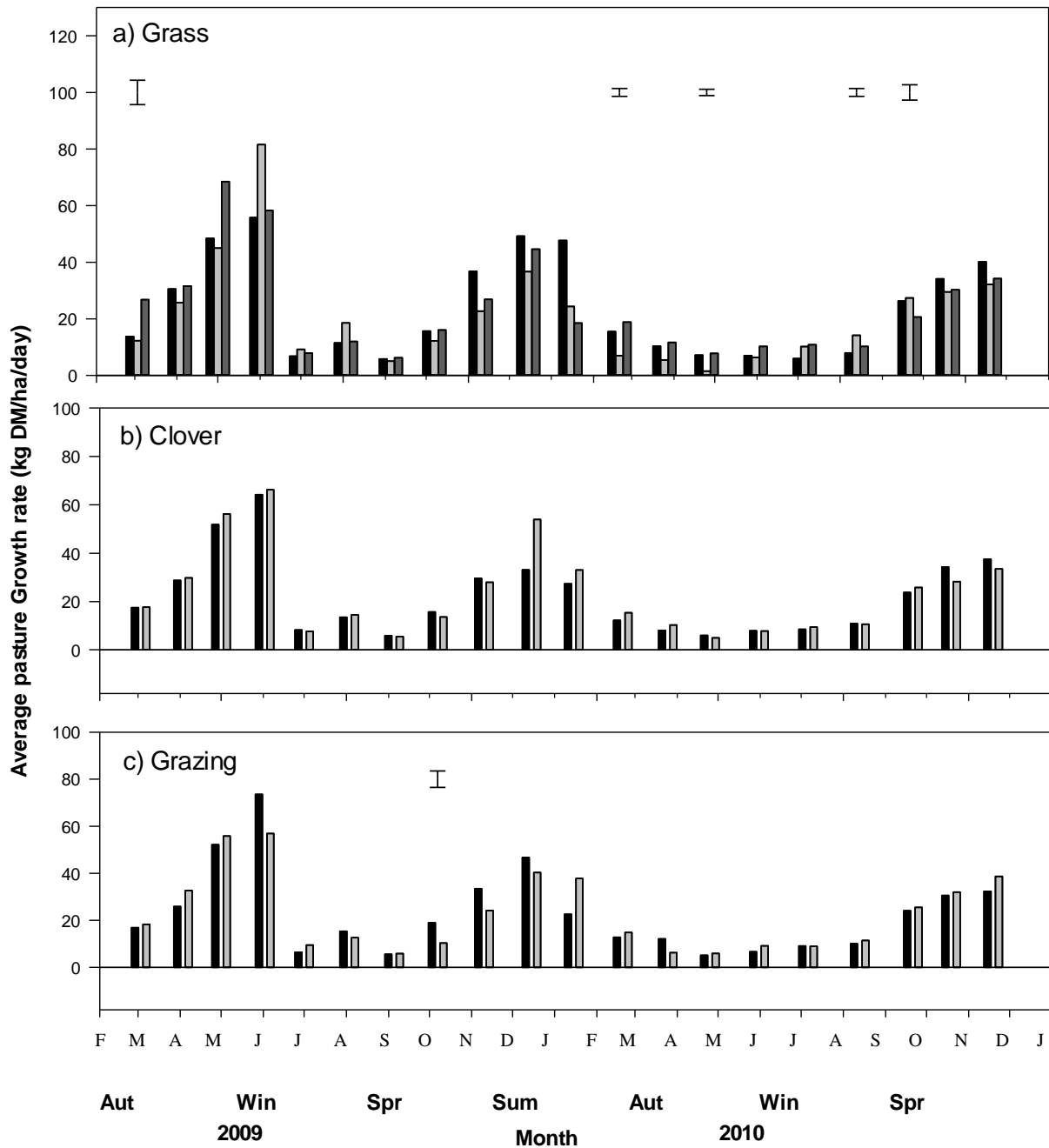


Figure 6.2 Average pasture growth rate (kg DM/ha/day) from March 2009 to November 2010 for main effects of a) grass species, (CT, ■; MT, □; PRG, ▨), b) perennial clover species, (StC, ■; WC, □) and c) grazing management (RS, ■; CS, □). Bars indicate LSD ($P=0.05$) for main effects where significant.

6.3.3 Percentage of sown species

Figure 6.3 and 6.4 show the percentage of clover and grass in pasture throughout the experimental period. Throughout 2009, the percentage of sown clover was generally higher ($P<0.05$) in WC than StC plots with marked differences occurring over the autumn to spring

period, April to December 2009. In January to May 2010, the proportion of sown clover was the highest in MT tall fescue plots. In August 2010, the proportion of sown clover was higher ($P<0.05$) in CS plots than RS plots (Figure 6.3); otherwise the effects of spring grazing management were small. There were no significant interactions between sown clover and grass species.

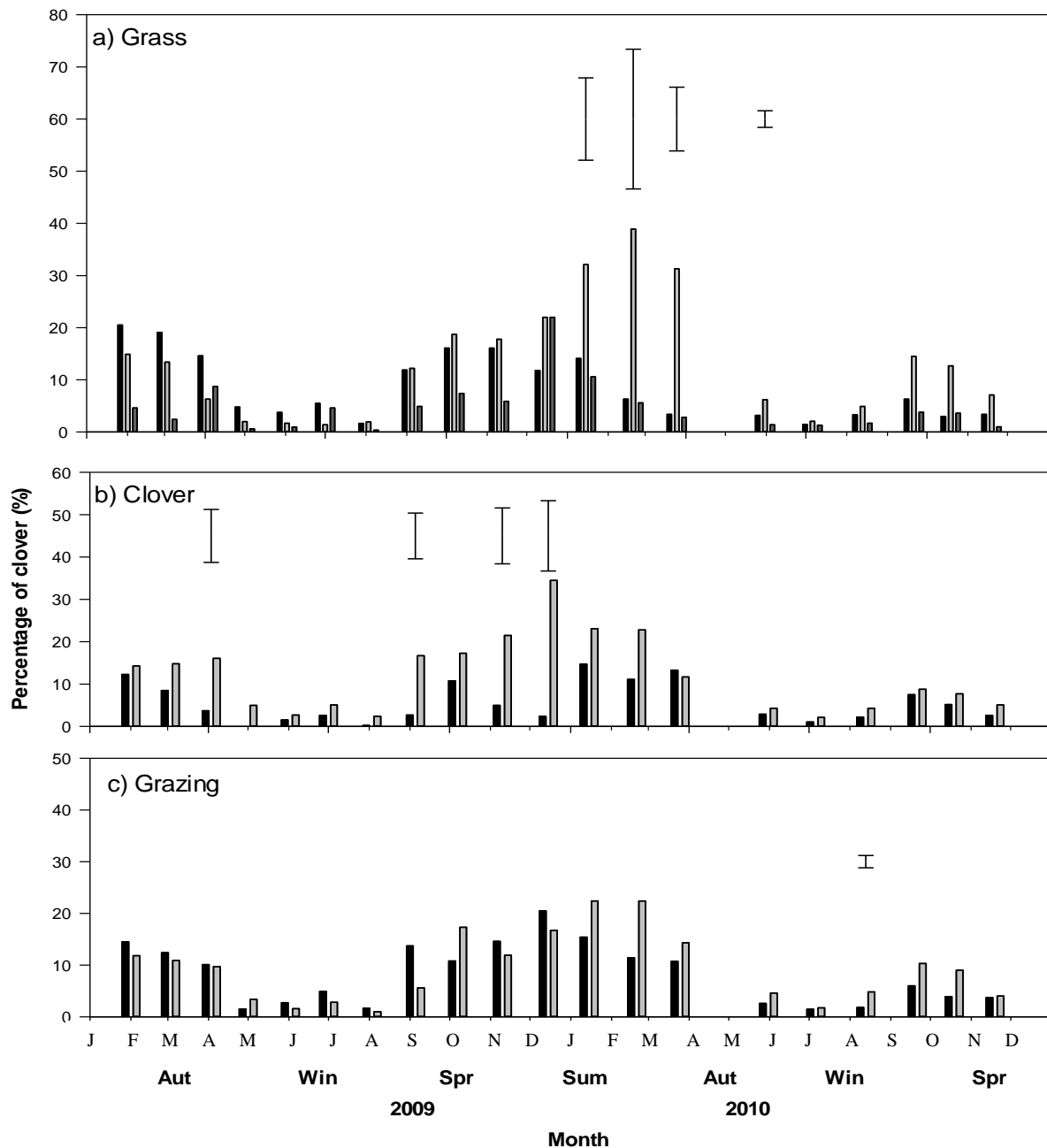


Figure 6.3 The percentage of sown clover (%) from March 2009 to November 2010 for main effects of a) grass species, (CT, ■; MT, □; PRG, ▨), b) perennial clover species, (StC, ■; WC, □) and c) grazing management (RS, ■; CS, □). Bars indicate LSD ($P=0.05$) for main effects where significant.

The percentage of sown grass was higher ($P < 0.05$) in PRG compared to CT and MT over first part of trial from February 2009 to December 2010. From January 2010 onwards, the percentage of grass was similar between CT and PRG, and both were higher ($P < 0.05$) than MT. There was a tendency for percentage of grass to be higher ($P < 0.05$) in StC than WC, probably reflecting overall low contribution of StC.

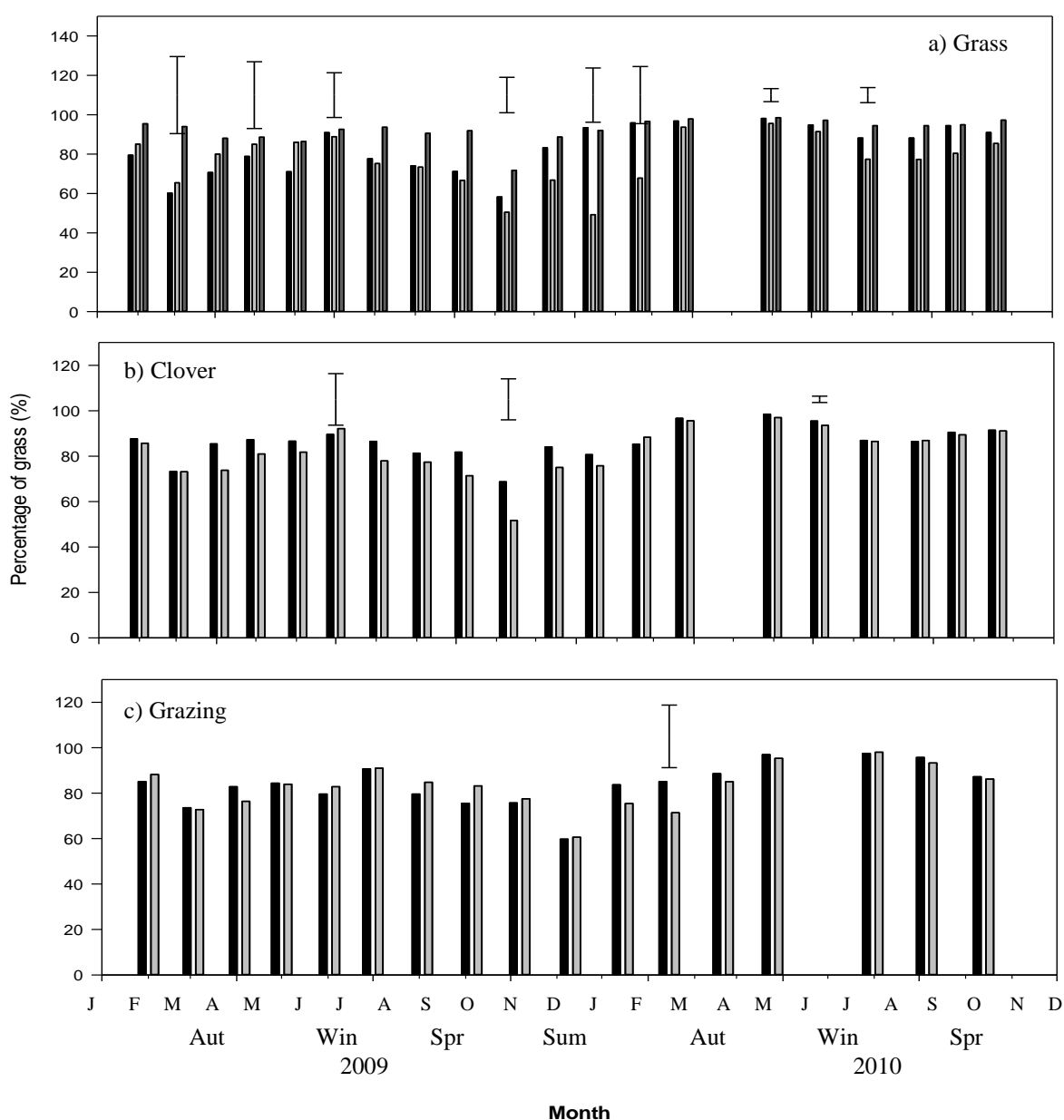


Figure 6.4 Percentage of grass (%) from March 2009 to November 2010 for main effects of a) grass species, (CT, ■; MT, □; PRG, ▒), b) perennial clover species, (StC, ■; WC, □), and c) grazing management (RS, ■; CS, □). Bars indicate LSD ($P = 0.05$) for main effects where significant.

6.3.4 Plant morphology

Changes in the population of clover and grass plants are shown in Figure 6.5. Clover populations were highest at the first harvest in both WC and StC, but then declined in both species (Figure 6.7b). The decline was continuous in StC so that by October 2010 populations were less than 10 plant/m². WC plant populations then increased due to fragmentation into smaller plant following loss of taproot in many plants around May 2010. The number of clover plants at establishment was higher ($P<0.05$) in MT than PRG and CT (Figure 6.7). The number of clover plants per m² and the number of nodal roots per plant was greater ($P<0.05$) in WC than StC on 20 April 2009.

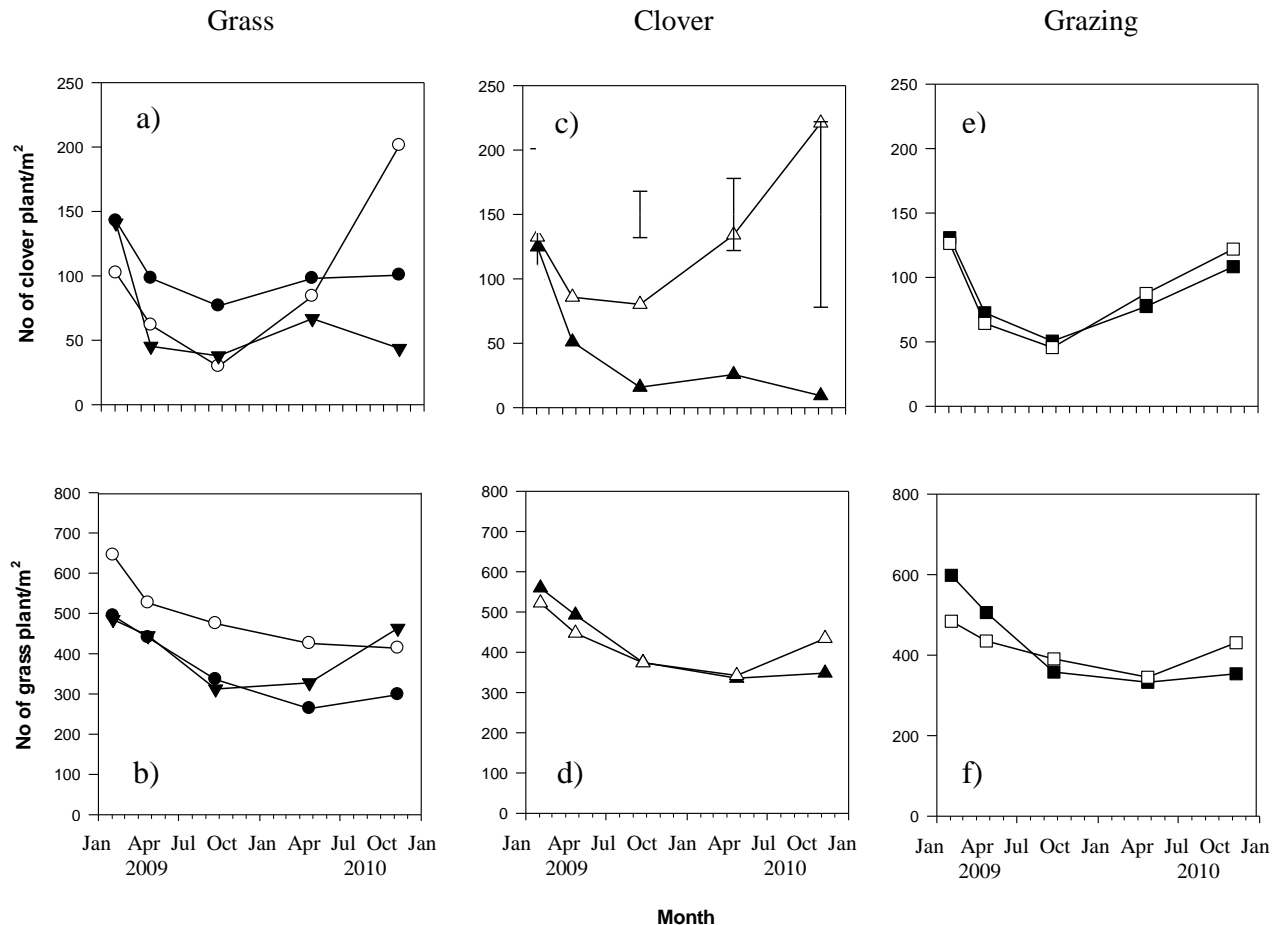


Figure 6.5 The number of plants per m² of clover and grass for main effects of a,b) grass species (CT, ●; MT, ○; PRG, ▼) and c,d) clover species (StC, ▲; WC, △), and e,f) grazing management practices (RS, ■; CS, □). Bars represent LSD for the above the periods when ANOVA was significant ($P<0.05$).

The number of clover stolons was higher ($P < 0.05$) in WC than StC on September 2009, and there was no significant difference between all treatments in comparison at other dates. .

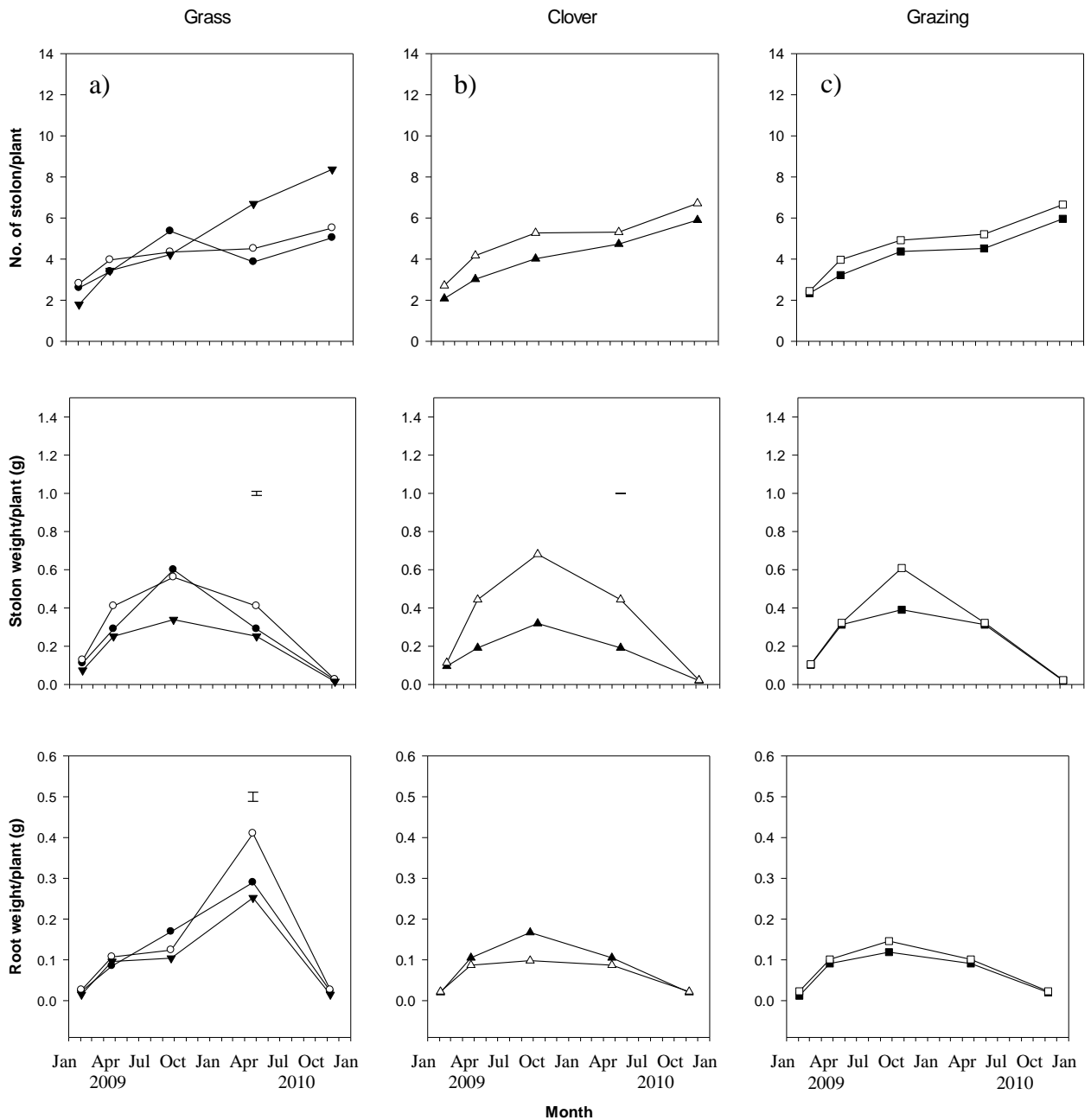


Figure 6.6 Number of stolons per clover plant, clover shoot mass per plant and clover root mass per plant for main effects of a) grass species (CT, ●; MT, ○; PRG, ▼) and b) clover species (StC, ▲; WC, △), and c) grazing management practices (RS, ■; CS, □). Bars represent LSD of the above the periods when ANOVA was significant ($P < 0.05$).

Taproot diameter of clover plants showed an increasing trend through time for CT tall fescue, remained relatively constant in PRG and MF tall fescue. Taproot diameter was in general greater

in StC than WC with this effect significant in 23 September 2009. Taproot length of clovers changed little over the course of the trial and was not unaffected by treatment (Figure 6.7).

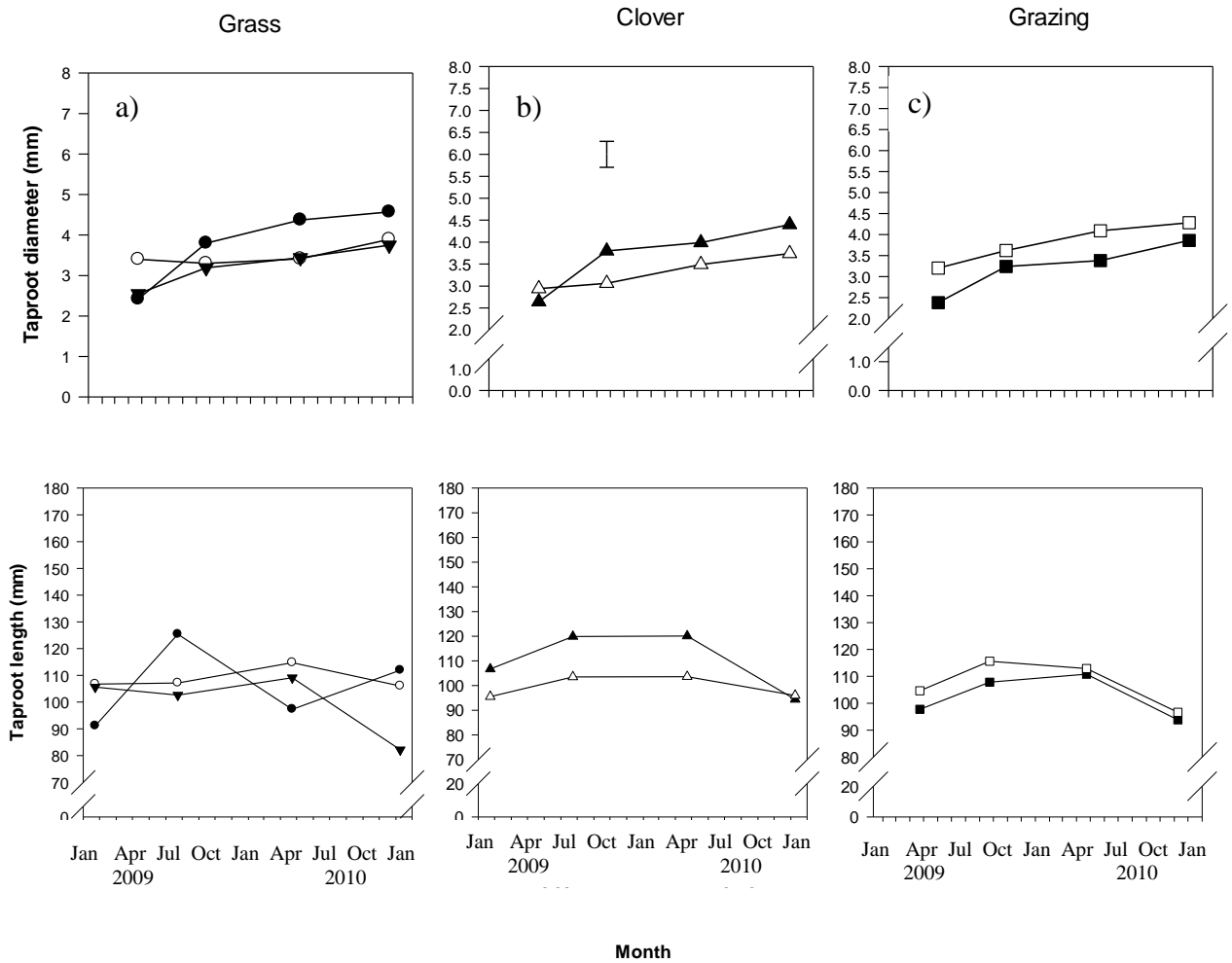


Figure 6.7 Taproot diameter and length of legume species for main effects of a) grass species (CT, ●; MT, ○; PRG, ▼) and b) clover species (StC, ▲; WC, △), and c) grazing management practices (RS, ■; RS, □). Bars represent LSD of the above the periods when ANOVA was significant (P<0.05).

The nodal root number per plant was higher (P<0.05) in CT tall fescue than MT tall fescue and PRG on 23 April 2010, and was higher (P<0.05) in WC than StC on 23 April 2009. In general, nodal root length increased throughout the experiment. Nodal roots were longer (P<0.05) in CT than MT and PRG on 23 April 2009. Nodal root length was unaffected by grazing management or clover species. Nodal rooting of StC was reduced markedly in PRG (Figure 6.8).

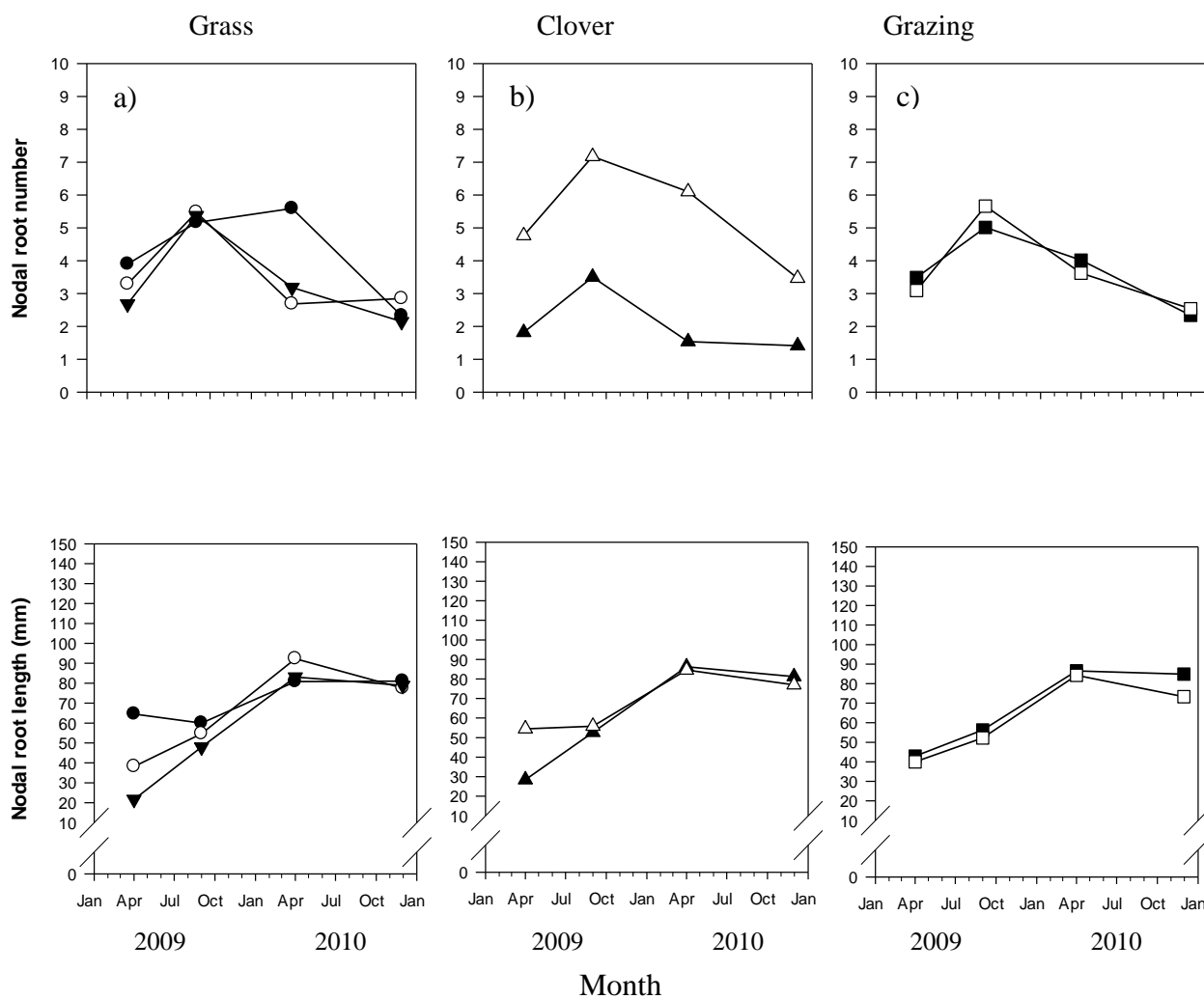


Figure 6.8 Number and length of nodal root of clover for main effects of a) grass species (CT, ●; MT, ○; perennial ryegrass, ▼) and b) clover species (StC, ▲; WC, △), and c) grazing management practices (RS, ■; CS, □). Bars represent LSD of the above the periods when ANOVA was significant ($P < 0.05$).

There was an interaction between clover species and grazing management practices where the CS had the highest root weight of StC on April 2010 and the stolon weight of white clover with CS on November 2009 (Table 6.3).

Table 6.2 The interaction between clover and grazing management on plant morphology of the StC and WC. Means within a row followed by different subscripts are significantly different according to LSD test (P=0.05) following a significant ANOVA.

	CS		RS		LSD	P value
	StC	WC	StC	WC		
Root weight (Apr 10)	1.92a	1.22b	0.82b	1.20b	0.903	0.010
Stolon weight (Nov 09)	1.07b	2.53a	1.18b	1.50b	0.872	0.037

6.3.5 Clover monoculture versus grass-clover mixtures

The comparative analysis of the strawberry clover plant morphology between treatments sown as monoculture and as grass-clover mixtures and samples on 30 April and 30 November 2010 is shown in Table 6.4. On 30 April 2010, the strawberry clover plants sown as monoculture had more stolons per plant. However, the petiole length and leaf size of clover plant sown in the mixtures was longer (P<0.05) than in the monoculture. There were approximately four times as many nodal roots in StC than WC. On 30 November 2010, the number of strawberry clover stolons per plant and nodal root diameter were significantly greater (P<0.05) in monocultures than in the mixture, but the leaf size and taproot length of the mixtures were greater (P<0.05) in mixture than monoculture (Table 6.4). The number of nodal roots per plant did not differ between StC and WC on 30 November.

Table 6.3 Comparison for morphology of strawberry clover plants in mixtures versus monoculture sampled on 30 April and 30 November 2010.

	30-Apr-10				30-Nov-10			
	Mono	Mix	Sig	LSD	Mono	Mix	Sig	LSD
No. of stolon/plant	21.5	6.0	*	7.38	13.0	4.9	*	5.27
Stolon length (mm)	15.5	17.6	NS		17.1	21.1	NS	
Stolon diameter (mm)	2.1	1.8	NS		1.6	2.1	NS	
Leaf size (mm)	6.5	7.5	*	0.92	7.6	12.4	*	0.97
Petiole length (mm)	10.3	20.4	*	4.71	13.2	18.1	NS	
No. of plant with taproot/5 plant	5	5	NS		4	3.4	NS	
Taproot diameter (mm)	5.6	4.1	NS		2.9	4.5	NS	
Taproot length (mm)	132.6	89.9	*	19.64	60.2	124.4	*	5.27
No. of nodal root /plant	6.9	1.7	*	4.37	2.3	1.5	NS	
Nodal root diameter (mm)	2.5	1.4	NS		1.9	1.1	*	0.71
Nodal root length (mm)	137.1	89.9	NS		77.4	72.7	NS	
No. of 2nd brch/nodal root	4.2	2.5	NS		3.1	2.4	NS	

Significance: * P <0.01 * P<0.05 NS - not significant**

6.4 Discussion

6.4.1 DM production

Total DM production was greater in the establishment phase in PRG than MT and CT. This was due to greater growth of the PRG, with a decrease in quantity of clover produced relative to CT and MT. This result confirms the fast establishment ability of PRG that has previously been recorded (Black *et al.*, 2007), and that this may impact negatively on the abundance of white clover during the establishment phase. Raeside *et al.* (2012) identified several issues that restrict the use of summer-active tall fescue in Victoria, Australia, most notably uncertainty about spring nutritive value, lack of information about new cultivars and slow establishment of tall fescue.

Total DM production in year 1 was greater in CT and PRG than MT. This was primarily due to lower growth of MT over the period from late spring to late summer, relative to CT and PRG. The second year result is similar to that reported in the third year of study under partial irrigation in Canterbury (Minee *et al.*, 2010), although PRG, CT and MT all produced a similar amount in the second year. There was limited evidence over the 2 year period of study that the MT had

improved winter or early spring growth. MT only had greater growth than other cultivars on one occasion (July 2010). The lack of a significant increase in early spring production in MT than CT, was also observed in first year of the study in Chapter 3, although in second year growth was greater in early spring in MT. This result indicates that in dryland pastures in Canterbury, MT will have similar pattern to PRG for spring growth.

Total DM production in year 1 was 1.0 t DM/ha higher where pastures were grown with WC than StC. This result was due to an additional 0.97 t DM/ha of clover DM as grass DM was similar across treatments. This result confirms the production advantage of WC over StC that was indicated by the low persistence of strawberry clover in Chapter 3. This result is consistent with the finding of Kemp *et al.* (2002) who showed that white clover was more productive and less variable in production than strawberry clover in studies in New South Wales, Australia. It is noteworthy, however, that white clover will be inferior in production to subterranean clover in dryland pastures (Chapter 3). Mills and Moot (2010) also reported that cocksfoot-subterranean clover yielded 2–3 times more metabolisable energy than perennial ryegrass-white clover pastures.

6.4.2 Strawberry clover versus white clover

A feature of the results was that strawberry clover failed to persist in the mixture pasture. It is notable this occurred with both PRG and tall fescue and under both RS and CS, a similar pattern to Chapter 3. Although, strawberry clover populations were established, the decline in populations was rapid, so that after 20 months less than 10 plant/m² remained. This confirms that under intensive sheep grazing and current sowing practices in dryland pastures strawberry clover is not a viable legume compared to white or subterranean clover.

The lack of persistence may be related to the inability of strawberry clover to form effective nodal rooting structure. In agreement with (Hofmann *et al.*, 2007), strawberry clover plants had longer and larger diameter taproots that were retained for longer than in white clover. However,

strawberry clover plants had fewer nodal roots than white clover (1.5 v 6.1 nodal roots/plant) on 23 April 2010. This confirms the concerns of Hofmann *et al.* (2007) from pot trial work, that although strawberry displayed a number of functional and morphological features of water deficit resistance, nodal formation was not as pronounced as in white clover. Together these results point towards the need for improvements in strawberry clover (e.g. development of nodal roots) through plant breeding, or through improved establishment methods. Nodal roots are important in defoliation control as they allow plants to regularly replace the aging root systems by newly formed vigorous nodal roots (Thomas and Hay, 2010).

The effect of establishment method on strawberry clover morphology was examined by measuring the morphology of plants established with and without clover. Black *et al.* (2006) showed that sowing Caucasian clover first then drilling grass later once clover was established to be an appropriate strategy to improve establishment and persistence of the slow establishing species. In this study, strawberry clover plants sampled 17 months after sowing in April 2010 in pure swards had more but shorter stolons per plant, more nodal roots, and bigger and longer taproots than those established in mixtures with grass. This indicates some advantages of being established as a pure sward. However, 24 months after sowing, the only major difference was that there were plants that had more stolons per plant and smaller leaves in pure swards. The lack of difference with pure swards may reflect that pure swards were grazed by sheep which may have inhibited growth; indeed an increased stolon number and small leaves are characteristics of intense grazing (Yu *et al.*, 2008). Thus, a further improvement in strawberry clover establishment and persistence may be achieved by delaying grazing for longer periods. However, this may constrain use of strawberry clover within farming system where a quick return to pasture is sought.

6.4.3 Grazing management

Brock *et al.* (2003) noted greater persistence and production of white clover when continuous stocked than rotationally grazed and greater recovery following water deficit. This was attributed to continuous stocking creating a dense pasture which protected plants from grazing and high soil surface temperatures (Edwards and Chapman, 2011) and promoted tolerance under dry spring, summer conditions. In the current study, there was negligible effect of grazing management in spring on WC or StC morphology and production. The lack of an effect of grazing management may reflect the short RS interval that was used in this study (14 days), in order to control development of seedhead in tall fescue in particular, relative to CS. This treatment resulted in only small differences in grass production and grass populations, and so effect on clover would be expected to be minimal. (Chapman *et al.*, 1984) also recorded similar findings on leaf death rates and leaf longevity were largely unaffected by grazing management and the number of live leaves/tiller or stolon did not differ greatly between continuous stocking and rotational grazing. Alternatively, climatic conditions may not have been severe enough to promote interactions between clover and grazing management. In the current study, the climatic condition was drier than the long term rainfall for the period from June 2009 to April 2010. In spring 2009, rainfall was less than average, with higher than average rainfall in October 2009.

6.5 Conclusions

The following main conclusions can be drawn from this Chapter.

- Perennial ryegrass established faster than summer-active (Continental) tall fescue and winter-active (Mediterranean) tall fescue, and inhibited clover growth during establishment.
- Once established, summer-active (Continental) tall fescue and perennial ryegrass produced more DM than winter active (Mediterranean) tall fescue.

- Under conditions of this experiment, pasture production was similar with continuous stocking and rotational grazing in spring.
- White clover produced more total DM than strawberry clover under both rotational grazing and continuous stocking. In dryland pastures, both are likely to be less than pastures based subterranean clover.
- Strawberry clover was not as successful in competing against grass in surviving intensive grazing, and failed to persist beyond 20 months. This is likely to be related to lack of nodal rooting.
- Reducing both competition from grasses and delayed grazing may be required to allow successful establishment and persistence of strawberry clover.

Chapter 7

General Discussion

7.1 Overview

Dryland pastures in Canterbury, New Zealand are characterized by low and variable spring and summer rainfall that is less than potential evapotranspiration by the end of summer (Ates, 2009). Perennial ryegrass-white clover pastures, although tolerant of a wide range of grazing and environmental conditions are disadvantaged by low rainfall, high soil temperatures and susceptibility to attacks by grass grub and Argentine stem weevil. This leads to low DM production and poor persistence in dryland conditions (Goh and Bruce, 2005). Early lambing and high growth rates to finish the majority of lambs before the water deficit halts pasture growth is the primary focus of decisions in this environment (Bywater *et al.*, 2011). This study considered a range of pasture species that are thought to maintain pasture production and persistence during this crucial period. Alternative options that were explored in this research including the Mediterranean and Continental tall fescue cultivars (McCallum *et al.*, 1992) grown in combination with annual and perennial clovers. From a series of experiments over two seasons (2008-2010), information on pasture production, persistence, sheep liveweight gain, seedling populations and plant morphology was obtained.

7.1.1 Pasture legumes

Strawberry clover was included in this study as a perennial legume showing greater water deficit tolerance characteristics than white clover (Hofmann *et al.*, 2007), and which therefore would be a useful species in dryland pastures. When perennial legumes were compared directly in Chapter 6, the production of white clover was 59% higher than that of strawberry clover. Strawberry clover was not as successful in competing against grass and surviving intensive grazing over a 20 month time period. This was probably due to less nodal rooting in strawberry clover during the establishment phase, which may limit its persistence under intensive sheep grazing. However, the

larger taproot of strawberry clover that lasted for longer than white clover was a promising attribute that could be developed as a water deficit resistant clover species (Hofmann *et al.*, 2007).

The current research showed some promising results of establishment of better plant structure of strawberry clover in pure swards rather than mixtures, particularly the increased nodal rooting per plant after 17 months. In a practical context, strawberry clover could be established first as a pure sward before drilling grass at a later stage may be required. This has been shown to be important for the slow establishing species Caucasian clover (Black and Lucas, 2000). However, as strawberry clover appeared particularly prone to intense grazing, it may also benefit from cessation of grazing for an extended period, unlike the pure swards that were grazed in this study. This in turn, may limit its usefulness as species for dryland pastures. However, Bellotti and Moore (1994) focuses on pre- and post-sowing grassland management techniques (with an emphasis on an ecological approach to establishment) which influence the survival of emerged seedlings.

While persistence and DM production of white clover was better than strawberry clover, DM production of white clover was significantly behind subterranean clover when grown with tall fescue. The other main perennial clover that has been tested in combination with tall fescue in dryland pastures in Canterbury has been the deep rooted legume Caucasian clover. Despite slow establishment, Black and Lucas (2000) reported in a 6 year study greater DM production of Caucasian clover than white clover when grown with Continental tall fescue, with this effect accentuated in a dry summer. This points toward further development of Caucasian clover, and Caucasian clover x white clover hybrids (Williams *et al.*, 2010), as opposed to strawberry clover, being a sensible strategy if a perennial legume that is capable of being continuous stocked is sought for dryland pasture mixtures. An alternative strategy may be to explore complementarity in growth of annual and perennial legumes within the same pasture (Tozer *et al.*, 2007).

The persistence and production of subterranean clover is dependent on successful recruitment of seedlings from the seed bank each autumn. In this study, the practical recommendation of ceasing grazing to allow a high level of flowering and seed production in the first year was carried out. While limiting grazing days, and so potential livestock production in the first year, this strategy ensured a large seed bank was established and that subsequent populations of seedlings were higher than 500 seedlings per m² recommended (Ates *et al.*, 2006). In the second spring, grazing management was hard throughout spring, and very high populations (2063 plants/m²) were achieved in the third year (Ates *et al.*, 2008). This confirms previous work by Ates *et al.* (2006) that where high initial seed bank populations are established, subterranean clover can continue to be grazed throughout spring at high stocking rates, with high seedling populations sustained. If populations in an established paddock were deemed to be low, then ceasing grazing earlier in spring (Ates *et al.*, 2008) may allow adequate populations to be re-established. Again, this would come at cost of livestock production; however, the benefits in terms of greater pasture production and livestock performance in subsequent years, is likely to be marked.

The alternative strategy studied here to promote high seedling populations was the timing of grazing relative to leaf stage in autumn. The autumn grazing study highlighted that grazing prior to the four leaf stage of subterranean clover reduced seedling survival during the first grazing. Therefore, for paddocks on a farm deemed to have low populations, grazing could usefully be delayed to beyond this point to promote seedling. In the context of this study, where populations were high (>500 seedlings per m²), grazing early had less impact on seedling numbers and DM production. The early grazing simply killed seedlings that appeared to die in the absence of grazing through other reasons such as strong interspecific competition. Indeed, DM production of subterranean clover was greater in spring for the spade leaf grazing, than three leaf or six leaf grazing stage, due to larger plants in this treatment. This was also found with tall fescue cultivar effects, where DM production of subterranean clover was greater in Flecha, in part due to larger

not more plants. This stresses the need for management of plant size being an important part of the practical management of subterranean clover in addition to plant number.

A combination of early (Campeda) and late flowering (Denmark) subterranean clover cultivars was used in the current study. A combination was sown in order to capture potential benefits in growth rate between cultivars; early flowering cultivars giving greater early season growth and late flowering cultivars, better late season growth if soil water is adequate (Smetham *et al.*, 1994; Dear *et al.*, 2007). This strategy may be useful in variable climates in spring. In this study, it was difficult to tell cultivars apart under intense sheep grazing and more years of data under variable climates is needed to fully measure the potential benefits.

Despite the success of subterranean clover for DM production demonstrated in this study, the usage of subterranean clover in New Zealand is still low particularly in North Island hill country and contribution of subterranean clover to total DM production remains low. This may reflect (i) conflicts between grazing management in spring for livestock production and flowering ((Ates *et al.*, 2008), (ii) greater incidence of wet summer and autumn in North Island hill country which limits establishment when competing with grasses (e.g. Gillespie *et al.*(2006) reported that the establishment of the slow growing species (Caucasian clover, lotus) and the large seeded subterranean clover appeared was unsuccessful) and (iii) lack of effective dispersal mechanism such as seed dispersal in dung to reach all sites in landscape.

7.1.2 Tall fescue

In the only full year of production data, Advance tall fescue produced a similar amount to perennial ryegrass when grown with perennial clovers, and both were greater than Flecha. As no comparative data was collected on other grass species, it is difficult to ascertain for certain how tall fescue production would compare relative to other dryland grass pastures such as cocksfoot in this environment. Other long term (8 year) dryland studies at the same site as the current study have noted that cocksfoot based pastures produce more DM than ryegrass based pastures (Mills

and Moot, 2010) which suggests that that the tall fescue pastures may produce less than the cocksfoot based pastures. However, this comparison used a different legume species – white clover with perennial ryegrass and subterranean clover with cocksfoot. Indeed, a comparison of perennial ryegrass and cocksfoot based pastures of a very dry, stony soil in Canterbury, Ates *et al.* (2010) reported similar DM production in both species when each was grown with subterranean clover. (Reed *et al.*, 2008) in reviewing pasture establishment and productivity in the regions with 465-680 mm average annual rainfall in Australia, found that tall fescue was 32% more productive than phalaris in winter.

It is also notable that growth over summer was greater in Advance than Flecha, however, even in Advance growth was relatively low (<20 kg DM/ha/day), and therefore opportunities to finish lambs post weaning would be limited. To achieve this, a summer forage (e.g. rape), or forage with greater growth under summer dry conditions, would be a useful part of sheep production systems. In a study at the same site as current work, the liveweight gain from sheep rotationally grazing lucerne was superior to all other pastures, particularly in summer (Mills *et al.*, 2008). Lucerne is generally more water deficit-tolerant due to water deficit-induced dormancy, deep rooting and high water use efficiency (Frame *et al.*, 2007). However, lucerne is winter dormant and cannot be grazed in Canterbury until at least late September (Brown *et al.*, 2000). Therefore, the use of lucerne could be a valuable option to complement the winter active pasture species such as Flecha tall fescue and subterranean clover in dryland pastures.

The liveweight gain study noted little effect of tall fescue cultivar on liveweight gain of suckling lambs during the crucial spring period. As noted in Chapter 4, differences may have become apparent if groups had been grazed on a clover basis (e.g. perennial versus subterranean clover basis) rather than a tall fescue basis. However, the objective here was to identify any advantages in terms of liveweight gain of using a cultivar of tall fescue that had earlier spring growth. Despite tentative evidence of more pasture growth in early spring and higher feed availability with Flecha than Advance, there was little difference in liveweight gain of lambs per head or per

ha in spring. This result, in part may have been influenced by the grazing management used, in particular, that grazing was started at a similar time in spring, and so therefore less opportunity to capture benefits of earlier pasture growth in grazing days. Future studies would usefully consider moving ewes from winter forage crops to their pastures earlier in spring, with ewes on the plots. Earlier lambing could be used on Flecha plots to attempt to capture further potential of early growth.

A further feature of the experimental design was the small number of ewes (<4 sheep) in each group for grazing management purposes. In this context, removal of ewes and lambs at a small number of time periods to adjust stocking rate creates relatively abrupt changes in overall stocking rate. For example, going from 4 to 3 sheep per group in spring 2009 reduced stocking rate from 25 to 18 ewes/ha. Such abrupt changes in stocking rate may limit some of the subtle changes in sheep grazing days to be captured. Using an alternative stock class (e.g. hoggets) (Black *et al.*, 2007) may allow a greater degree of control over stocking rate; however, these may be less responsive in terms of the magnitude of liveweight gain achievable compared to suckling lambs. Further, it was deemed desirable to use lambs and lactating ewes as this is the key practical context in which these pastures are used.

7.1.3 Soil Fertility

DM production was greater in pastures fertilized to achieve and Olsen P of 18 mg/L compared to those maintained at the lower Olsen P of 8 mg/L. This was primarily due to stimulation of tall fescue growth, with legume growth in the first year greater at low fertility. This indicates the complex effects that soil fertility may have on pasture growth. Of note, was that pasture growth was 1274 kg DM/ha/yr less (15%) than the high fertility treatment. Pasture quality did not, however, appear to be affected by soil fertility and with legume composition often higher at low fertility.

The current result for dryland pasture is important as many dryland sheep farmers, particularly in hill country, have struggled to maintain fertilizer inputs in recent years (Davidson 2010). The 15% reduction in dryland pasture is likely to be significant given that a high proportion (5.8%) of production occurs during the spring period when additional growth is important, although the high ability of legume growth to be sustained at low fertility may offset some of the potential impacts. In related work, the effect of withholding fertilizers has been studied extensively in summer moist North Island hill country (Clark *et al.*, 1990; Lambert *et al.*, 1990; Rowarth and Gillingham, 1990; Mackay and Lambert, 2011). The message from these papers was that withholding S and P fertilizer may offer a short term strategy for reduced expenditure, but in the longer term, the opportunity cost of withholding fertilizer will increase with time, with greater cost if soil fertility is initially high. Long term monitoring of the current plots will indicate whether similar patterns exist in summer dry pastures.

7.1.4 Economic implication of using legumes

The study showed that subterranean clover was the most successful legume for dryland pastures, with greater DM production. While cost of establishment of subterranean clover is initially expensive due to high seed price, careful grazing management to ensure flowering and seed production in the first spring can greatly enhance the seedbank. For example, the original 10kg subterranean clover seed/ha sown can be turned into excess of 200 kg/ha through allowing subterranean clover to flower (Ates, 2009). The study also indicated that to establish strawberry clover is likely to require the legume to be sown first with the grass later if this was to be used as pasture legume; this would add additional costs associated with drilling of a second occasion, as oversowing of the grass is unlikely to be successful.

In the longer term, the initial cost to establishing subterranean clover or another legume in the pasture will be offset through farm operation/productivity benefiting due to the higher quality feed with the increment of clover component in the swards. The higher clover content in the pasture is the key driver to farm profitability, through increased liveweight gain and reduced N

fertilizer. The cost benefit of this may include higher lambing percentage and faster growth rate from birth to weaning of the lambs that finished earlier, mean lambs can be slaughtered earlier.

7.3 Recommendations for future work

The result from this thesis highlighted that there might be places for further research on tall fescue based pastures in dryland farming which add to the current understanding of tall fescue-legumes mixtures grazing management.

- The production and persistence of Mediterranean and Continental tall fescue cultivars could be evaluated under a range of grazing intervals and regrowth periods. Of note, is that all grazing intervals conducted in this study were relatively short (<14 days) and post grazing residuals were also low. More research is needed to identify the minimum defoliation interval to provide adequate recovery period of regrowth for optimum production and persistence, and whether longer grazing periods are detrimental to quality. Therefore, a grazing experiment comparing intensive and other types of grazing managements may bring further insight into the grazing management of tall fescue, as the adaptation of tall fescue to different grazing management regimes may be different.
- As strawberry clover seems unsuitable as a companion clover species to tall fescue under intensive grazing, the other tall fescue perennial grass combinations could be considered. Tall fescue grows aggressively and needs intensive grazing to control the growth and to avoid the formation of seedhead (Tozer *et al.*, 2007). Thus, other companion perennial clovers may need to be robust under intensive grazing. The combinations of tall fescue with red clover suggested as it seem to grow well with perennial ryegrass (Black and Lucas, 2000).

- Strawberry clover seems incompatible with tall fescue in a mixture. However, the observation in monoculture plots showed that strawberry clover retained a more desirable plant structure with greater nodal rooting for longer under dryland conditions. Therefore, a study on of strawberry clover established with and without grass, and grazers excluded for different time periods could be conducted to determine the value of strategies of sowing clover first and grass later in order to achieve pastures of high legume abundance.
- The advantage of the earlier growth of Flecha was limited under current experimental conditions. More research could be conducted to identify the most suitable climatic condition in New Zealand for Mediterranean cultivars. These may include those regions drying out more readily in summer and so condensing the spring period and highlighting the importance of early spring growth.
- Subterranean clover appeared superior to the perennial clovers. Studies could be conducted to explore the hypothesis that combinations of annual and perennial legumes would complement each other and lead to more consistent production in in both wet and seasons.

7.4 Conclusions

The research presented in this thesis has provided insight into the effects of grazing management on tall fescue-legume mixtures production and persistence and animal production from dryland pastures. The main conclusion from each chapter can be summarized as follows:

- Tall fescue performance was depended on type and season. Winter-active (Mediterranean) Flecha thrived in late winter and early spring, whereas summer-active (Continental) Advance thrived in late spring and summer if there was enough soil moisture. Subterranean clover produced more DM than perennial clover, but the perennials can substitute during the absence of subterranean clover in summer.
- High lamb liveweight gains of 250 g/head/day can be obtained in dryland pastures where high fertility tall fescue-legume mixtures are the main pasture component. The grazing management of tall fescue pasture should be done intensively in spring and early summer to avoid it becoming rank and producing seedhead that will reduce quality and palatability.
- Subterranean clover seedlings can be a source of high quality feed in autumn if the seedling numbers is more than 500 plant/m². It can be grazed at spade leaf stage, but if the seedling numbers are less, it will reduce the clover production in the following spring.
- Strawberry clover had a longer taproot lifespan, but less tolerance to an intensive grazing regime while white clover cannot withstand dry conditions after the death of the taproot.
- The current study of defoliation management did not affect plant morphology, but it gave significant effects on pasture production. However, strawberry clover did not persist under current defoliation management, therefore the defoliation management needs to be altered for improved persistence.

References

- Adesogan, A. T., Givens, D. I. and Owen, E. eds). 2000. Measuring chemical composition and nutritive value in forages. Wallingford, UK.: CABI Publishing, pp. 263-244.
- Ates, S. 2009. Grazing management of subterranean clover (*Trifolium subterraneum* L.) in south island (New Zealand) summer dry pastures, Lincoln University, Christchurch
- Ates, S., Brown, H. E., Lucas, M. C. and Edwards, G. R. 2006. Effect of ewe stocking rate in spring on subterranean clover persistence and lamb liveweight gain. *Proceedings of the New Zealand Grassland Association* **68**, 95 – 99.
- Ates, S., Lucas, R. J. and Edwards, G. R. 2008. Pasture production and liveweight gain from cocksfoot-subterranean clover pastures grazed at two stocking rates and closed at different times during spring. *In: Proceedings of the New Zealand Grassland Association, Blenheim, New Zealand, October 2008. New Zealand Grassland Association. Vol. 70. p 225-232.*
- Ates, S., Tongel, M. O. and Moot, D. J. 2010. Annual herbage production increased 40% when subterranean clover was over-drilled into grass dominant dryland pasture. *Proceedings of the New Zealand Grassland Association*, **72**, 3-10.
- Bacon, C. W., Porter, J. K., Robbins, J. D. and .S. Luttrell. 1977. Epichoe typhina from toxic tall fescue grasses. *Appl. Environ. Microbiol.*, **35** 576-581.
- Bellotti, W. D. and Moore, A. D. 1994. Management for pasture establishment. East Melbourne, Australia: CSIRO Information Services. 26-37 pp.
- Black, A. D. and Lucas, R. J. 2000. Caucasian clover was more productive than white clover in grass mixtures under drought conditions. *Proceedings of the New Zealand Grassland Association*, **62**, 183-188.
- Black, A. D., Lucas, R. J., Moot, D. J. and Sedcole, J. R. 2007. Liveweight gains of lambs from Caucasian clover/ryegrass and white clover/ryegrass swards on soils of high and low fertility. *Grass and Forage Science*, **62**, 225-238.
- Black, A. D., Moot, D. J. and Lucas, R. J. 2006. Spring and autumn establishment of Caucasian and white clovers with different sowing rates of perennial ryegrass. *Grass and Forage Science*, **61**, 430-441.
- Bourner, T. C., Glare, T. R., Ocallaghan, M. and Jackson, T. A. 1996. Towards greener pastures - Pathogens and pasture pests. *New Zealand Journal of Ecology*, **20**, 101-107.
- Breen, J. P. 1994. Acremonium endophyte interactions with enhanced plant resistance to insects. *Agronomy Journal* **39**, 401-423.
- Brock, J. L. 2006. Grazing management of white clover in mixed pastures. *Proceedings of the New Zealand Grassland Association*, **68**, 303-307.
- Brock, J. L. 1988. Evaluation of New Zealand bred white clover cultivars under rotational grazing and set stocking with sheep. *Proceeding of New Zealand Grassland Association*, **49**, 203-206.
- Brock, J. L., Albrecht, K. A., Tilbrook, J. C. and Hay, M. J. M. 2000. Morphology of white clover during development from seed to clonal populations in grazed pastures. *Journal of Agricultural Science*, **135**, 103-111.
- Brock, J. L. and Caradus, J. R. 1996. Influence of grazing management and drought on white clover population performance and genotypic frequency. *In: White clover: New Zealand's competitive edge. Joint symposium, Lincoln University, New Zealand, 21-22 November, 1995. Agronomy Society of New Zealand. p 79-82.*
- Brock, J. L. and Fletcher, R. H. 1993. Morphology of perennial ryegrass (*Lolium perenne*) plants in pastures under intensive sheep grazing. *Journal. of Agricultural Science, Cambridge*, **120**, 301-310.
- Brock, J. L., Hyslop, M. G. and Widdup, K. H. 2003. A review of red and white clovers in the dryland environment. 101-107 pp.

- Brock, J. L. and Kim, M. C. 1994. Influence of the stolon/soil surface interface and plant morphology on the survival of white clover during severe drought. *Proceedings of the New Zealand Grassland Association*, **56**, 187-191.
- Brown, C. D. and Green, R. B. 2003. The challenges facing legumes in a dryland environment – a consultant’s view. Legumes for dryland pastures. *Proceedings of a New Zealand Grassland Association Symposium, Grasslands Research and Practice Series no 7-12*.
- Brown, H. E., Moot, D. J., Lucas, R. J. and Smith, M. 2006. Sub clover, cocksfoot and lucerne combine to improve dryland stock production. *Proceedings of the New Zealand Grassland Association*, **68**, 109-115.
- Brown, H. E., Moot, D. J., Pollock, K. M. and Inch, C. 2000. Dry matter production of irrigated chicory, lucerne and red clover in Canterbury. *Agronomy New Zealand*, **30**, 129-137.
- Bywater, A. C., C.M., L. and G.R., E. 2011. Flexibility and climate risk management in high stocking rate dryland sheep farming systems. *In: New Zealand Society of Animal Production, 29 June - 1 July 2011, Invercargill. New Zealand Society of Animal Production*, **71**, 96 - 102.
- Campillo, R., Urquiaga, S., Undurraga, P., Pino, I. and Boddey, R. M. 2005. Strategies to optimise biological nitrogen fixation in legume/grass pastures in the southern region of Chile. *Plant and Soil*, **273**, 57-67.
- Caradus, J. R. 1980. Distinguishing between grass and legume species for efficiency of phosphorus use. *New Zealand Journal of Agricultural Research* **25**, 75-81.
- Caradus, J. R., Woodfield, D. R. and A.V.Stewart. 1995. Overview and vision for white clover. In White clover: New Zealand's competitive edge. *In: joint symposium between Agronomy Society of New Zealand and New Zealand Grassland Association 21-22 November, 1995, Lincoln University, NNew Zealand. Agronomy Society of New Zealand and New Zealand Grassland Association*. p 1-6.
- Cayley, J. W. D. and Bird, P. R. 1996. Techniques for measuring pastures (2nd ed. Ed). Hamilton, Vic.: Pastoral and Veterinary Institute. 49 pp.
- Chapman, D. F. and Caradus, J. R. 1997. Effects of improved, adapted white clover (*Trifolium repens* L.) germplasm on the productive properties of a hill pasture. *New Zealand Journal of Agricultural Research*, **40**, 207-221.
- Chapman, D. F., Clark, D. A., Land, C. A. and Dymock, N. 1984. Leaf and tiller or stolon death of *Lolium perenne*, *Agrostis* spp., and *Trifolium repens* in set-stocked and rotationally grazed hill pastures. *New Zealand Journal of Agricultural Research*, **27**, 303-312.
- Chapman, D. F., Sheath, G. W., MacFarlane, M. J., Rumball, P. J., Cooper, B. M., Crouchley, G., Høglund, J. H. and Widdup, K. H. 1986. Performance of subterranean and white clover varieties in dry hill country. *Proceedings of the New Zealand Grassland Association*, **47**, 53-62.
- Charlton, D. and Stewart, A. 2006. Pasture and forage plants for New Zealand Grassland Assoc and NZ Grassland Trust. 96 pp.
- Cherney, J. H., Johnson, K. D., Lechtenberg, V. L. and Hertel, J. M. 1986. Biomass yield, fiber composition and persistence of cool-season perennial grasses. *Biomass*, **10**, 175-186.
- Clark, D. A., Ledgard, S. F., Lambert, M. G., O'Connor, M. B. and Gillingham, A. G. 1990. Long term effects of withholding phosphate application on North Island hill country. *Proceedings of the New Zealand Grassland Association*, **51**, 29-33.
- Clarke, J. N., Bennett, G. L. and Kirton, A. H. 1984. Relative performance of meat breeds of sheep in New Zealand and overseas. *Proceedings of the New Zealand Society of Animal Production*, **44**, 239-242.
- Cosgrove, G. P., Waghorn, G. C. and Parsons, A. J. 1999. Exploring the nutritional basis of preference and diet selection by sheep. *Proceedings of the New Zealand Grassland Association*, **61**, 175-180.
- Cox, J. E. 1978. Soils and agriculture of Paparua County, Canterbury, New Zealand. Canterbury, New Zealand: New Zealand Soil Bureau.

- Crush, J. R. (ed. 1987. Nitrogen fixation. In White clover, . Wallingford, UK.: C.A.B International, pp. 185-202.
- Dear, B. S., Sandral, G. A., Virgona, J. M., Swan, A. D., Orchard, B. A. and Cocks, P. S. 2007. Lucerne, phalaris, and wallaby grass in short-term pasture phases in two eastern Australian wheatbelt environments. 2. Effect of perennial density and species on subterranean clover populations and the relative success of 3 clover cultivars of different maturity. *Australian Journal of Agricultural Research*, **58**, 123-135.
- Dear, B. S. and Virgona, J. M. 1996. Legumes in low-input perennial pastures of southern Australia: Historical role and future development. *New Zealand Journal of Agricultural Research*, **39**, 579-589.
- Dodd, M. B. and Orr, S. J. 1995. Seasonal growth, phosphate response, and drought tolerance of 18 annual legume species grown in a hill-country soil. *New Zealand Journal of Agricultural Research* **38**, 21-32.
- Donaghy, D. J., Turner, L. A. and Adamczewski, K. A. 2008. Effect of defoliation management on water soluble carbohydrate energy reserves, dry matter yields and herbage quality in tall fescue. *Agronomy Journal* **100** 122-127.
- Ebrahimiyani, M., Majidi, M. M. and Mirlohi, A. 2013. Genotypic variation and selection of traits related to forage yield in tall fescue under irrigated and drought stress environments. *Grass and Forage Science*, **68**, 59-71.
- Edmeades, D. C., Feyter, C. and O'Connor, M. B. 1984. Lime and phosphorus requirements for hill country yellow-brown earths. *Proceedings of the New Zealand Grassland Association*, **45**, 98-106.
- Edwards, G. R. and Chapman, D. F. 2011. Plant responses to defoliation and relationship with pasture persistence. *Pasture persistence symposium*.
- Edwards, G. R., Lucas, R. J. and Johnson, M. R. 1993. Grazing preference for pasture species by sheep is affected by endophyte and nitrogen fertility. . *Proceedings of the New Zealand Grassland Association* **55**, 137-141.
- Exton, P. R., Dawson, J. E., Thomson, N. A., Moloney, S. and Lomas, J. 1996. More summer milk progress to date, the place if tall fescue in intensive dairying. *Proceedings of the 48th Ruakura Farmers' Conference* ., 34-41.
- Frame, J. 2000. Grassland species profiles: *Trifolium fragiferum* L.: Food and Agriculture Organization of the United Nations
- Frame, J. 2005. Forage Legumes for temperate grasslands. USA: Science Publishers
- Frame, J., Laidlaw, A. S. and Bi, C. 2007. Temperate forage legumes for adverse conditions. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, **2**, 10 pp.
- Gierus, M., Kleen, J., Loges, R. and Taube, F. 2012. Forage legume species determine the nutritional quality of binary mixtures with perennial ryegrass in the first production year. *Animal Feed Science and Technology*, **172**, 150-161.
- Gillespie, B. J., Lucas, R. J., Moot, D. J. and Edwards, G. R. 2006. Can topdressing with salt increase oversowing success and pasture quality on steep, south facing slopes in hill country pastures? *Proceedings of the New Zealand Grassland Association*, **68**, 349-353.
- Goh, K. M. and Bruce, G. E. 2005. Comparison of biomass production and biological nitrogen fixation of multi-species pastures (mixed herb leys) with perennial ryegrass-white clover pasture with and without irrigation in Canterbury, New Zealand. *Agriculture Ecosystems & Environment*, **110**, 230-240.
- Hand, M. L., Cogan, N. O., Stewart, A. V. and Forster, J. W. 2010. Evolutionary history of tall fescue morphotypes inferred from molecular phylogenetics of the *Lolium-Festuca* species complex. *Bmc Evolutionary Biology*, **10**.
- Harris, W., Forde, B. J. and Hardacre, A. K. 1981. Temperature and cutting effects on the growth and competitive interaction of ryegrass and paspalum .2. interspecific competition. *New Zealand Journal of Agricultural Research*, **24**, 309-320.

- Hay, R. J. M. 1987. Understanding pasture growth. *Proceeding of the Massey Dairy Farmers Conference* **39**, 55-63.
- Hayes, R. C., Dear, B. S., Li, G. D., Virgona, J. M., Conyers, M. K., Hackney, B. F. and Tidd, J. 2010. Perennial pastures for recharge control in temperate drought-prone environments. Part 1: productivity, persistence and herbage quality of key species. *New Zealand Journal of Agricultural Research*, **53**, 283-302.
- Hayes, R. C., Dear, B. S., Orchard, B. A., Peoples, M. B. and Eberbach, P. L. 2008. Response of subterranean clover, balansa clover, and gland clover to lime when grown in mixtures on an acid soil. *Australian Journal of Agricultural Research*, **59**, 824-835.
- Hodgson, J., Matthews, P. N. P., Matthew, C. and Lucas, R. J. 1999. Pasture measurement, In: New Zealand Pasture and Crop Science Oxford University Press
- Hofmann, R. W., Lin, W., Stilwell, S. A. and Lucas, R. J. 2007. Comparison of drought resistance in strawberry clover and white clover. . *Proceeding of the New Zealand Grassland Association*, **69**, 219-222.
- Hoglund, J. H. and Brock, J. L. eds). 1987. Nitrogen fixation in managed grasslands. In *Managed Grasslands: Analytical studies*. Amsterdam: Elsevier, pp. 187-196.
- Hull, J. L., Meyer, J. H. and Raguse, C. A. 1967. Rotation and continuous grazing on irrigated pasture using beef steers. *Journal of Animal Science*, **26**, 1160-1164.
- Hurst, R. G. M., Black, A. D., Lucas, R. J. and Moot, D. J. 2000. Sowing strategies for slow-establishing pasture species on a North Otago dairy farm. In: Proceedings of the New Zealand Grassland Association 62nd Conference, Invercargill, New Zealand, 31 October-2 November 2000. New Zealand Grassland Association. **Vol. 62**. p 129-135.
- Hyslop, M. G., Fraser, T. J., Smith, D. R., Knight, T. L., Slay, M. W. A. and Moffat, C. A. 2000. Liveweight gain of young sheep grazing tall fescue or perennial ryegrass swards of different white clover content *Proceedings of the New Zealand Grassland Association* **60**, 51-54.
- Jackman, R. H. and Mouat, M. C. H. 1972. Competition between grass and clover for phosphate. II. Effect of root activity, efficiency of response to phosphate and soil moisture. *New Zealand Journal of Agricultural Research* **15**, 667-675.
- Johnson, K. L. and Raguse, C. A. 1985. Comparative effects of repeated cycles of water stress on growth and apparent dinitrogen fixation of Ladino and strawberry clovers. *Crop Science*, **25**, 299-306.
- Judd, T. G. N. A. T. a. D. A. M. 1990. Pasture management and pasture species for improved dry matter production in south Taranaki. *Proceedings of the New Zealand Grassland Association* **51**, 109-112.
- Kain, W. M., Slay, M. W. and Atkinson, D. S. 1979. Evaluation of grass grub interactions of grasses sown with and without white clover in central Hawke's Bay. In: Proceedings of the 32nd New Zealand Weed and Pest Control Conference. (Dunedin: NZ Weed and Pest, 86-91 pp.
- Kemp, D. R., Michalk, D. L. and Goodacre, M. 2002. Productivity of pasture legumes and chicory in central New South Wales. *Australian Journal of Experimental Agriculture*, **42**, 15-25.
- Kemp, P. D., Matthew, C. and Lucas, R. J. 1999. Pasture species and cultivars. In: J. White and J. Hodson, (eds). *New Zealand Pasture and Crop Science*,. New Zealand: Oxford University Press
- Kerrisk, J. J. and Thomson, N. A. 1990. Effect of intensity and frequency of defoliation on growth of ryegrass, tall fescue and phalaris. *Proceedings of the New Zealand Grassland Association* **51**, 135-138.
- Knowles, I. M., Fraser, T. J. and Daly, M. J. 2003. White clover: loss in drought and subsequent recovery, Legumes-for-dryland-pastures. In: Proceedings-of-a-New-Zealand-Grassland-Association-Inc-Symposium-held-at-, 18-19-November, Lincoln-University. New-Zealand-Grassland-Association-Inc. **Vol. 11**. p 37-42.

- Korte, C. J., Chu, A. C. P. and Field, T. R. O. 1987. Pasture production *In*: A. M. Nicol, (ed). Livestock Feeding on Pasture: New Zealand Society of Animal Production. . **Vol. Occasional publication no. 10** 7-20
- Lambert, M. G., Clark, D. A. and Mackay, A. D. 1990. Long term effects of withholding phosphate application on North Island hill country: Ballantrae. *Proceedings of the New Zealand Grassland Association*, **51**, 25-28.
- Lambert, M. G., Luscombe, P. C. and Clark, D. A. 1982. Soil fertility and hill country production. *Proceedings of the New Zealand Grassland Association* **43**, 153-160.
- Lattanzi, F. A., Mazzanti, A. and Wade, M. H. 2007. Seasonal animal production of temperate and Mediterranean tall fescue cultivars under continuous variable stocking with close control of sward state. *Australian Journal of Agricultural Research*, **58**, 203-213.
- Lazenby, A. 1997. Selection and breeding of pasture plants. *In*: J. V. L. a. J. M. Scott, (ed). Pasture production and management. Melbourne: Inkata press
- Lewis, G. C. 1992. Effect of ryegrass endophyte in mixed swards of perennial ryegrass and white clover under 2 levels of irrigation and pesticide treatment. *Grass and Forage Science*, **47**, 302-305.
- Litherland, A. J. and Lambert, M. G. 2007. Factors affecting the quality of pastures and supplements produced on farms. *Occasional Publication - New Zealand Society of Animal Production*, 81-96.
- Lowe, K. F. and Bowdler, T. M. 1995. Growth, persistence, and rust sensitivity of irrigated perennial temperate grasses in the Queensland subtropics. *Australian Journal of Experimental Agriculture* **35**, 571-578.
- Mackay, A. D. and Lambert, M. G. 2011. Long-term changes in soil fertility and pasture production under no, low and high phosphorus fertiliser inputs. *In*: New Zealand Grassland Conference, Gisborne. New Zealand Grassland Association. **Vol. 73**. p 37 - 42.
- Malinowski, D. P. and Belesky, D. P. 2000. Adaptation of endophyte-infected cool-season grasses to environmental stresses: Mechanisms of drought and mineral stress tolerance. *Crop Science*, **40**, 923-940.
- Malinowski, D. P., Kigel, J. and Pinchak, W. E. 2009. Water deficit, heat tolerance, and persistence of summer-dormant grasses in the U.S. Southern Plains. *In*: First International Workshop on Summer Dormancy in Grasses: Coping with Climate Change, Samuel Roberts Noble Foundation, Ardmore, OK, USA, 6-8 April 2009. Crop Science Society of America. **Vol. 49**. p 2363-2370.
- Malinowski, D. P., Zuo, H., Kramp, B. A., Muir, J. P. and Pinchak, W. E. 2005. Obligatory summer-dormant cool-season perennial grasses for semiarid environments of the southern Great Plains. *Agronomy Journal*, **97**, 147-154.
- McCallum, D. A., Thomson, N. A. and Thom, E. R. 1992. The place of tall fescue in intensive dairying. *Proceedings of the Ruakura Farmer's Conference* **41**, 93-97.
- Mills, A. and Moot, D. J. 2010. Annual dry matter, metabolizable energy and nitrogen yields of six dryland pastures six and seven years after establishment. *Proceeding of New Zealand Grassland Association*, **72**, 177 - 183.
- Mills, A., Smith, M. C., Lucas, R. J. and Moot, D. J. 2008. Dryland pasture yields and botanical composition over 5 years under sheep grazing in Canterbury. *In*: Proceedings of the New Zealand Grassland Association, Blenheim, New Zealand, October 2008. New Zealand Grassland Association. **Vol. 70**. p 37-44.
- Milne, G., Hamilton-Manns, M. and Fraser, T. 1998. Tall Fescue Users GuideAgricom (NZ) Ltd, Wrihston Nutrition Ltd, Coated Seeds, New Zealand.
- Minee, E. M. K., T.L. Knight, B.L. Sutherland, J.B. Vlaming, Flecher, L. R. and Clark., D. A. 2010. Herbage production from perennial ryegrass and tall fescue pastures under irrigation in the Canterbury and Waikato regions of New Zealand. *In*: New Zealand Grassland Association, Lincoln, New Zealand. NZGA. **Vol. 72**. p 185 - 189.

- Minnee, E. M. K., Knight, T. L., Sutherland, B. L., Vlaming, J. B., Fletcher, L. R. and Clark, D. A. 2010. Herbage production from perennial ryegrass and tall fescue pastures under irrigation in the Canterbury and Waikato regions of New Zealand. *In: New Zealand Grassland Association Conference, Lincoln University, New Zealand. New Zealand Grassland Association. Vol. 72.* p 185 - 189.
- Moorhead, A. Personal Communication.
- Moot, D. J., Black, A. D., Scott, W. R. and Richardson, J. 2003. Leaf development and dry matter production of subterranean clover cultivars in relation to autumn sward management, Legumes for dryland pastures. *Proceedings of a New Zealand Grassland Association Symposium, Grasslands Research and Practice Series*, 193-208.
- Morley, F. H. W. 1958. Effects of strain and temperature on the growth of subterranean clover (*Trifolium subterraneum* L.). *Australian Journal of Agricultural Economics*, **9**, 745-753.
- Nichols, P. G. H., Revell, C. K., Humphries, A. W., Howie, J. H., Hall, E. J., Sandral, G. A., Ghamkhar, K. and Harris, C. A. 2012. Temperate pasture legumes in Australia - their history, current use, and future prospects. *Crop & Pasture Science*, **63**, 691-725.
- Nichols, P. G. H., Rogers, M. E., Craig, A. D., Albertsen, T. O., Miller, S. M., McClements, D. R., Hughes, S. J., D'Antuono, M. F. and Dear, B. S. 2008. Production and persistence of temperate perennial grasses and legumes at five saline sites in southern Australia. *Australian Journal of Experimental Agriculture*, **48**, 536-552.
- Nicol, A. M. (ed. 1989. Feeding livestock on pasture. Hamilton, New Zealand: New Zealand Society of Animal Production. Vol. 10, pp. 145.
- Nicol, A. M., R.H., B., M.J., R. and G.R., E. 2010. Liveweight gain per head and per ha throughout the year of lambs grazing conventional pastures and those that switch from grass to clover. *In: New Zealand Grassland Conference, Lincoln. New Zealand Grassland Association. Vol. 72*
- Norton, M. R., Volaire, F. and Lelievre, F. 2006. Summer dormancy in *Festuca arundinacea* Schreb.; the influence of season of sowing and a simulated mid-summer storm on two contrasting cultivars. *Australian Journal of Agricultural Research*, **57**, 1267-1277.
- Ofir, M. and Kerem, D. 1982. The effects of temperature and photoperiod on the onset of summer dormancy in *Poa bulbosa* L. *Ann. Bot (London)* **50**, 259 -264. .
- Olusuyi, S. A. and Raguse, C. A. 1968. Effect of temperature on germination and seedling development of Ladino clover (*Trifolium repens* L.) and Salina strawberry clover (*Trifolium fragiferum* L.). *Crop Science*, **8**, 543-544.
- Omacini, M., Semmartin, M., Pérez, L. I. and Gundel, P. E. 2012. Grass–endophyte symbiosis: A neglected aboveground interaction with multiple belowground consequences. *Applied Soil Ecology*, **61**, 273-279.
- Overseer, N. B. M. 2010. Palmerston North, New Zealand: Agresearch Ltd.
- Parish, J. A., McCann, M. A., Watson, R. H., Hoveland, C. S., Hawkins, L. L., Hill, N. S. and Bouton, J. H. 2003. Use of nonergot alkaloid-producing endophytes for alleviating tall fescue toxicosis in sheep. *Journal of Animal Science* **81**, 1316-1322.
- Parsons, A. J., Edwards, G. R., Chapman, D. F. and Carran, R. A. 2006. How far have we come: 75 years 'in clover'? *Proceedings of the New Zealand Grassland Association* **68**, 7-13.
- Penning, P. D., Parsons, A. J. and Orr, R. J. 1991. Patterns of ingestive behaviour of sheep continuously stocked on monocultures of ryegrass or white clover. *Applied Animal Behaviour Science*, **31** 237-250.
- Popay, A. J. and Ball, O. J. P. 1998. The development of fungal endophytes as a pest management tool for New Zealand grasslands. St Lucia: Univ Queensland, Dept Hosp Tourism Prop Management Lawes. 373-381 pp.
- Popay, A. J., Jensen, J. G. and Cooper, B. M. 2005. The effect of non-toxic endophytes in tall fescue on two major insect pests. *Proceedings of the New Zealand Grassland Association* **67**, 169-173.

- Praat, J. P., Ritchie, W. R., Baker, C. J. and Hodgson, J. 1996. Target populations for direct-drilled ryegrass and tall fescue. *Proceedings of the New Zealand Grassland Association*, **57**, 77-81.
- Prestidge, R. A., Badan, D. and Zijpp, S. v. d. 1986. The effect of Argentine stem weevil on cocksfoot and tall fescue when sown with ryegrass. *In: Proceedings of the 39th New Zealand Weed and Pest Control Conference*, . (Nelson, 33-37 pp.
- Prioul, J. L. and Silsbury, J. H. 1982. A physiological analysis of the effect of sowing density on the growth-rate of subterranean clover. *Australian Journal of Agricultural Research*, **33**, 213-222.
- Raeseide, M. C., Friend, M. A., Behrendt, R., Lawson, A. R. and Clark, S. G. 2012. Tall fescue establishment and management in south west Victoria. *New Zealand Journal of Agricultural Research*, **55**, 31-46.
- Reed, K. F. M. 1996. Improving the adaptation of perennial pasture grasses. *New Zealand Journal of Agricultural Research* **39**, 457-464.
- Reed, K. F. M., Nie, Z. N., Miller, S., Hackney, B. F., Boschma, S. P., Mitchell, M. L., Albertsen, T. O., Moore, G. A., Clark, S. G., Craig, A. D., Kearney, G., Li, G. D. and Dear, B. S. 2008. Field evaluation of perennial grasses and herbs in southern Australia. 1. Establishment and herbage production. *Australian Journal of Experimental Agriculture*, **48**, 409-423.
- Rickard, D. S. and McBride, S. D. 1986. Irrigated and non-irrigated pasture at Winchmore, 1960 to 1985. *Winchmore irrigation research station*. **No.** pp
- Rollo, M. D., Sheath, G. W., Slay, M. W. A., Knight, T. L. and Judd, T. G. 1998. Tall fescue and chicory for increased summer forage production. *Proceedings of the New Zealand Grassland Association* **60**, 249-253.
- Rowarth, J. S. and Gillingham, A. G. 1990. Effects of withholding fertiliser on pasture production and phosphate cycling in hill country. *Proceedings of the New Zealand Grassland Association*, **51**, 17-20.
- Rumball, W., Claydon, R. B. and Miller, J. E. 1991. Grasslands Onward strawberry clover (*Trifolium fragiferum* L.). *New Zealand Journal of Agricultural Research* **34**, 131-133.
- Saul, G. R. and Chapman, D. F. 2002. Grazing methods, productivity and sustainability for sheep and beef pastures in temperate Australia. *Wool Technology and Sheep Breeding*, **50**, 449-464.
- Scheneiter, O. and Amendola, C. 2012. Tiller demography in tall fescue (*Festuca arundinacea*) swards as influenced by nitrogen fertilization, sowing method and grazing management. *Grass and Forage Science*, **67**, 426-436.
- Smetham, M. L. 2003. Subterranean clover (*Trifolium subterraneum*): its history and current and future research in New Zealand. 61-72 pp.
- Smetham, M. L. 1999. The ecology and use of subterranean clover (*Trifolium subterraneum* L.) as a pasture legume. An Australasian perspective, Lincoln University, New Zealand.
- Smetham, M. L. and Jack, D. W. 1995. Herbage production under grazing, of some subterranean clover lines compared with lucerne. *Agronomy Society of New Zealand - Proceedings, Twenty-Fifth Annual Conference 1995/96*, **25**, 69-76.
- Smetham, M. L., Jack, D. W. and Hammond, S. E. H. 1994. The influence of patterns of flowering of some subterranean clover (*Trifolium subterraneum* L.) accessions and cultivars on total seed set and autumn germination in a cool temperate environment with sporadic summer rain. *Proceedings of the New Zealand Grassland Association*, **56**, 127-131.
- Smetham, M. L. and Sparks. 2003. A review of subterranean clover (*Trifolium subterraneum* L.): its ecology, and use S a pasture legume in Australasia*. *In. Advances in Agronomy: Academic Press*, 303-350

- Smith, D. R., Fraser, T. J., Moffat, C. A. and Daly, M. J. 1998. Effects of soil fertility on the persistence of dryland cocksfoot and tall fescue pastures. *Proceedings of the New Zealand Grassland Association* **60**, 265-270.
- Solter, U., Hopkins, A., Sitzia, M., Goby, J. P. and Greef, J. M. 2007. Seasonal changes in herbage mass and nutritive value of a range of graze legumes swards under Mediterranean and cool temperate conditions. *Grass and Forage Science*, **62**, 372 – 388.
- Stephenson, R. J. and Posler, G. L. 1988. The influence of tall fescue on the germination, seedling growth and yield of birdsfoot trefoil *Grass and Forage Science* **43**, 273-278.
- Stewart, A. and Charlton, D. 2003. Pasture and forage plants for New Zealand NZ Grassland Assoc and NZ Grassland Trust. 96 pp.
- Swift, G., McClelland, T. H., Cleland, A. T., Milne, J. A. and Hunter, E. A. 1993. A comparison of diploid and tetraploid perennial ryegrass and tetraploid ryegrass/white clover swards under continuous sheep stocking at controlled sward heights. 1. Sward characteristics. *Grass and Forage Science* **48**, 279-289.
- Tharmaraj, J., Chapman, D. F., Nie, Z. N. and Lane, A. P. 2008. Herbage accumulation, botanical composition, and nutritive value of five pasture types for dairy production in southern Australia. *Australian Journal of Agricultural Research* **59**, 127-138.
- Thomas, H. and Wilson, D. 1979. Advances in breeding herbage varieties tolerant of water stress. *UK, British Grassland Society: Water control and grassland productivity. Papers presented at the Winter Meeting 4 December 1979.*, 3.1-3.10.
- Thomas, R. G. 2003. Comparative growth forms of dryland forage legumes. *In: Legumes for dryland pastures*, 18-19 November Lincoln University. Proceedings of a New Zealand Grassland Association **Vol. Grasslands Research and Practice Series**
- Thomas, R. G. and Hay, M. J. M. 2010. The role of nodal roots in prostrate clonal herbs: 'phalanx' versus 'guerrilla'. *Evolutionary Ecology*, **24**, 1489-1504.
- Thomas, R. J. 1992. The role of legumes in the nitrogen cycle of productive and sustainable pastures. *Grass and Forage Science* **47**, 133-147.
- Tozer, K. N., Ates, S., Mapp, N. R., Smith, M. C., Lucas, R. J. and Edwards, G. R. 2007. Effects of the MaxP endophyte in tall fescue on pasture production and composition, and sheep grazing preference, in a dryland environment. *Proceedings of the 6th International Symposium on Fungal Endophytes of Grasses*, 259-262.
- Turner, L. R., Holloway-Phillips, M. M., Rawnsley, R. P., Donaghy, D. J. and Pembleton, K. G. 2012. The morphological and physiological responses of perennial ryegrass (*Lolium perenne* L.), cocksfoot (*Dactylis glomerata* L.) and tall fescue (*Festuca arundinacea* Schreb.; syn. *Schedonorus phoenix* Scop.) to variable water availability. *Grass and Forage Science*, **67**, 507-518.
- Turner, N. C., Thomson, C. J. and Rawson, H. M. 2001. Effect of temperature on germination and early growth of subterranean clover, capeweed and Wimmera ryegrass. *Grass and Forage Science*, **56**, 97-104.
- Valentine, I. and Kemp, P. D. 2007. Pasture and supplement resources. *In: P. V. Rattray, I.M. Brookes and A.M. Nicol (ed). Pasture and supplements for grazing animals: NZ Soc. of Animal Production* 3 -11
- Vallentine, J. F. 2001. Introduction to Grazing. *In. Grazing Management (Second Edition)*. San Diego: Academic Press, 1-27
- Vazquez de Aldana, B. R., Garcia-Ciudad, A., Zabalgoceazcoa, I. and Garcia-Criado, B. 2012. Effect of endophyte infection in red fescue-red clover simple mixture. 193-195 pp.
- Villiers, T. A. 1975. Dormancy and the survival of plants. London: Edward Arnold
- Waghorn, G. C. and Clark, D. A. 2004. Feeding value of pastures for ruminants. *New Zealand Veterinary Journal*, **52**, 320-331.
- White, T. A. and Knight, T. L. 2007. Pasture yield and composition under different land uses in North Otago Rolling Downlands. *Proceedings of the New Zealand Grassland Association*, **69**, 65-71.

- Williams, W. M., Verry, I. M., Ansari, H. A., Ellison, N. W., Hussain, S. W., Widdup, K., Nichols, S. N., Williamson, M. L., Naem, M. and Ullah, I. 2010. Splitting the clover genome: radical new clovers for agriculture. *In: New Zealand Grassland Conference, Lincoln. New Zealand Grassland Association. Vol. 72.* p 273 -276.
- Woodfield, D. R., Caradus, J. R., Causins, G. R. and Dunn, T. 1995. Response to selection for increased taproot diameter. *White Clover: New Zealand's Competitive Edge., Agronomy Society of New Zealand No.* pp. 141-143.
- Wurst, M. 2004. Pasture legume for temperate farming system Primary industries and Resources South Australia
- Yu, Y., Nan, Z. B. and Matthew, C. 2008. Population relationships of perennial ryegrass and white clover mixtures under differing grazing intensities. *Agriculture, Ecosystems & Environment, 124,* 40-50.

Appendix 1

The meteorological data obtain from Broadfield Weather station situated 2 km from the experimental plots.

Year	Rain	Air Temperature			Grass min	Solar Rad.	Wind Run	VP	Penman	Soil Temperatures				
		max	min	mean						10cm	30cm	100cm		
2008	March	23.6	20.4	10.0	14.9	8.1	448	10913	13.6	93.3	16.4	17.1	16.8	
	April	35.7	17.5	6.7	12.1	3.8	271	8681	11.6	57.6	12.6	13.7	15.1	
	May	59.9	12.9	2.4	7.4	-1.0	196	8975	9.2	34.5	7.4	8.5	11.5	
	June	88.9	12.1	1.6	7.0	-1.7	126	9507	8.5	30.8	5.8	6.4	9.0	
	July	145.0	10.7	3.0	6.7	0.3	134	10698	8.7	29.1	5.8	6.1	7.7	
	August	94.2	10.9	2.1	6.3	-0.3	227	9207	8.3	39.3	6.1	6.5	7.8	
	September	39.1	15.8	5.2	10.4	2.4	341	11120	9.6	74.9	9.8	9.6	9.3	
	October	22.1	17.4	5.0	11.2	1.9	560	11450	9.6	112.0	12.3	12.0	11.1	
	November	11.4	19.7	8.3	13.8	5.5	683	11898	11.5	139.4	16.6	15.9	13.5	
	December	76.6	19.8	10.4	15.2	8.2	699	12778	13.4	139.3	18.0	17.7	15.6	
	2009	January	46.4	24.4	12.0	18.0	9.4	723	11425	13.9	167.3	20.9	20.5	17.7
		February	58.6	20.2	11.4	15.3	9.8	444	9433	13.7	94.5	17.4	18.0	17.6
March		36.2	20.0	9.1	14.3	6.4	478	11753	12.3	106.2	15.1	15.5	16.0	
April		52.9	17.7	7.4	12.5	4.8	285	10267	11.2	69.2	12.2	12.6	13.9	
May		145.0	10.7	3.0	6.7	0.3	134	10698	8.7	29.1	5.8	6.1	7.7	
June		13.8	10.5	1.7	5.6	-1.0	137	7985	8.0	26.9	5.4	6.1	8.6	
July		36.7	10.3	1.0	5.7	-1.6	180	8077	7.6	35.8	4.9	5.2	7.2	
August		51.8	14.3	4.5	9.3	1.8	254	10800	9.1	60.0	7.7	7.5	7.7	
September		15.4	15.4	4.1	9.6	1.2	414	10743	8.9	84.0	9.4	9.4	9.2	
October		82.6	14.3	4.4	9.4	2.0	570	11727	9.2	102.0	11.1	11.3	10.6	
November		8.8	18.6	6.5	12.6	4.0	616	11541	10.5	127.0	15.1	15.0	12.9	
December		36.7	19.9	9.2	14.3	6.9	701	11932	12.3	139.3	16.8	16.8	14.6	
2010	January	48.8	20.8	10.8	15.3	9.3	647	12572	13.5	132.9	17.9	18.0	16.1	
	February	21.7	21.7	10.9	16.2	8.4	565	9213	14.4	114.1	19.4	19.3	17.2	
	March	22.8	21.6	8.8	14.9	6.2	456	11204	12.6	104.9	16.3	16.6	16.5	
	April	25.2	19.7	7.7	13.4	5.0	303	9505	11.4	74.8	13.3	13.6	14.4	
	May	153.4	14.0	5.9	9.9	3.8	163	11069	10.8	34.8	10.0	10.6	12.2	
	June	109.0	10.7	2.4	6.5	0.1	122	9302	8.7	24.1	6.3	7.0	9.2	