Strategies to improve sheep liveweight gains and dry matter production of dryland tall fescue/clover pastures in Canterbury

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Louise Victoria Livesey

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This study examined ways to improve sheep liveweight gains and dry matter production on dryland Canterbury farms using tall fescue/clover pastures. There were four pasture mixes sown in 2008 at Lincoln University. Each combination included one tall fescue cultivar ('Advance' (continental, summer active type) or 'Flecha' (Mediterranean, winter active type)) with either white clover ('Nomad') or subterranean clover ('Denmark' and 'Campeda'), and was repeated at low (8 mg P/L) and high (18 mg P/L) soil fertility. Sheep liveweight gains and pasture yields were measured during the seventh year (2014). From 17 March to 27 May, the hoggets on the tall fescue/subterranean clover pastures gained 37 g/head/day compared with 14 g/head/day on tall fescue/white clover pastures at a similar stocking rate (31.3 sheep/ha). Clover content in the subterranean clover pastures was 8.5% compared with 5.6% in the white clover pastures. 'Denmark' was more abundant than 'Campeda' in the subterranean clover pastures after 6 years. 'Flecha' tall fescue swards produced more DM yield, but the yield had more weeds (49%) and less tall fescue (30%) than 'Advance' swards (34% and 46%). Subterranean clover pastures at high soil fertility provided a greater total herbage yield (6180 kg DM/ha) than white clover/high fertility pastures (6072 kg DM/ha), which contained more weeds than subterranean clover swards. Soil in the ‘Advance’/high fertility pastures contained more anaerobically mineralisable N (116 kg N/ha) than the ‘Flecha’/high fertility pastures (100 kg N/ha), but both treatments produced similar clover yields. Total N content in the top 7.5 cm of soil in subterranean clover pastures (0.226%) was higher than in the white clover pastures (0.218%), suggesting that the subterranean clover pastures fixed more N. The final recommendation obtained from the results of this study was that ‘Advance’ tall fescue should be sown with ‘Denmark’ subterranean clover in high fertile soils as a strategy to improve sheep liveweight gains and DM production of dryland tall fescue swards in Canterbury.

Keywords: ‘Campeda’, continental, cultivar, ‘Denmark’, *Festuca arundinacea* Schreb., Mediterranean, soil fertility, *Trifolium repens, Trifolium subterraneum*

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1 Introduction

New Zealand dryland pastures are concentrated in the eastern regions which are subjected to periods of summer and autumn moisture stress (Mills *et al.*, 2008). This reduces pasture production, persistency and recovery of the traditional perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pastures (Woodman *et al.*, 1992; Knowles *et al.*, 2003). This pasture mix is what is often described as New Zealand's key competitive advantage in the pastoral industry over other pastoral farming nations as it generally has a high nutritive value, which can lead to increased animal performance compared with some other pasture options (Knowles *et al*., 2003). However, growth of perennial ryegrass and white clover is severely diminished in dryland environments.

Tall fescue (*Festuca arundinacea* Schreb.) is recognised in New Zealand as a suitable alternative to perennial ryegrass, particularly where potential evapotranspiration (PET) exceeds rainfall in summer (Tonmukaykul *et al.*, 2009; Moot, 2012). It is a deep-rooted perennial grass which is adapted to survive a range of environments including: summer droughts, water-logged soils and hard frosts. It is slower to establish than perennial ryegrass owing to its slow mobilization of seed reserves and slow seedling growth (Kemp *et al.*, 1999b). However, once established, tall fescue has a similar annual dry matter (DM) production to perennial ryegrass where soil moisture is adequate, but in dryland conditions it is more productive and persistent than perennial ryegrass (Brock, 1982; Rollo *et al.*, 1998), as it can recover quicker from periods of water deficit. Tall fescue cultivars sown in New Zealand are classified into two types: continental types, which are summer active and are the most common types of tall fescue sown, and Mediterranean types, which are winter active and summer dormant. Tall fescue/clover pastures have proven to produce more lambs reaching target draft weights than lambs grazing on pure perennial ryegrass swards in dryland systems (Fraser *et al.*, 1999). This indirectly increases the income from lambs and assists ewe lambs to reach maturity quicker. However, the commonly used continental cultivars, like ‘Advance’, show limited growth during the cool autumn, winter and spring months (Schiller and Lazenby, 1975). This is the time of year on dryland farms when soil moisture is adequate for pasture growth. Potentially, a strategy to better exploit this limited amount of soil moisture is to use a Mediterranean type cultivar, such as ‘Flecha’, which is purported to be more productive in the cool season than the continental types of tall fescue (Reed *et al.*, 2004).

Legumes are needed pastures on dryland farms to improve soil fertility through the biological process of nitrogen (N) fixation. This is to increase pasture production and quality which indirectly assists with improved liveweight gains in grazing animals (Caradus *et al.*, 1996; Hyslop *et al.*, 2000). White clover (*Trifolium repens*) is a common choice of companion legume for tall fescue in many environments. However, white clover requires at least 40 mm/month of rainfall to survive and at least 60 mm/month for performance over summer (Brock, 2006). Therefore it has a poor recovery after droughts (Knowles *et al.,* 2003) and limited survival in dryland environments where annual rainfall is 600 mm or less. This means that animal production and DM of tall fescue-based pastures are often limited due to low white clover content on dryland farms. Therefore farmers wanting to increase the legume content of their dryland tall fescue pastures need to use a companion legume better suited to their short growth season. In these conditions the likely option is subterranean clover (*T. subterraneum*). Subterranean clover is adapted to dryland conditions because it buries its seed in late spring/early summer and the seeds remain dormant over summer until the autumn rains arrive (Kemp *et al.*, 1999b; Smetham, 2003). Under the correct stocking rate tall fescue/subterranean clover swards can increase spring clover content and therefore provide high quality pasture to lactating ewes to achieve high liveweight gains to finish lambs earlier before the onset of the dry summer conditions (Ates *et al.*, 2006). The normal recommendation is to sow a mix of subterranean clover cultivars with different flowering dates in spring. The idea here is that a mid-flowering cultivar will survive and act as insurance against dry years while a late flowering cultivar will grow more clover later in spring in years when rainfall is higher.

Like most productive pasture species, tall fescue, white clover and subterranean clover require regular applications of phosphorus (P) and sulphur (S) fertiliser to thrive. Legumes require P to allow the nitrogenase enzyme to fix N. Some legumes are more P efficient where they can achieve maximum growth at 12 µg P/g soil whereas others require 24 µg P/g (Pang *et al.*, 2010). Sulphur supply may be more important than P to stimulate N_2 fixation of introduced clovers under dryland conditions, particularly in the South Island (McLaren and Cameron, 1996). Phosphorus and S are generally applied through the application of phosphate fertilisers, such as superphosphate. Applying fertiliser on dryland pastures can be an expensive exercise where farmers may only receive a small return of increased pasture and animal production. However, it has been stated that the cessation of phosphate fertiliser will decrease sustainable productivity and the land's resale value (Clark *et al.*, 1990). Therefore, in reality tall fescue/clover swards are likely to be grown in soils with levels of plant available P and S ranging from optimal (Olsen P 20-25 mg/L and 10-12 mg S/kg) to suboptimal (Olsen P 10-15 mg/L) for pasture production (McLaren & Cameron, 1996). Therefore, any comparison of tall fescue cultivar and companion clover species should be made in a range of soil P and S ("fertility") conditions so the results can have a wider relevance to dryland farmers.

Therefore, the objectives of this study were to quantify the effects of 1) continental and Mediterranean type cultivars of tall fescue ('Advance' and 'Flecha') and 2) white clover and subterranean clover as companion species for tall fescue, on sheep liveweight gains and DM production of dryland tall fescues/clover pastures under two contrasting levels of soil fertility. The swards were sown in March 2008 and results from their seventh year (March to September 2014) will be reported in this dissertation. In addition to the main objectives, the study assessed the relative abundance of two sown cultivars of subterranean clover pastures and the effects that tall fescue cultivar and soil fertility have had on this clover composition after 6 years. The effects that the pasture and soil fertility treatments have had on soil N and carbon (C) contents were also examined in this study.

2 Literature review

2.1 Tall fescue versus perennial ryegrass

Tall fescue is a deep-rooted perennial grass with large tillers and ribbed, hairless leaves with a coarse leaf margin (Kemp *et al.*, 1999b). It has a large, spreading panicle with small, awned spikelets. It has the ability to survive summer droughts and tolerate waterlogged soils and hard frosts. It is slower to establish than perennial ryegrass due in part to its slow mobilization of seed reserves and slow seedling growth (Kemp *et al.*, 1999b). However, once established tall fescue has a similar DM production to perennial ryegrass where water is not limiting but in dryland conditions tall fescue has greater pasture production, as it can recover quicker after a water deficit (Kemp *et al.*, 1999b). Optimal air temperature for growth of leaves of tall fescue is 25°C and 15-29°C is sufficient for growth within 20% of its maximum daily leaf growth rate (Robson, 1972). Tall fescue's natural range of habitat is limited by rainfall below 450 mm/yr (Easton *et al.*, 1994). Fertility and grazing management influence its persistency in New Zealand (Easton *et al*., 1994). Rollo *et al.* (1998) stated that the rhizome development does not begin until 2 years after autumn sowing and it can be reduced by poor grazing management.

2.1.1 Dry matter production

Tall fescue is an important cool season perennial where summer moisture stress limits the persistence and yield of perennial ryegrass in the dry east coast of New Zealand and semi-arid areas of Australia (Easton *et al*., 1994). Brock (1982) showed that both tall fescue cultivars, 'Roa' and 'S170', yielded significantly higher than 'Ruanui' ryegrass by 172 and 163%, respectively, with only 55% of the normal rainfall in the summer to autumn period (January-April) of the first year. However, both cultivars also out-yielded 'Ruanui' during the same period of the wetter second year, by 40 and 54%, respectively. In this study, the tall fescue was sown 1 year before the ryegrass due to its slower establishment.

Rollo *et al*. (1998) found that the average annual tall fescue yield over a 5 year period was greater than perennial ryegrass across three dryland sites in New Zealand (Figure 2.1). The annual yields reflected the local climatic conditions between the dryland sites. Pasture production for both grass species was greatest at the Taranaki Agricultural Research Station (TARS) which had the highest summer rainfall (290 mm) and lowest water deficit (161 mm) out of the three sites. At this site, tall fescue produced 17 t DM/ha which was 13.5% more than ryegrass. The Winchmore site had the lowest herbage production as it had the lowest summer rainfall (256 mm) and soil temperature (15.6°C) and highest water deficit (235 mm) over summer. At this site, the tall fescue produced an average 11.2 t DM/ha compared with 10.1 t DM/ha from perennial ryegrass. The Poukawa site in the Hawke's Bay showed no significant difference in the yields of the two grasses as the hot dry conditions restricted the tall fescues advantage to 570 kg DM/ha.

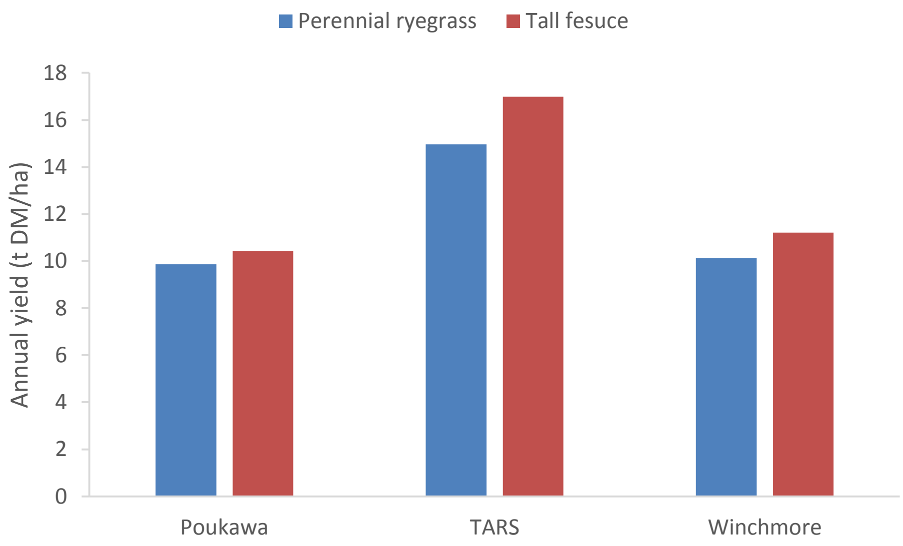

Figure 2.1 Average annual yields of perennial ryegrass and tall fescue across three dryland sites (Poukawa, Taranaki Agricultural Research Station (TARS) and Winchmore) in New Zealand over a 5 year period from 1990/91 to 1994/95 (Rollo *et al.,* 1998).

2.1.2 Nutritive value

The nutritive value of tall fescue can be greater than perennial ryegrass pastures. Waghorn and Clark (2004) showed that tall fescue's CP content (16%) is the same as perennial ryegrass but DM composition (25%) is greater and neutral detergent fibre (NDF) content (42%) is lower than perennial ryegrass (19% and 48%, respectively) (Table 2.1). Tall fescue swards are known to have a greater compatibility with clover species (Hyslop *et al*., 2000). Therefore, tall fescue/clover pastures usually have a greater pasture quality because of greater clover content in the swards increases the nutritive value due to the high metabolisable energy (ME) (more than 11.5 MJ/kg DM) value of clover (Waghorn & Clark, 2004).

Table 2.1 Dry matter (DM), crude protein (CP) and neutral detergent fibre (NDF) composition of tall fescue and perennial ryegrass (Waghorn & Clark, 2004).

	DM (%)	CP (% of DM)	NDF (% of DM)
Tall fescue	25	16	42
Perennial ryegrass	19	16	48

Lacefield *et al.* (2003) reported changes in forage quality between the seasons for sugar content and digestibility whereas CP content in green leafy tall fescue leaves were found to be high throughout the year (Table 2.2). The reported values for tall fescue showed that sugar content and digestibility of dry matter (DDM) were greatest in autumn (19 and 74%, respectively) and lowest in summer (8.5% and 66%, respectively). However, feed quality can be improved when grown in mixed swards with legumes, such as white clover and subterranean clover or with summer-active forages with high nutritive qualities like chicory (*Cichorium intybus*) and plantain (*Plantago lanceolata*).

Table 2.2 Seasons chemical composition and digestibility of tall fescue (Lacefield *et al*., 2003).

	Spring	Summer	Autumn
Sugars (%)	9.5	8.5	19
CP (%)	22	18	19
DDM (%)	69	66	74

2.2 Continental versus Mediterranean cultivars

Tall fescue cultivars are classified as continental and Mediterranean. Mediterranean types have been described as having longer and softer leaves, lower plant leafiness and earlier flowering than continental types has demonstrated to have good persistence in environments with summer drought stress (Pecetti *et al.*, 2011).

Assuero *et al.* (2002) reported that both types demonstrated common responses to water deficit which were characterised by diminished evaporative surface area and increased root:shoot ratio. For example, the Mediterranean cultivar, Maris Kasba (MK), mainly exhibited morphological responses to water stress as it had a smaller plant size (4.72 g), higher root:shoot ratio (0.4) and lower growth rates than the measured continental cultivars of Grasslands Advance and El Palenque (8.56 g and 0.25 g OM: g DM, respectively) (Assuero *et al.*, 2002). In contrast, the continental varieties displayed physiological responses to water deficit as their stomatal conductance was lower and they tended to have a greater leaf lamina osmotic adjustment than MK. For example, the continental cultivars had an average stomatal conductance of 0.156 cm/s compared with 0.293 cm/s for MK. This translated to a 71% lower transpiration rate than the continental cultivars. Overall, there was 50-60% higher stomatal conductance on the adaxial (upper) leaf surface than the abaxial (lower) leaf surface due to the lower stomatal density. Tall fescue's morphological response when exposed to moisture stress was to roll its leaves to reduce the adaxial leaf surface. It was also suggested that Mediterranean cultivars develop thicker roots to restrict water leakage as the soil dries, to help maintain root turgor so that the root can reinitiate growth upon relief of water deficit (Asseuro *et al*., 2002).

The shoot dormancy and increased root development in MK appears to be effective only when it is grown in monoculture but not when it is in competition with another plant, such as EP. This is because the temperate variety possesses a drought tolerant mechanism and presumably is capable of extracting more soil moisture to a greater osmotic tension (Asseuro *et al.,* 2002). However, this study was not carried out in the field and was only conducted over one season; therefore these conclusions are limited.

Schiller and Lazenby (1975) in Australia observed differences in yield between Mediterranean and continental types of fescues in the second year of production when there was a rapid decline in daily growth rates of Mediterranean types in late spring and early summer than continental plants. Throughout the summer, the continental (17 kg DM/ha/day) than the Mediterranean cultivars (5 kg DM/ha/day). In contrast in winter the Mediterranean cultivars produced 14 kg DM/ha/day compared with 2 kg DM/ha/day for the continental cultivars.

The Mediterranean climate has great year-to-year variation in rainfall amount and distribution with an annual mean of 300-800 mm and a water deficit which can reach up to 1000 mm (Pecetti *et al*., 2011). Due to these harsh summer conditions, Mediterranean tall fescue types have adapted by being summer dormant and having a greater winter growth than the continental types (Schiller and Lazenby, 1975; Reed *et al.*, 2004). In contrast, continental cultivars of tall fescue have evolved to survive in environments with low summer water deficit (Asseuro *et al*., 2002).

Reed *et al.* (2004) reported that the Mediterranean cultivar, Melik Select, had a winter production (6.86 t DM/ha) greater than continental cultivars, Demeter (4.25 t DM/ha) and AU Triumph (5.01 t DM/ha) (Table 2.3). The winter growth of Melik Select was 55% of its annual yield whereas the winter production of Demeter contributed to one third of its annual yield. However, the summer active continental cultivars produced greater spring and summer growth than Melik Select. It was also stated that Melik Select pastures had a higher contribution of other species (mainly the sown subterranean clover) than the continental cultivars due to the slower growth of Melik Select in late spring and summer. However, despite its lower seedling density, seasonal and cumulative yields of Melik Select were similar to those of Demeter and AU Triumph.

Table 2.3 Herbage production of tall fescue and herbage contribution of tall fescue to total yield during winter, spring, summer and annually averaged over 3 years in South West Victoria, Australia (adapted from Reed *et al.,* 2004).

Cultivar	Winter	Spring	Summer	Total
		t DM/ha (% of total herbage yield)		
Melik Select	6.86 (79)	5.33 (52)	0.44 (67)	12.43 (63)
Demeter	4.25 (85)	7.70 (85)	1.02 (97)	12.97 (86)
Au Triumph	5.01 (81)	6.97 (67)	0.91 (95)	12.89 (74)
Significant	***	**	***	NS
l.s.d. (P=0.05)	0.663	0.769	0.143	1.149

* P<0.05; ** P<0.01; *** P<0.001; NS, not significant

In comparison to the yields of Reed *et al.* (2004), Schiller & Lazenby (1975) reported that continental cultivars were higher yielding in spring, summer and autumn and produced a greater total DM yield than Mediterranean cultivars. They also observed greater winter production from the Mediterranean types which yielded on average 10 kg DM/ha/day more than continental fescues during the second winter.

A study conducted across six Mediterranean sites (Alger, Algeria; Elvas, Portugal; Merchouch, Morocco; Montpellier France; Sassari, Sardinia; Sétif, Algeria) on five Mediterranean cultivars, including ‘Flecha’, found that the site mean yield and winter temperatures were positively correlated as there were greater yields with fewer frosts and higher minimum daily temperatures (Pecetti *et al.*, 2011) (Figure 2.2). Flecha had a wide adaptation response as it was the top yielding cultivar across locations which exceed 525 mm of spring-summer drought stress, index. It also out-yielded the second ranked cultivars (‘Fraydo’ and ‘Centurion’) within the range of 630-720 mm spring-summer drought stress which included four out of six test locations, and was not statistically out-yielded by the top-yielding cultivar Centurion in the least stressful site of Montpellier (Figure 2.2).

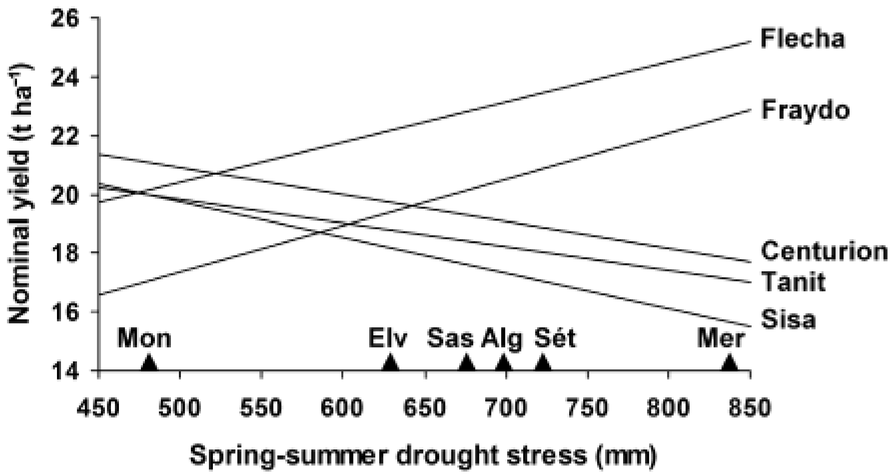

Figure 2.2 Nominal 3-year dry matter yield of five tall fescue cultivars as a function of site spring–summer (April–September) drought stress index calculated as the difference between estimated long-term potential evapotranspiration and actual water available for the crop (Pecetti *et al*., 2011).

Sward persistence of Mediterranean cultivars was positively correlated to lower site heat and drought stress (Pecetti *et al*., 2011) (Figure 2.3). Again, ‘Flecha’ displayed greater persistence than other cultivars, bar ‘Fraydo’, at the two sites, Merchouch and Sétif, which had greater drought stress and lower cover of tall fescue (Figure 2.3). ‘Flecha’ was top ranking in the range of 490-1020 mm annual drought stress index, which excluded Montpellier. At Montpellier, ‘Tanit’ was the top performing cultivar; however, it did not statistically outperform ‘Flecha’ at an annual drought stress range of 420-490 mm. Therefore Flecha also had a wide adaptation to annual drought stress showing that this cultivar had the highest potential in a wide range of Mediterranean environments and locations.

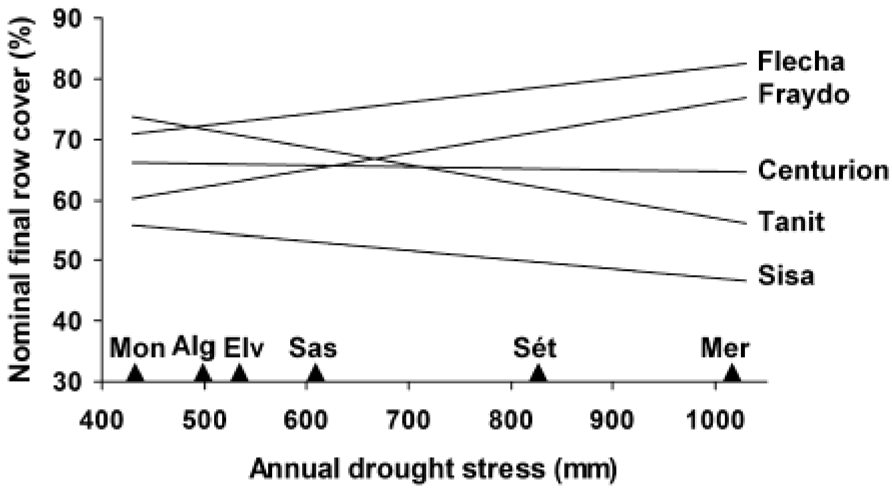

Figure 2.3 Nominal final row cover of five tall fescue cultivars as a function of site annual drought stress index computed as the difference between estimated long-term potential evapotranspiration and actual water available for the crop (Pecetti *et al.*, 2011).

Overall, Mediterranean cultivars appear to have a greater water use efficiency than continental cultivars allowing them to survive harsh summer droughts. However, the continental cultivars can tolerate cooler winter temperatures and are more resistant to frosts. The good winter/spring growth of Mediterranean cultivars assists with providing sufficient forage for lactating ewes whereas the continental cultivars are useful plants to improve summer/autumn dry matter for improving liveweight gains of weaned lambs and flushing ewes as those cultivars are less sensitive to summer heat than Mediterranean cultivars.

2.3 Suitable companion legumes for tall fescue

2.3.1 White clover

White clover is the most important pastoral legume in temperate regions around the world (Frame and Newbould, 1986) and is most commonly sown with tall fescue. Four main benefits of white clover in agriculture include its ability to fix N, improve forage quality, increase herbage intake and utilisation rates of grazing animals and its ability to complement the seasonal growth patterns of most grass species including tall fescue (Frame and Newbould, 1986; Caradus *et al.*, 1996). Optimum growth of white clover occurs at 25°C and growth and N fixation ceases at 9°C (Frame and Newbould, 1986; Kemp *et al.*, 1999b). These critical temperatures are greater than those for growth of perennial ryegrass (18°C and 5°C, respectively) (Kemp *et al.*, 1999b). As a result, growth of white clover occurs later in summer and autumn than most temperate grasses (Caradus *et al.*, 1996). This can cause the clover to be out-competed in early spring by the grass component, which is generally ryegrass**.**

Growth of white clover can be interrupted by moisture stress in summer when the annual rainfall is less than 600 mm (Kemp *et al.*, 1999b). White clover tries to survive a short-term drought by senescing its leaves and may recover by re-growing from stolons in the autumn. In spring plant survival is reduced under stress, i.e., drought and over-grazing, as stolon numbers are at their lowest. Set stocking of white clover in spring stimulates stolon production (Kemp *et al.*, 1999b). The tap root of white clover has been estimated to live up to <1-2 years (Westbrooks and Tesar, 1955). Westbrooks and Tesar (1955) stated that the continued production of white clover in a forage stand is dependent on rooted nodes and natural reseeding which make this legume a perennial. Other important factors which influence prolonged productivity of white clover for several years are fertiliser use, choice of associated species and grazing management to permit adequate carbohydrate storage.

2.3.1.1 Animal performance on white clover

The high nutritive and feeding values of white clover have been shown to increase liveweight gains of lambs. This is also because lambs grazing on white clover have a 20% higher voluntary intake of DM than a sheep grazing on grass (Frame *et al.,* 1998). This superiority of white clover intake is due to its physical, chemical and plant anatomical features (Frame *et al.*, 1998). For example, white clover has a lower cell wall content and length:width ratio of fibres than grass which lowers chewing resistance (Caradus *et al.*, 1996). Penning *et al.* (1995) stated that non-lactating sheep grazing white clover spent 25 and 57% less time grazing and ruminating, respectively, and 41% more time idling than sheep grazing perennial ryegrass. Bite weight of clover (0.47 mg DM/kg liveweight) was significantly greater than grass (0.29 mg DM/kg liveweight) due to a greater bulk density in the grazed horizon. Overall, this resulted in animals eating more but in shorter grazing periods and more frequently (Penning *et al.*, 1995).

The review reported by Frame *et al.* (1998) found that lambs grew 65% and 25% faster when grazing white clover and mixed white clover-grass swards, respectively, compared with sheep grazing grass. Ulyatt *et al.* (1977) stated that lambs gained 86% more when grazing on white clover compared with perennial ryegrass.

Hyslop *et al.* (2000) compared the liveweight gains of lambs grazing tall fescue/white clover swards and perennial ryegrass/white clover swards. This study showed increases in liveweight gain with small increases in the percentage of white clover grown with both grasses in spring (Figure 2.4). Tall fescue-based pastures produced 37 kg/day lower liveweight gains than perennial ryegrass-based pastures in spring. However, the regression lines between the two grasses was not different over a range of 0 to 60% clover DM.

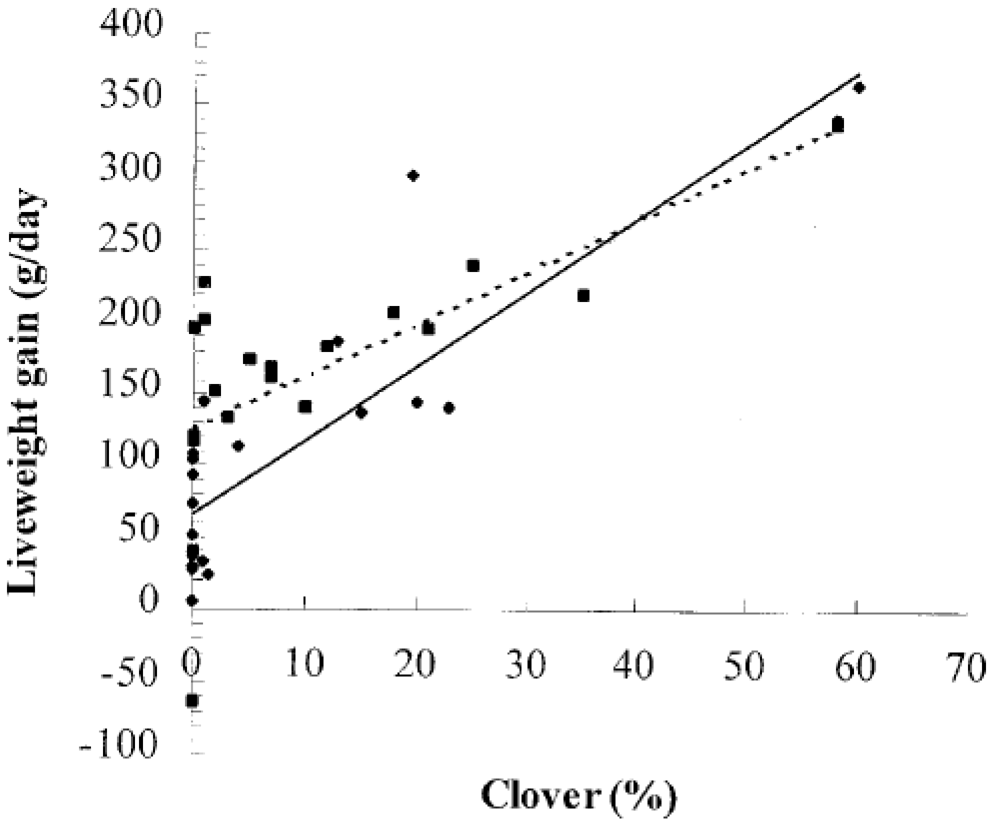

Figure 2.4 Spring liveweight gains (g/head/day) in young sheep grazing tall fescue (—■—) or ryegrass swards (---●---) of different white clover contents (of % total herbage mass, in Canterbury (Hyslop *et al.,* 2000).

In autumn there was no significant correlation between white clover content and liveweight gain for both grass species in young sheep (Hyslop *et al.*, 2000) (Figure 2.5). Autumn daily liveweight gains averaged 76 g/day across all treatments whereas daily growth rates were 98-257 g/day in spring for 40% clover DM. One strategy to improve liveweight gain on tall fescue pastures is to increase the clover percentage because white clover has a higher nutritive value and feeding value than tall fescue. However, white clover does not persist in dryland conditions so tall fescue pastures require a clover that does survive in dryland environments to improve the quality of the pasture, for example, subterranean clover.

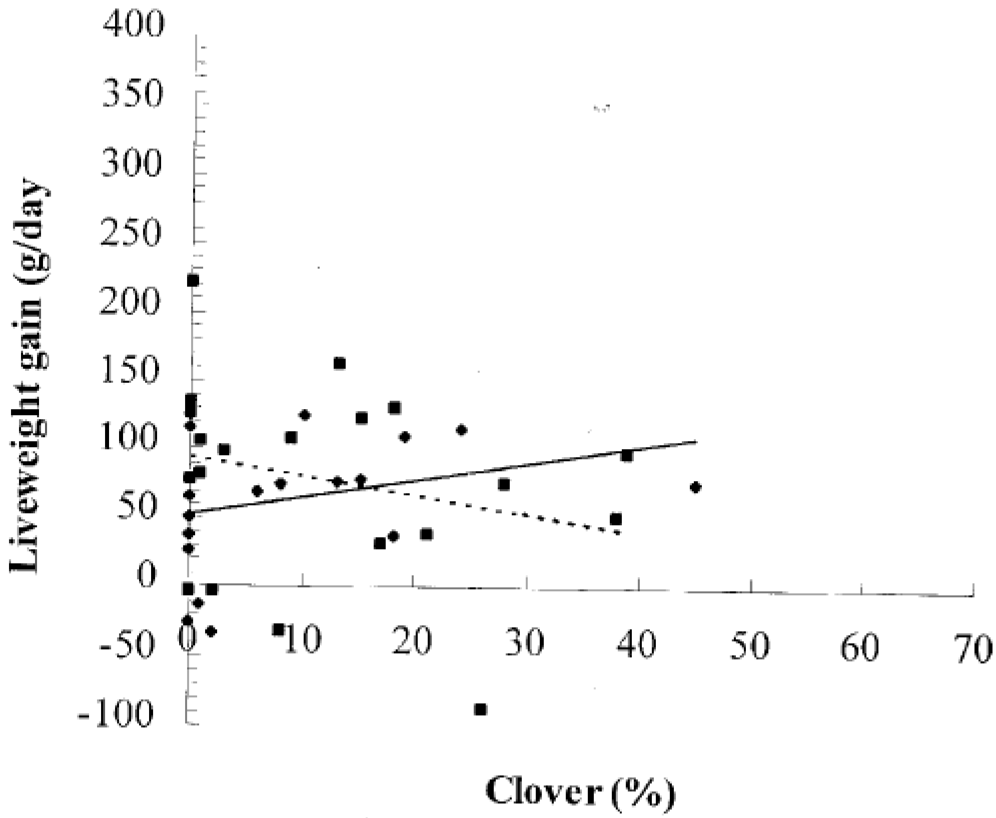

Figure 2.5 Autumn liveweight gains (g/head/day) in young sheep grazing tall fescue (—■—) or ryegrass swards (---●---) of different white clover contents of total herbage DM, in Canterbury (Hyslop *et al.,* 2000).

Based on their overall results, Hyslop *et al.* (2000) proposed an empirical model to illustrate the effect of white clover content on the liveweight gain of young sheep for both tall fescue and perennial ryegrass (Figure 2.6). This showed that the greatest increase in liveweight gain occurs when white clover content increases between 0 and 10%. Tall fescue was estimated to produce greater clover levels due to its less competitive growth habit compared with perennial ryegrass which allows the white clover more space to compete for light. Therefore, a relatively small increase in clover content of a tall fescue-based pasture, for example from 1% to 10% in spring or autumn, could result in a significant improvement in lamb liveweight gain.

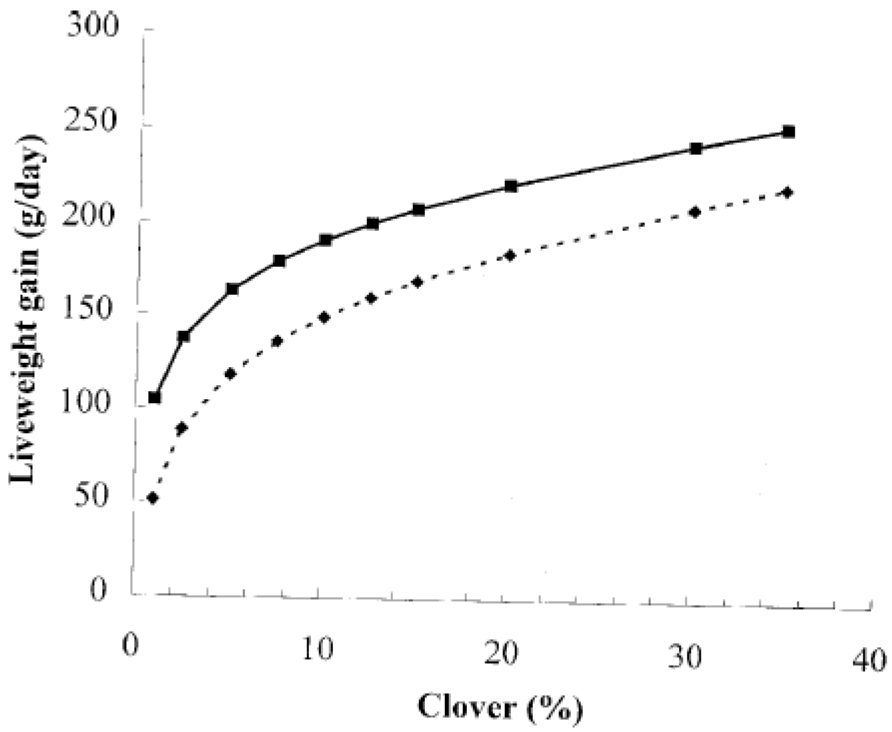

Figure 2.6 Predicted relationship between white clover percentage in the diet on offer and liveweight gain in young sheep fed either tall fescue (—■—) or perennial ryegrass swards (---●---) at 1200 kg DM/ha and 30% dead & stem (Hyslop *et al.,* 2000).

2.3.2 Subterranean clover

Subterranean clover is a winter annual clover that originated from the Mediterranean region and is well adapted to hot, dry summers and cool, moist winters. This has allowed for successful clover establishment in the arid southern Australian regions (Smetham, 2003) and dry east coast regions of New Zealand (Ates *et al.,* 2006). Environments with a moderate rainfall of 250-600 mm/yr falling mainly in late autumn, winter and spring and temperatures of 7-15°C in winter and 18-24°C in summer and autumn will support subterranean clover growth (Smetham, 2003). Subterranean clover avoids the harsh dry summers by setting seed in early summer and germinating in the first autumn rains (Kemp *et al.*, 1999b; Smetham, 2003). Peak herbage growth occurs in spring. Persistency and productivity is driven by the plant receiving enough soil moisture for a long enough period to produce a sufficient amount of seed to reach full maturation (Smetham, 2003).

2.3.2.1 Animal performance on subterranean clover

Subterranean clover has demonstrated to be a useful legume in dryland conditions to improve animal production where white clover cannot persist. In an Australian grazing study, liveweight gains of lambs reached up to 208 g/day from early to mid-flowering with 'Trikkala' and 204 g/day from mid to end of flowering with 'Goulburn' (Mulholland *et al.*, 1996). A New Zealand study observed the effect of stocking rate of lambs grazing on dryland subterranean clover pastures on lamb growth rates and subterranean clover persistency (Ates *et al.,* 2006). In that study lambs grew at 374 g/day at a low stocking rate of 10 ewes/ha and 307 g/day at 20 ewes/ha (Table 2.4). This resulted in twin lambs under the low stocking rate to be on an average 3.1 kg heavier than lambs on the high stocking rate treatment. In the Australian study the stock grazed subterranean clover monocultures whereas the stock grazed a mixed sward of 'Advance' tall fescue, 'Endura' Caucasian clover (*T. ambiguum*) and 'Demand' white clover in the New Zealand study.

Table 2.4 Effects of low (10 ewes/ha) and high (20 ewes/ha) stocking rates on lamb and ewe growth rates per head and per hectare while on subterranean clover-based pastures from 22 September to 7 November 2005 (Ates *et al.,* 2006).

Stock class	10 ewes/ha	20 ewes/ha	SED	*P*
Lambs				
g/head/day	373.9	307.2	23.2	0.06
kg/ha/day	7.5	12.3	0.7	<0.01
Ewes				
g/head/day	48.3	-106.6	62.4	0.08
kg/ha/day	0.5	-2.1	1.2	0.12

Ates *et al.* (2006) stated that the ewes at the high stocking rates lost a total of 4.9 kg compared with the ewes at the low stocking rate which gained 2.2 kg (Table 2.4). The lamb liveweight gains from the high stocking rate shows how ewes mobilise their body tissue to act as a buffer to maintain milk production. In an ideal situation the stock would have been moved off earlier to avoid losing condition and affecting clover reproduction.

2.3.3 Nutritive value of legumes

The nutritive value of herbage has been defined by Ulyatt (1973) as the concentration of nutrients in the feed, or animal response per unit of intake. However, the nutritive value of a diet depends on its digestibility and the efficiency of how well these nutrients have been absorbed and utilized into body tissue (Ulyatt *et al.*, 1977). Legumes in the vegetative state have a high apparent digestibility of approximately 75-85% (Ulyatt *et al.,* 1977). White clover maintains a high digestibility because it is mainly made up of leaves and petioles which have a high turn-over rate to assist with forage quality as aged material is replaced with new growth (Ulyatt *et al.,* 1977). However, the leaves and stem components of some forage legumes vary greatly in their digestibility (Ulyatt *et al.,* 1977). For example, the digestibility and water soluble carbohydrate (WSC) content of the petiole and stem fractions of subterranean clover were found to be higher than the leaf fraction of the plant, even though the leaves had a lower level of cell wall organic matter (Mulholland *et al.,* 1996). This study found that after 57 days of grazing, the digestibility of the leaf, petiole and stem of subterranean clover ranged from 63-66%, 73-75% and 70-73%, respectively, between the three cultivars produced.

Ru and Fortune (2000) in Australia, also stated differences of nutritive value between cultivars of subterranean clover within each maturity group (flowering date). Here, it was reported that the DMD ranged from 53-64%, 44-62% and 45-53% for early, mid and late flowering cultivars of subterranean clover, respectively, at the end of their growing season (late spring). The lower digestibilities recorded in this study could have been due to grazing starting earlier (August compared with October), a longer grazing period (3 to 5 months compared with 2 months) or from a different grazing intensity (2-weekly compared with monthly intervals). Mulholland *et al.*

(1996) found that the ratio of lignin to cell wall organic matter was also lower in the leaf fraction in subterranean clover. The petioles contained the most DM and therefore this component was the major contributor to energy supply.

Legumes have higher feeding value than perennial ryegrass due to the animals' higher intake and higher ratio of protein:energy absorbed (Ulyatt *et al*., 1977). Ulyatt *et al.* (1977) stated that white clover has a higher utilisation efficiency for liveweight gain than perennial ryegrass. The utilization coefficient of metabolisable energy to gain fat (k_f) increases as the nutritive value increases. The k_f values for subterranean clover and white clover have been measured as 54 and 51%, respectively, compared with 32.9% for perennial ryegrass (Ulyatt *et al.* 1977). This means that these clovers are close to what would be expected from their ME content and provide animals with a better balanced diet than ryegrass. Therefore, this shows that subterranean clover has a similar nutritive value to white clover, so assuming it can increase the clover percentage of tall fescue pastures then it should also increase liveweight gain.

White clover has been reported to increase the palatability of animal forage over grasses because of its higher crude protein content (Martin, 1960) and readily fermentable carbohydrate: structural carbohydrate ratio and lower lignin, cellulose and fibre content (Ulyatt *et al.*, 1977; Caradus *et al.*, 1996). Table 2.5 illustrates this as 'Huia' white clover has a higher readily fermentable carbohydrate:structural carbohydrate ratio of 1.2 compared with 'Ruanui' ryegrass (0.42).

Table 2.5 Chemical composition of 'Huia' white clover and 'Ruanui' perennial ryegrass grown in New Zealand (adapted from Ulyatt *et al.*, 1977).

Cultivar	Readily Fermentable Carbohydrate (% DM)	Structural Carbohydrate (% DM)	Crude Protein (% DM)	Lignin (% DM)
'Ruanui'	12.3	29.5	23.1	2.4
'Huia'	20.3	17.3	24.4	2.2

2.3.4 Legume N fixation

New Zealand pastoral agriculture has been supported by the ability of the legume to fix atmospheric N. The literature has reported varying quantities of N fixed by clover on a yearly basis. Hoglund *et al.* (1979) found N fixation ranged between 34-342 kg N/ha/yr across 10 grazing-trial sites in New Zealand, over a range of climatic conditions formed mainly of white clover. In Australia, subterranean clover has been estimated to fix between 50-188 kg N/ha under grazed studies (Frame *et al.,* 1998). Nitrogen fixation is dependent on the level of soil mineral N and other limiting factors which affect clover growth such as, soil fertility, soil temperature, soil moisture (Kemp *et al.*, 1999a), grazing and grass competition (Caradus *et al.*, 1996). Legumes must form an effective symbiotic relationship with rhizobia bacteria to fix N. It is important to have the correct rhizobia strain species inoculated to help with clover production, nodulation and N fixation. Frame and Newbould (1986) stated that once rhizobia are established the quantity of N fixed depends on the photosynthates reaching the nodules (on the roots of legumes where N fixing takes place); hence N fixation also depends on the amount of photosynthetically active leaf area of clover in the sward. Therefore there needs to be a balance between having enough clover leaf for N fixation and providing adequate feed for animals. Many papers state that the ideal amount of clover in a sward for both animal production and N fixation should be 30% of the total

DM of the herbage (Frame and Newbould, 1986; Kemp *et al.*, 1999a). This can be achieved on warm, high fertile farms as shown in Table 2.6.

Table 2.6 Clover yields, clover content in total pasture yield and N fixation of white clover grass pastures at different sites across New Zealand (adapted from Hoglund *et al.* (1979)).

Site (environment)	Clover yield (kg DM/ha/yr)	Clover %	N fixation (kg N/ha/yr)
Kairanga (mild winters & summers)	3040	22	211
Gore (cold winters, wet summers)	2910	26	265
Kaikohe (warm, high rainfall)	3750	34	342
Masterton (dry summers)	1500	15	152
Kirwee (dry)	3910	39	120
Kirwee (irrigated)	5040	38	192
Woodville (low fertility hills)	150	2	34

Table 2.6 shows how clover growing in low fertile hilly country, such as Woodville in New Zealand, may only compose 2% of total pasture yield and fix a total of 34 kg N/ha/yr compared with an average clover content of 38.5% in pastures at Kirwee, in Canterbury. However, it is interesting to note that Hoglund *et al.* (1979) found that the clover yield in mixed pastures did not correlate with the amount of N fixed over the two year study across New Zealand. For instance, in a warm, high rainfall environment, such as Kaikohe, near Auckland, clover reached 34% of a pasture yield and fixed 342 kg N/ha/yr, whereas, a non-irrigated pasture at Kirwee producing 39%

clover fixed approximately 120 kg N/ha/yr. Kemp *et al.* (1999a) showed that N fixation is greatest in November at about 0.33 kg N/ha/day where soil moisture is not limiting and soil temperature is approximately 18°C. The dryness and heat of summer and cold of winter decreases the N fixation rate of clover (Kemp *et al*., 1999a).

Nitrogen fixation could be considered as the function of legume N requirement less mineral N uptake (Hoglund and Brock, 1978). Hoglund *et al.* (1979) stated that temperature was the most influential climatic factor on the seasonal variation of N fixation. Hoglund & Brock (1978) found that the effects on temperature are different between short and long term studies on N fixation. Temperatures above or below the optimum (22°C) for N fixation has a greater effect on N fixation than legume growth on a short term basis. Whereas the long term studies increased nodule mass due to the reduced activity per unit weight of nodule at temperature extremes (Hoglund & Brock 1978). Generally, high levels of soil mineral N are related to low rates of N fixation and reduced efficiency (Hoglund *et al.,* 1979). Temperature influences the availability of soil N for legume growth. This is illustrated in Table 2.7**,** where the N fixation efficiency was greater in winter at 84 kg N/t DM than spring (55 kg N/t DM) as the low temperatures of winter reduces the availability of soil N. This forces the clover to rely on fixing N as the grass component utilises the available N. In spring the N fixation efficiency of white clover is reduced as the warmer temperatures increase soil N mineralization. Furthermore, more N is fixed in a mixed sward than a monoculture as most of the available N is taken up by the grass component of the sward (Frame *et al*., 1998); however, the clover can utilize more soil N if the companion grass is growing poorly. This could mean that the annual N fixation of subterranean clover could be greater than white clover as it is a winter legume with presumably a greater winter production. The annual average fixation efficiency measured for white clover (59 kg N/t DM) was similar to that reported by Hoglund and Brock (1978) (49 kg N/t DM), and Brock (1973) who measured 62 and 54 kg N/t DM for soil under low and high P treatments, respectively.

Table 2.7 Seasonal pasture yields, N fixation and N fixation efficiency of white clover based pastures averaged over several site across New Zealand (Hoglund *et al*., 1979).

Season	Grass (kg DM/ha)	Clover (kg DM/ha)	N fixation (kg N/ha)	Fixation efficiency (kg N/t DM)
Spring	3550	1200	74	55
Summer	2380	1120	63	48
Autumn	1530	540	32	50
Winter	940	270	16	84
Total	8400	3130	185	59

Soil moisture is also a major factor influencing the ability of legumes to fix N. Hoglund *et al.* (1979) found that when 80% of N fixation occurred in the top 75 mm of soil, soil moisture was optimal. The long term effects of moisture stress show that as the surface layers dry out to permanent wilting point, N fixation activity moves down the soil profile as a survival mechanism (Hoglund and Brock, 1978; Hoglund *et al.*, 1979). However, neither white clover nor subterranean clover are deep-rooting legumes and N fixation by both species is likely to decrease with increased water stress. This is likely to be more of an issue for white clover than for subterranean clover, which is more productive than white clover in spring when water is available, and avoids summer dry conditions by setting seed.

2.3.5 Legume Water use efficiency of white clover and subterranean clover

Dryland farming in New Zealand occurs in the eastern regions where evapotranspiration exceeds rainfall (Moot *et al.*, 2003; Tonmukaykul *et al.*, 2009; Moot, 2012). In dryland Canterbury, the monthly potential evapotranspiration exceeds rainfall from September to April, which produces a long term (1975-2007) average potential moisture deficit of approximately 430 mm/yr in April

(Tonmukaykul *et al.*, 2009). It has been reported that increasing the legume content of pastures, or applying N fertiliser, improves water use efficiency (WUE) and increases animal and pasture production (Moot, 2012; Tonmukayakul *et al.,* 2009). Water use efficiency can be defined as the ratio of total DM accumulation of total water input into the system (Moot *et al.*, 2003; Tonmukaykul *et al.*, 2009). Figure 2.7 illustrates the positive regression between WUE and yield. Studies have found that in spring cocksfoot (*Dactylis glomerata*)/subterranean clover (CF/Sub) swards have a greater WUE compared with the CF/white clover and perennial ryegrass/white clover (RG/WC) due to their greater clover yields (Moot *et al.*, 2003; Tonmukaykul *et al.*, 2009; Moot, 2012) (Figure 2.7). The water use of the CF/subterranean clover pasture was similar to the RG/WC sward (approximately 280 mm), but the higher yield of total dry matter of the CF/sub pasture gave a calculated WUE of 21 kg DM/ha/mm of water used compared with 13.8 kg DM/ha/mm for RG/WC. The CF/WC sward had a lower WUE efficiency (14.3 kg DM/ha/mm) than CF/Sub pastures as well, which demonstrates how subterranean clover is more suited to dryland conditions than white clover. It achieves this by burying its seeds in late spring and then being dormant over the dry summer period until the autumn rains.

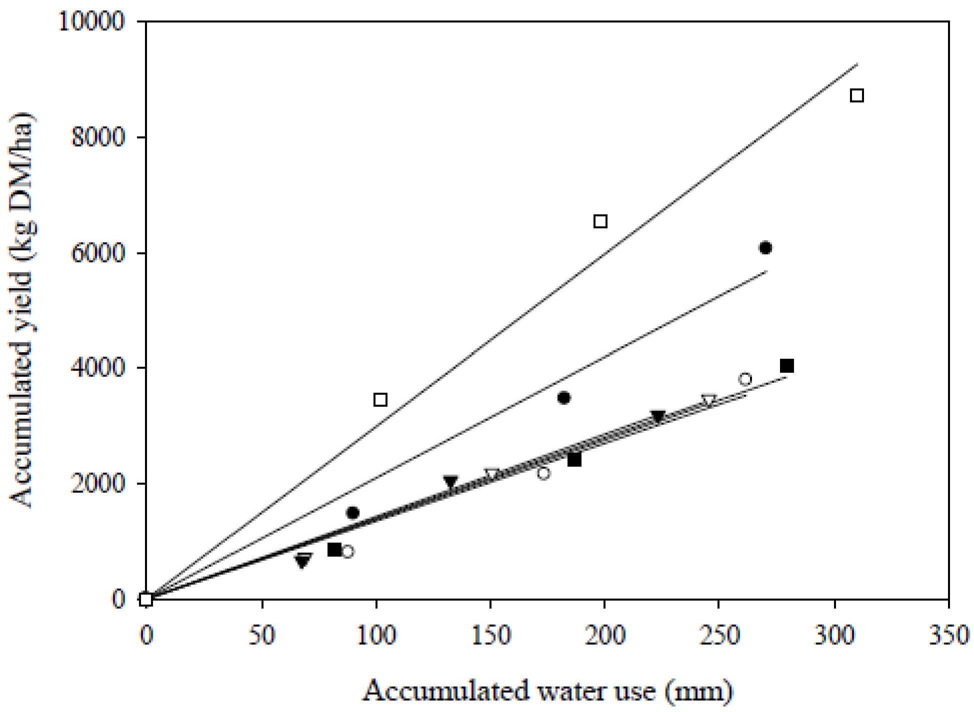

Figure 2.7 Relationship between accumulated yield (kg DM/ha) and water use (mm) over spring season for cocksfoot/subterranean clover (CF/Sub) (●), cocksfoot/Balansa clover (CF/Bal) (○), cocksfoot/white clover (CF/WC) (▼), cocksfoot/Caucasian clover (CF/CC) (▽), ryegrass/white clover (RG/WC) (■) and lucerne (□) pastures at Lincoln, Canterbury (Tonmukayukal *et al*., 2009).

These WUE values reflect the total N content of the sward (Table 2.8). For example, the CF/Sub pasture had the highest N yield of 120 kg N/ha due to its higher clover content (49%) and N yield (45.3 kg N/ha) than the other grass/clover pastures. For instance, white clover only made up 14% of the botanical composition in the CF/WC pasture, which resulted in 67% less N from the legume component than the CF/Sub sward. This highlights the importance of N availability in dryland conditions to maximise WUE (Tonmukayukal *et al*., 2009). The higher N content increases the photosynthetic efficiency per unit leaf area and the photosynthetic rate per unit of water used which leads to higher DM production (Moot *et al*., 2003). This shows the importance of achieving early growth and adequate leaf area in spring to be able to maximise water use, WUE and yield (Bolger and Turner, 1999).

Table 2.8 Nitrogen yields of the sown grass and legume components of the six dryland pastures at Lincoln University, Canterbury in spring (Tonmukayukal *et al*., 2009).

Treatment	Grass N yield (kg DM/ha)	Legume N yield (kg DM/ha)	Sown N yield (kg DM/ha)
CF/Sub[2]	74.2 a[1]	45.3 b	119.5 b
CF/Bal	65.0 a	9.3 b	74.3 cd
CF/CC	74.2 a	16.3 b	91.0 bc
CF/WC	58.3 a	15.1 b	73.4 cd
RG/WC	24.4 b	19.1 b	43.5 d

[1]Means followed by a same letter were similar at $P<0.05$ level. [2]CF/sub – cocksfoot/subterranean clover; CF/Bal – CF/Balansa clover; CF/CC – CF/Caucasian clover; CF/WC – CF/white clover; RG/WC – perennial ryegrass/WC.

2.4 Soil fertility

Tall fescue pastures require high fertile soils to produce well and be persistent (Kemp *et al*., 1999b). Tall fescue responds to a high level of nitrogen (N) fertility, but is also found on impoverished soils (Easton *et al*., 1994). It is tolerant of acidic and moderately saline soils and more tolerable than perennial ryegrass to high aluminium levels (Easton *et al*., 1994). However, in low fertile soils they are usually invaded by other grasses if fertility is medium to low (Kemp *et al*., 1999b) (see Table 2.4 for optimum soil fertility values).

McLaren & Cameron (1996) listed the soil requirements for New Zealand pastures (unspecified species) to reach near maximum pasture production over three different soil types (Table 2.9). Overall, the minimum Olsen P requirement is 20 mg P/g for sedimentary and ash based soils whereas pumice soils have a higher requirement (35-45 mg P/g) due to their higher soil P retention. Over most soil types the ideal pH ranges from 5.8 to 6.0. This suggests that tall fescue/clover pastures are likely to have similar soil fertility requirements.

Table 2.9 Soil fertility soil test ranges to achieve near maximum pasture production across three different soil parent material types in New Zealand (McLaren & Cameron, 1996).

Soil test	Soil parent material		
	Sedimentary	*Ash*	*Pumice*
Olsen P (mg/g)	20-25	20-30	35-45
Sulphate-S (mg/kg)	10-12	10-12	10-12
Organic-S (mg/kg)	15-20	15-20	15-20
Soil test K (QTU)[1]	5.8-6.0	5.8-6.0	5.8-6.0
Soil test Mg (QTU)	8-10	8-10	8-10
pH	5.8-6.0	5.8-6.0	5.8-6.0

[1]QTU – Quick Test Units

2.4.1 Soil fertility requirements of white clover

White clover requires well managed, fertile soils for optimal performance (Kemp *et al*., 1999b). However, white clover can survive under moderately-low to extremely-high fertile soils (Caradus *et al.,* 1996). In mixed swards it is a poor competitor for P, K and S which becomes more pronounced when companion grasses increase shading.

Soil fertility has a direct effect on the ability of legumes to fix atmospheric N as P is essential for nodulation (Martin, 1960). Brock (1973) found that, at a high input of P (112 kg P/ha/yr), white clover fixed 570 kg N/ha compared with 400 kg N/ha under low P management with only 22 kg P/ha applied in the establishing year. This study also found white clover produced significantly less DM from the low P treatment compared with the high P treatment (Table 2.10). In the establishing year, white clover yielded 10110 kg DM/ha in the high P treatment which was 22% greater than at low P. By the third year, the clover yields were substantially greater in the high P treatment by 104% than the low P treatment. Clover yield at low P was reduced by 42% from 8290 kg DM/ha, whereas the clover yield at high P was the same as previous years. This illustrates how white clover requires a fertile soil for high pasture growth but also to maintain persistence. Increasing P is important to stimulate root growth, improve the DMD and increase feed intake of grazing sheep (Martin, 1960; Ru and Fortune, 2000). Therefore, white clover is a good companion legume for tall fescue, which also requires high fertility soils; however, white clover is less suited to dryland conditions than tall fescue.

Table 2.10 Differences in yields of white clover at two levels of phosphorus over 3 years from 1967/68 to 1969/70 at Palmerston North (Brock, 1973).

Year	Rate of P (kg P/ha/year)	Yield (kg DM/ha/year)
1	22	8290 de[1]
	112	10110 bc
2	0	6370 f
	112	12010 a
3	0	4790 g
	112	9760 c

[1] Yields with different letters are significantly different at the 5% level of probability.

There is a direct relationship between white clover growth and N fixation when there is a decreasing supply of mineral N (Caradus *et al.,* 1996). As more soil mineral N is immobilized during microbial breakdown of the soil microorganisms the soil carbon (C) increases (Hoglund *et al.,* 1979). The soil C:N ratio has been positively associated with N fixation and fixation efficiency (measured N fixed: measured legume growth – kg N/t DM) and negatively with total DM yield and total grass production (Hoglund *et al.,* 1979). However, in contrast to Caradus *et al.* (1996) the percentage or total clover yields showed little relationship with the C:N ratio (Hoglund *et al.,* 1979).

2.4.2 Soil fertility requirements for subterranean clover

Subterranean clover is adapted to low to moderately fertile soils (pH<5.2) (Kemp *et al.,* 1999b). However, low soil P levels can hinder subterranean clover production. In a glasshouse experiment, adding 2000 ppm P to soil was found to increase the shoot dry weight of subterranean clover by 86% from 3.5 g at 300 ppm P added (Caradus, 1980). However, subterranean clover was one of two legumes which had a shoot dry weight greater than 2 g under the low P regime and the highest under the high P regime (6.5 g) (Caradus, 1980). This demonstrates that although subterranean clover responded positively to the more fertile soil it was more efficient at utilizing P under low fertility conditions than most other legumes. Jones *et al.* (1970) found that subterranean clover yields did not increase when P or S were applied alone to a P and S deficient soil. However, this study reported that yields increased by five-fold when 25 ppm or more P plus 5 ppm or more S were applied.

2.5 Grazing management

Nutritive value of tall fescue is influenced by grazing intensity (Easton *et al.*, 1994; Burns *et al.*, 2002). *In vitro* dry matter disappearance (IVDMD) and crude protein (CP) increase and DM yields and neutral detergent fibre (NDF) decrease as the defoliation intensity increases during the growing season (Burns *et al*., 2002). This North American study observed the nutritive characteristics of tall fescue across eight grazing intensities where values varied greatly across 3 years. The annual mean IVDMD for the 3 years ranged from 679 g/kg when grazed from 31 cm down to 9 cm to 743 g/kg when grazed from 10 cm to 5 cm. This produced an average IVDMD of 721 g/kg. Producing a more palatable forage came at a cost as there was less pasture production under the more intensive grazing management systems. The year effect on CP concentrations was large during the growing season where the 31-9 cm treatment had a significantly lower CP concentration than the grazing treatments of a higher intensity in the second and third year (Figure 2.8). Here, the CP concentration of 31-9 cm treatment sat at around 130 g/kg and 120 g/kg between 4 July and 13 August for year 2 and 3, respectively. Over the same time frame the CP concentrations of the other three treatments were around 160 g/kg and 150 g/kg for year 2 and 3, respectively. It was stated that CP concentrations less than 150 g/kg during the growing season may hinder growth rates of young animals where pasture is their main feed source.

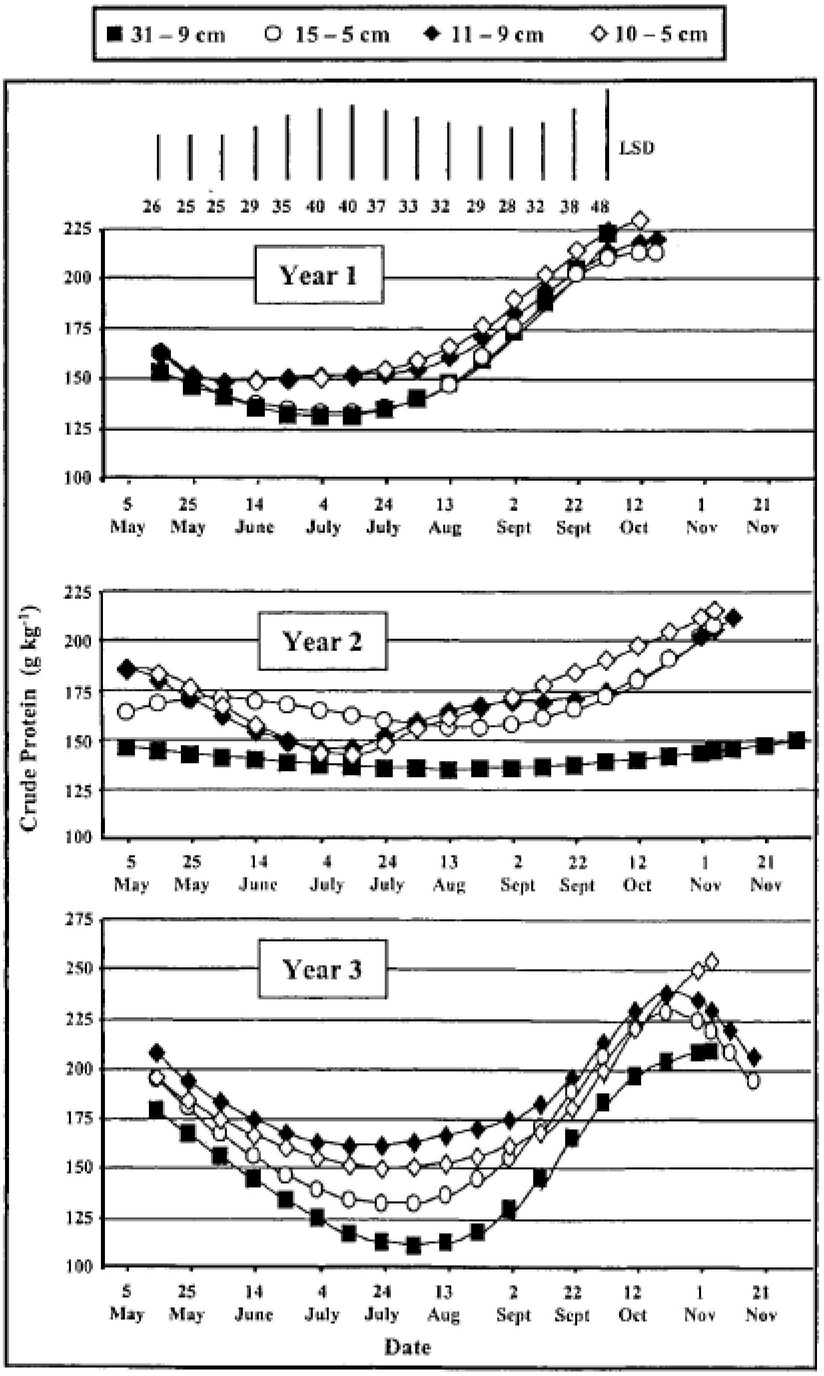

Figure 2.8 Changes in crude protein of tall fescue by year throughout the growing season from four selected defoliation intensities (31-9 cm, 15-5 cm, 11-9 cm and 10-5 cm). The Least Significant Difference (LSD) ($P \leq 0.05$) applies to all years (Burns *et al.*, 2002).

Grazing management is important to maintain pasture quality and stand persistence. Donaghy *et al.* (2008) studied the effects of defoliation intensity on the differences in herbage quality at each leaf stage, i.e. from leaf one to leaf five on a tiller, to observe the physiological changes within the plant. Their conclusions agreed with those of Burns *et al.* (2002) that increasing the pre-grazing pasture height to the four-leaf stage increased leaf DM production by 20% than the two-leaf stage, but compromised the nutritive value. Metabolisable energy, CP and DMD decreased with increasing leaf stage, from 11.3 MJ ME/kg DM, 27% and 78% at the one-leaf stage to 9.2 MJ ME/kg DM 16.1% and 65.7% at the five-leaf stage, respectively (Table 2.11). The NDF concentrations increased with increasing leaf stage from 50.1% to 62.1% from the one-leaf stage to the five-leaf stage. These results were expected because as plants age they generally decline in quality where they lignify and increase in cell wall concentration.

Table 2.11 Mean leaf crude protein (CP), neutral detergent fibre (NDF), and dry matter digestibility (DMD) concentrations (% DM), and metabolisable energy (MJ ME/kg DM) concentration of tall fescue before defoliation and at each corresponding leaf regrowth stage (0 to 5 fully grown leaves per tiller), under greenhouse conditions in Tasmania, Australia (Donaghy *et al.,* 2008).

Leaf re-growth stage	CP (% DM)	NDF (% DM)	DMD (% DM)	ME (MJ kg/DM)
0	19.6	58.1	74.6	10.7
1 leaf	27.0	50.1	78.0	11.3
2 leaves	21.1	53.9	76.1	10.9
3 leaves	17.9	57.5	73.0	10.4
4 leaves	15.5	59.2	71.3	10.1
5 leaves	16.1	62.1	65.7	9.2

To maintain pasture quality, a pre-grazing pasture height of 15 cm should not be exceeded except in autumn when the roots are being replenished for the following season's growth (Milne, 2009). Grazing residual should remain at 5 cm throughout the year via rotational grazing or set stocking. At the heading phase of the plant, the residual can be lowered to 3 cm to control reproductive growth (Milne, 2009). The recommended grazing heights for rotational grazing through the year are illustrated in Figure 2.9. However, due to its different grazing management requirements to perennial ryegrass pastures not many farmers have adopted to growing this species.

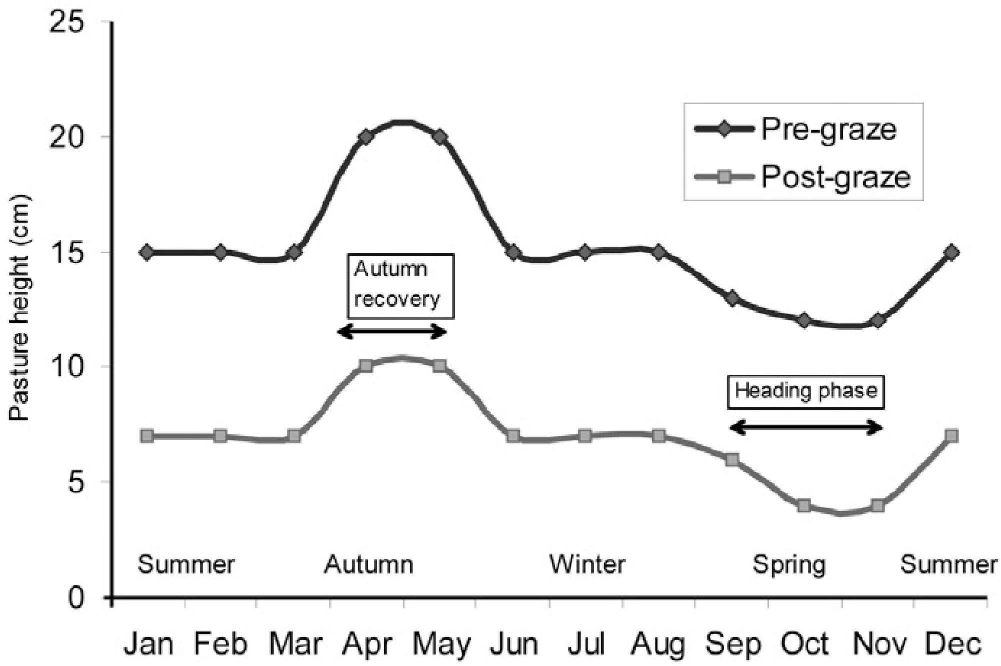

Figure 2.9 Recommended grazing heights for rotational grazing of continental tall fescue types (Milne, 2009).

2.5.1 White clover compared with subterranean clover

Frequency, intensity and timing of grazing can all significantly influence the botanical composition of the sward (Caradus *et al.*, 1996; Frame *et al.*, 1998) and pasture production (Ru & Fortune, 2000). The grazing system must adapt with the seasons to maintain clover production and persistence as shown in Figure 2.9. However, it is important to manage pastures well to not compromise either pasture quality, production and persistence or animal performance.

Firstly, it is best to frequently defoliate white clover under a hard grazing regime in winter to early spring, irrespective of stock class (Caradus *et al*. 1996; Frame *et al*. 1998). This has shown to improve the growing point density which assists with growth and development as more solar radiation is exposed into the sward (Frame *et al*. 1998). However, overgrazing in winter and early spring is undesirable because too much photosynthetic tissue is removed and under a long period of low temperatures stolons will die (Frame *et al*. 1998). Consequently, smaller-leaved varieties of white clover are more suitable for sheep grazing as more leaves per stolon are left ungrazed. However, if white clover is left ungrazed it will be outcompeted by grasses as its petioles are shorter than grass laminae. In summer, Caradus *et al*. (1996) stated that under sheep grazing, the grazing intensity should be less frequent than in spring as overgrazing can lead to excessive loss of stolons which is detrimental for clover persistence. However, lax grazing in summer due to lower stocking rates will cause a reduction in the density of growing points and stolon branching due to increased shading (Frame *et al*., 1998).

Clover pastures grazed rotationally by sheep throughout the year have higher N fixation rates in spring, but lower rates in summer and autumn, than set-stocked systems (Caradus *et al*. 1996). Overall, Caradus *et al*. (1996) stated that sheep selectively graze for white clover which reduces the clover content in mixed pastures compared with pastures grazed by cattle. White clover is particularly valuable for grazing as it is a flexible plant which can survive under intensive defoliation (Caradus *et al.,* 1996; Martin, 1960).

Like white clover, subterranean clover must be grazed carefully as it is essential for subterranean clover to produce a large seed crop and successful seeding in autumn to be persistent in pasture as it is an annual legume (Ates *et al*., 2006; Frame *et al*., 1998). In spring, subterranean clover flowers when most other species increase their growth rates which coincides with lambing and the high feed demand from lactating ewes (Ates *et al*., 2006). This presents a challenge to farmers on how they manage their pastures as they strive for high animal performance they must not negatively impact seed production. Ates *et al*. (2006) recommended in moist springs that subterranean clovers should be set-stocked so that a pasture mass of 2000 kg DM/ha is maintained to ensure adequate seed production. Although subterranean clover is a dryland legume, it is affected by moisture stress. For example, Ates *et al*. (2006) reported that a drier than average October resulted in subterranean clover wilting about 4 weeks earlier than expected. On top of this, the seed production markedly declined under both low (10 ewes/ha) and high (20 ewes/ha) stocking rates (Table 2.12). There were 443 burrs/m^2 produced under the low stocking rate which was more than twice as many under the high stocking rate (169 burrs/m^2). This was mainly due to there being half as many burrs/plant produced at the high stocking rate (Table 2.12).

Table 2.12 Effect of low (10 ewes/ha) and high (20 ewes/ha) stocking rate on subterranean clover seed production in November 2005, in Canterbury (adapted from Ates *et al*., 2006)

	10 ewes/ha	20 ewes/ha	SED	*P*
Burrs/plant	0.8	0.4	0.04	<0.01
Burrs/m^2	443	169	94.3	0.05

Companion grasses must be kept in check when sown with clovers to optimise clover persistence and production. Frame *et al*. (1998) stated that prostrate subterranean clover cultivars grazed by sheep are more suited to continuous stocking than upright cultivars, although the upright cultivars are well suited to rotational grazing. It is best to manage subterranean clover pastures that maximise the proportion of petioles as the lower nutritive value of the leaves will reduce animal production. Treading damage needs to be minimised during grazing but continuous stocking throughout the growing season to maintain pasture heights of 6-8 cm has given optimum yields of both herbage and seed of subterranean clover (Frame *et al*., 1998).

Grazing intensity affects nutritive value of subterranean clover (Ru & Fortune, 2000). In that study, the DMD decreased by 5% in October under heavy grazing for early maturity cultivars but increased by 3% by for mid maturity cultivars in September. However, there was little influence of grazing intensity on N content. Acid detergent fibre (ADF) for early maturing cultivars were not affected by heavy grazing whereas ADF content decreased for the mid maturity group throughout the growing season. It is important to have a flexible grazing management system for clover pastures throughout the growing season to maintain quality.

2.6 Establishment of tall fescue

2.6.1 Effect of Temperature

There are many factors which affect tall fescue establishment and soil temperature is the most influential (Charles *et al.*, 1991). Achieving a successfully established tall fescue pasture requires the soil temperature to be ≥9°C at sowing (Charles *et al.*, 1991), which is similar to the ≥10°C recommended by Kemp *et al.* (1999b), in conditions with adequate soil moisture. Charlton *et al.* (1991) found that soil temperature was strongly correlated with sowing depth in its effect on final emergence percentage. At 3 and 6°C final emergence was low (less than 35%) for all sowing depths (0-45 mm). When the soil temperature was at 12 and 24°C for sowing depths of 0, 15 and 30 mm the final emergence was at least 80%, but at 45 mm depth it only increased to 46%. On the whole, surface sowing had higher final emergence percentages and deeper sowing (30 and 45 mm) had lower final emergence percentages across all temperatures. The time to first emergence decreased as the soil temperature increased. However, this effect was enhanced with greater sowing depths; tall fescue took 9 days to emerge at 24°C and 65 days at 3°C at 45 mm depth (Figure 2.10). The rate of emergence increased gradually as temperature increased whereas sowing depth had no effect. Furthermore, a 6/12°C (12 h day/12 h night) temperature regime had a similar response to constant 12°C and a higher response than the 9°C treatment for the final emergence of tall fescue. This study shows that the constant temperature treatments are comparable with the variable temperatures experienced in the field. However, this study may have overestimated successful seedling establishment as it was conducted in controlled temperature cabinets where moisture was not limiting.

It is important to have rapid seedling emergence in order to not be outcompeted by weeds. Charlton *et al.* (1991) stated that 50% sown seeds emerged in 16 days from a sowing depth of 15 mm at 9°C. Therefore, they suggested to sow tall fescue in early autumn (before temperatures drop below 9°C or before May) or at reduced sowing depths to allow for a faster establishment; however this would increase the risk of inadequate soil moisture. The other option is to sow in early spring while soil temperatures are increasing and soil moisture is adequate.

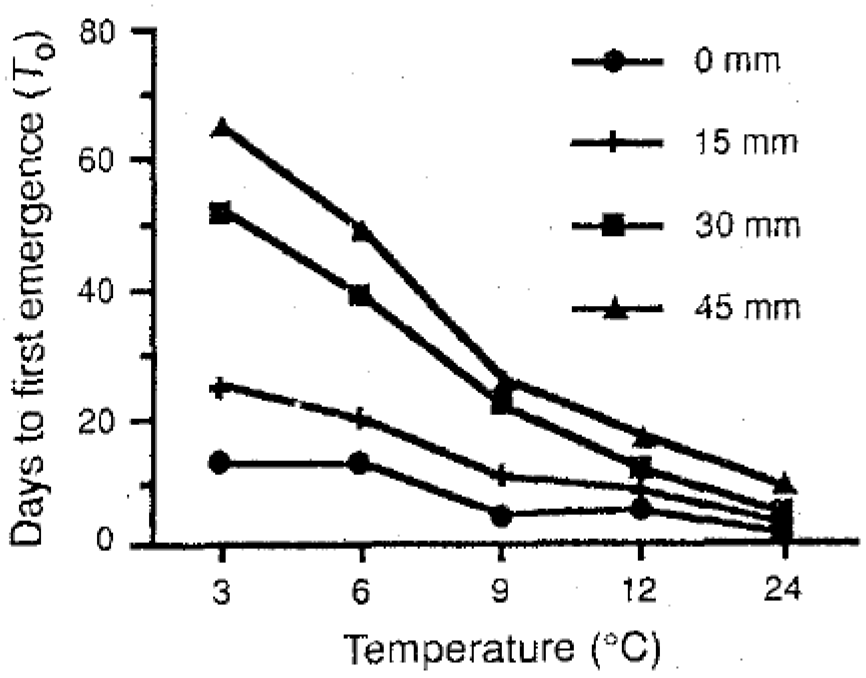

Figure 2.10 The effect of temperature and sowing depth on the time to first emergence of tall fescue/white clover pastures in controlled environmental conditions (Charles *et al.,* 1991).

Sowing date is important as the seasonal temperature changes will influence the rate of plant development. The later the sowing date the longer the plant takes to emergence (Moot *et al.*, 2000). Moot *et al.* (2000) showed that 'Nui' perennial ryegrass and 'Advance' tall fescue sown on 21st March reached 50% final field emergence at a similar time after sowing (10 and 11 days, respectively) (Table 2.13). In contrast, sowing both of these species 48 days later demonstrated how tall fescue is a slower establishing species as it took 7 days longer to reach 50% field emergence. Moot *et al.* (2000) stated that 'Advance' tall fescue would start to emerge later than 'Nui' perennial ryegrass as its base temperature (T_b) for plant development was higher (3.6°C compared with 2.1°C for perennial ryegrass) causing a slower accumulation of thermal time (T_t) or growing degree days, hence the reason for its slower establishment. On top of this, the perennial ryegrass has a lower T_t of 160°Cd for 50% field emergence compared with the tall fescue's 190°Cd which also restricts tall fescue's emergence rate. This puts the tall fescue at a disadvantage as weeds may outcompete tall fescue in the establishing year. However, this gives favourable companion species, such as clovers, a chance to become a more significant component to the botanical composition.

Table 2.13 Number of days to 50% of final field emergence of 'Nui' perennial ryegrass and 'Advance' tall fescue sown on five different dates in 1996 at Lincoln University, Canterbury (adapted from Moot *et al.*, 2000).

	Sowing date				
Species	8 March	21 March	4 April	24 April	8 May
'Nui' perennial ryegrass	11	10	11	15	25
'Advance' tall fescue	13	11	14	23	32

2.7 Conclusions

1. Tall fescue is an important cool season perennial grass where summer moisture stress limits the persistency and yield of perennial ryegrass. Tall fescue can produce 6-14% more annual yield than perennial ryegrass. In summer, tall fescue has a greater production over ryegrass of approximately 168% which is more pronounced under below average rainfall during the first 2 to 3 years after establishment.
2. Mediterranean tall fescue cultivars, like 'Flecha', display morphological responses to water stress by reducing their size, increasing their root:shoot ratio and having lower growth rates than continental cultivars. In contrast, continental cultivars exhibit physiological responses to water deficit by having a lower stomatal conductance and greater leaf lamina osmotic adjustment. Annual yields of mediterranean and continental types of tall fescue are similar but mediterranean types of tall fescue have a greater winter production than continental types. In summer, the continental types of tall fescue have higher growth rates than mediterranean types.
3. Tall fescue is a more compatible companion grass for clovers, like white clover and subterranean clover, than perennial ryegrass as it has a less aggressive growth which allows clovers to compete for light. However, white clover growth is restricted when there is inadequate rainfall (<600 mm). This makes subterranean clover a more suitable companion clover in dryland conditions which can produce lamb growth rates higher than when sown with tall fescue.
4. White clover and subterranean clover fix about 34-342 and 50-188 kg N/ha, respectively. The amount of N fixed by clover is dependent on soil moisture, temperature and competitiveness of other species. White clover fixation efficiency improves in winter as the low temperatures reduce the soil mineral N levels which forces the legume to fix more N per tonne of DM.

5. Tall fescue pastures with white or subterranean clover require a minimum of 20 mg/g Olsen P to reach maximum pasture production in either ash, sedimentary or pumice soils in New Zealand. Legumes require P to stimulate root growth, increase N fixation, improve nutritive value and increase feed intake of grazing sheep.
6. A flexible grazing management system for clover pastures throughout the growing season is important to maintain pasture quality, persistence and production and animal performance. Subterranean clover has a greater WUE than white clover making it the preferred legume option for dryland pastures. Subterranean clover's greater DM yield than white clover in water deficit areas increases the N availability to pastures which improves the WUE from the increased photosynthetic efficiency and rate per unit of water used.
7. Tall fescue has a slower establishment than perennial ryegrass as its thermal time requirement for 50% field emergence is higher (190°Cd compared with 160°Cd). This gives companion clover the opportunity to be more competitive.

3 Materials and methods

3.1 Experimental design

A 2^3 factorial experiment was conducted from 7 March to 15 September 2014 to investigate strategies to improve lamb growth on tall fescue/clover swards under dryland conditions. The grazing experiment was established in paddock H17 at Lincoln University in March 2008 with two cultivars of tall fescue (‘Advance’ and ‘Flecha’), two mixtures of clover (perennial mix; ‘Nomad’ white clover (small-leaved, high stolon density) and ‘La Lucilla’ strawberry clover (*Trifolium fragiferum*), and annual mix ‘Denmark’ and ‘Campeda’ subterranean clover), and two levels of soil fertility (low and high Olsen P). However, the strawberry clover failed to persist after the first two years. The eight treatment combinations were applied to 0.04 ha (14 m x 29 m) plots in a randomised complete block design with four replicates, giving 32 plots. Every plot was individually fenced with a race way between each block and around the perimeter of the experiment (Figure 3.1). All plots contained a water trough.

Block 1	1 FSL	2 ASL	3 AWH	4 FWH	5 AWL	6 ASH	7 FSH	8 FWL	
Block 2	9 ASH	10 FSH	11 AWL	12 FWL	13 FSL	14 FWH	15 AWH	16 ASL	
Block 3	17 FSH	18 ASH	19 FWL	20 AWL	21 FWH	22 ASL	23 FSL	24 AWH	
Block 4	25 ASL	26 FSL	27 AWH	28 FWH	29 ASH	30 AWL	31 FWL	32 FSH	Yards

Figure 3.1 Experimental design (paddock H17) shows the plot layout of the tall fescue experiment with four blocks and 32 plots (14 m x 29 m) at Lincoln University, Canterbury.

3.2 Experimental site

The experiment was located in paddock H17 at Lincoln University, Canterbury, New Zealand (43° 39'S, 172° 28'E, 11 m above sea level). The soil at the site was a Templeton silt loam (Udic Haplosteps) of variable depth (0.4-1.5 m) over underlying gravels (Cox, 1978). The site had a shelterbelt of poplar (*Populus deltoids x nigra*) trees (8-10 m) on the west and north boundaries.

The site was established in August 2007 with Roundup Transorb applied at 3 L/ha (540 g/L glyphosate) on the 22 August 2007, then ploughed and sown with triticale (*Triticosecale*). The triticale was grazed by sheep and mown to remove the remainder of the residual in January 2008.

The site was left fallowed prior to being ploughed on the 29 February 2008; Dutch harrowed and rolled on the 3 March 2008 before being heavy rolled on the 10 March 2008. It was sown on the 11 March 2008 with tall fescue (20 kg/ha with Max P endophyte) and either subterranean clover (10 kg/ha), or white clover and strawberry clover (3 kg/ha/each) with a cone seeder at 150 mm wide drill rows. The experiment was managed under dryland conditions and grazed by young sheep until August 2007 (Black *et al.*, 2007).

Soil fertility treatments were initially established in December 1996 (Black, 2004; Black *et al.*, 2007). A grazing experiment was carried out that compared lamb liveweight gain on Caucasian clover (*Trifolium ambiguum*)/perennial ryegrass and white clover/perennial ryegrass swards on high fertility (Olsen P 20 mg/L, SO_4-S 12 mg/kg) and low fertility (Olsen P 11 mg/ L, SO_4-S 7 mg/kg) soils from 1998 to 2001 (Black *et al.,* 2007) (Table 3.1). Based on soil test results (Table 3.1) since the beginning of the grazing experiment when the soil fertility treatments began, fertiliser applications (Table 3.2) were based on output from Overseer® (Version 5.4.10, AgResearch Ltd.). A diagonal transect of 20 deep 7.5 cm core samples were taken from each plot and analysed in bulk samples for soil pH (Blakemore *et al.*, 1987), plant available soil P (Olsen, 1954) and extractable soil sulphate S (Searle, 1979). No fertiliser was applied during the experimental period of this study.

Table 3.1 Soil test results of soil pH, Olsen P and sulphate S for the soil fertility treatments established in 1996 for the top 7.5 cm for all test dates and 7.5-15 cm for August 2014.

Date	Core depth (cm)	Plots	pH	Olsen P (mg/L)	Sulphate S (mg/kg)
August 1996	0-7.5	All	5.9	11	6
May 1998	0-7.5	HF	6.1	22	14
	0-7.5	LF	6.3	10	8
May 1999	0-7.5	HF	6.0	18	7
	0-75	LF	6.0	13	6
May 2000	0-7.5	HF	5.8	16	9
	0-7.5	LF	5.9	9	5
May 2001	0-7.5	HF	6.1	22	20
	0-7.5	LF	6.2	11	8
July 2008	0-7.5	HF	5.7	17	3
	0-7.5	LF	5.6	8	3
July 2009	0-7.5	HF	5.8	17	4
	0-7.5	LF	5.9	10	4
August 2010	0-7.5	HF	-	18	-
	0-7.5	LF	-	7	-
May 2012	0-7.5	HF	5.7	18	6
	0-7.5	LF	5.8	8	4
August 2014	0-7.5	HF	5.8	18	3
	0-7.5	LF	5.8	8	2
	7.5-15	HF	5.5	9	3
	7.5-15	LF	5.8	5	1

HF – high fertility; LF – low fertility

Table 3.2 Fertiliser applications since the establishment of the soil fertility treatments in 1996.

Date	Plots	Fertiliser applied
December 1996	HF	600 kg/ha superphosphate (9% P; 12% S)
	All	1 t/ha lime
August 1997	HF	600 kg/ha superphosphate (9% P; 12% S)
November 1999	HF	250 kg/ha sulphur superphosphate 20 (8.1% P; 20.5% S)
August 2008	HF	190 kg/ha sulphur superphosphate 20 (8.1% P; 20.5% S)
	LF	80 kg/ha sulphur superphosphate 15 (8.7% P; 14.7% S)
July 2009	HF	150-300 kg/ha sulphur superphosphate 20 (8.1% P; 20.5% S)
	LF	60 kg/ha sulphur superphosphate 15 (8.7% P; 14.7% S)
August 2012	HF	220 kg/ha sulphur superphosphate 20 (8.1% P; 20.5% S)
	LF	60 kg/ha sulphur superphosphate 20 (8.1% P; 20.5% S)

HF – high fertility; LF – low fertility

3.3 Grazing management

Plots were rotationally grazed with Coopworth ewe hoggets in autumn 2014. Thirty two ewe hoggets were selected as treatment animals after being weighed on two days in March 2014 (12 and 17 March 2014) to determine an average weight. They were then grouped based on average liveweight and assigned to one of the eight treatments. Eight groups of ewe hoggets each grazed four plots in order (blocks 1-4) of the same treatment over two rotations in autumn from 17 March to 27 May 2014. There were four measurement animals per group and the number of extra grazing animals required was based on a feed budget at the start of each rotation and the pasture cover of each block prior to the sheep entering. Table 3.3 shows the mean number of animals in each grazing rotation, rotation length and average number of days between grazing (grazing interval). Every treatment animal had its own identification tag number to ensure it was easily recognisable to monitor individual performance.

Table 3.3 Grazing rotation details for the eight treatments on the tall fescue/clover experiment from 17 March to 27 May 2014 including rotation start date, finish date, rotation length, average grazing interval between grazings and average number of sheep per treatment group.

Rotation number	Start date	Finish date	Rotation length		Average number of sheep per treatment group							
			Days	Interval*	FSH	FSL	FWH	FWL	ASH	ASL	AWH	AWL
1	17/03/14	16/04/14	30	111	6.0	6.5	6.0	6.0	6.3	6.0	6.0	5.5
2	16/04/14	27/05/14	41	38	4.4	4.4	4.4	4.0	4.4	4.3	4.4	4.0

F – 'Flecha' tall fescue; S – Subterranean clover; L – Low fertility; A – 'Advance' tall fescue; W – white clover; H – High fertility. * - Average interval since last grazing

3.4 Climate

Meteorological data, including rainfall, PET and air temperature, were collected from Broadfields National Institute of Water and Atmospheric Research (NIWA) meteorological station located on Boundary road, 3 km north-northeast of Lincoln University. The long-term mean (LTM) PET was collected from Christchurch Aero station 21 km north-northeast of Lincoln University. The site is characterised by cool, moist winters and warm, dry summers (Figure 3.1). The total rainfall and PET from 1 October 2013 to 30 September 2014 was 707 mm and 976 mm, respectively. The annual LTM rainfall and PET from 1981-2010 is 599 mm and 924 mm, respectively. The warm dry north-west winds frequently occur mainly in summer across Canterbury which increases the PET rates causing it to exceed the annual rainfall. Monthly PET exceeded the LTM in October, January, February, May, July, August and September by 3-53 mm and rainfall was less than the monthly LTM in November, January and May to September by 4, 30, and 9-46 mm, respectively. Rainfall was greater than monthly LTM in October, December and February to April by 20, 12 and 13-117 mm, respectively, making it a wetter than average autumn by 178 mm (Figure 3.2). The annual air temperature closely followed the LTM.

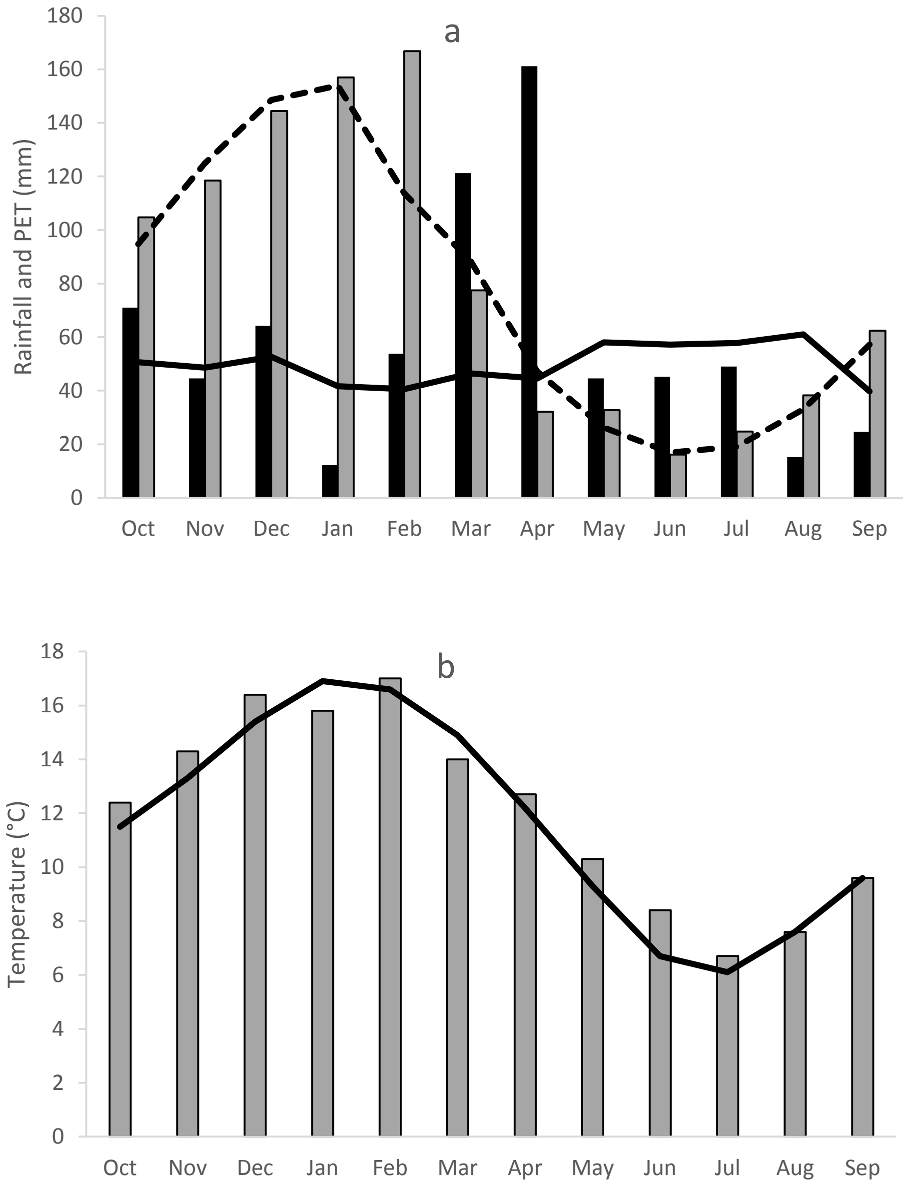

Figure 3.2 (a) Monthly mean rainfall (mm, black columns) and potential evapotranspiration (PET) (mm, grey columns) from October 2013 to September 2014 compared with long-term mean (LTM) monthly rainfall (mm, —) and PET (mm, - - -) (1981-2010). (b) Mean monthly air temperature (°C, grey columns) from October 2013 to September 2014 and LTM monthly temperature (°C, —) from 1981-2010 from Broadfields weather station located 3 km from Lincoln University.

3.5 Measurements

3.5.1 Animal liveweight gain

The liveweights of the four measurement animals per group were measured at the start and end of each grazing rotation. Animals were weighed unfasted and recorded in nearby yards then drafted back into their treatment groups to start a new grazing rotation. Animal liveweight gain (g/head) was then calculated from across the two grazing rotations. Liveweight gain (g/head/day) can then be calculated from the number of grazing days each treatment was grazed for in the rotation then multiplied by the total number of hoggets in each treatment. This can then be converted to a liveweight gain per ha (kg/ha) by multiplying the liveweight gain per head (g/day) by the number of grazing days in each rotation and divided the average sheep per group (Table 3.3) by the size of the treatment area (0.16 ha).

3.5.2 Pre- and post-grazing herbage mass and botanical composition

Botanical composition of the pasture was measured by harvesting 10 pre-grazing pasture clips (20-25 cm long) with electric shears prior to the sheep being shift into each block. A subsample was then separated into the components of the pasture which included; tall fescue, white clover, 'Denmark' subterranean clover, 'Campeda' subterranean clover, weeds and dead material (Plate 3.1). The difference between 'Denmark' and 'Campeda' subterranean clover is 'Denmark' has smaller leaves with faint or no white markings, hairless petioles, and white coloured stipule during vegetative growth and flowers later in season (November). Comparatively, 'Campeda' has larger, darker green leaves with white marks, hairs on both sides of the leaf, sparse hairs on the petiole, a purplish coloured stipule during vegetative growth and flowers in late October (Wurst *et al.*, 2004) (Plate 3.2). The separated components were then oven dried for 48 hours at 65°C and weighed to determine botanical composition of the pasture prior to grazing.

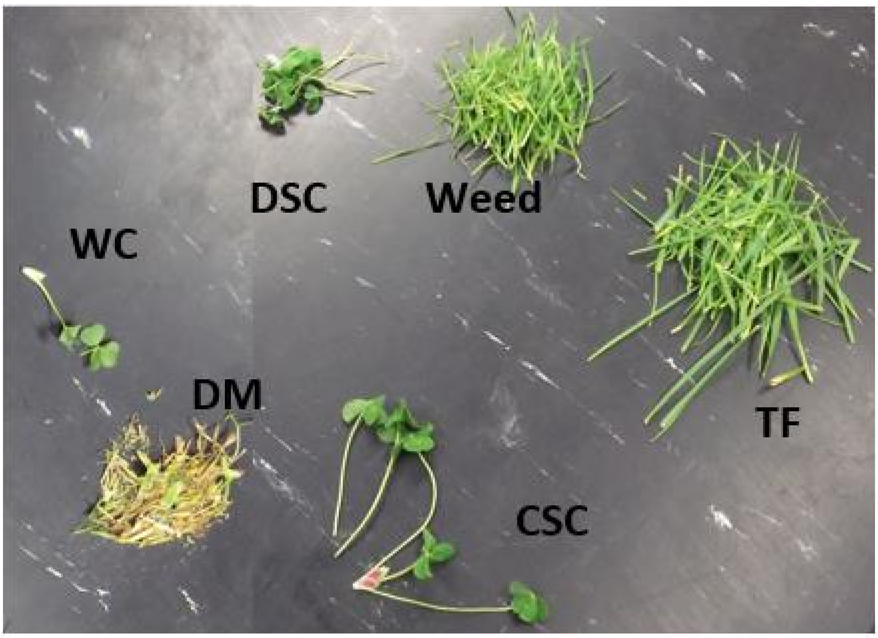

Plate 3.1 Botanical composition of a pre-grazing pasture sub-sample and separated into tall fescue (TF), weed, ‘Denmark’ subterranean clover (DSC), ‘Campeda’ subterranean clover (CSC), white clover (WC) and dead material (DM).

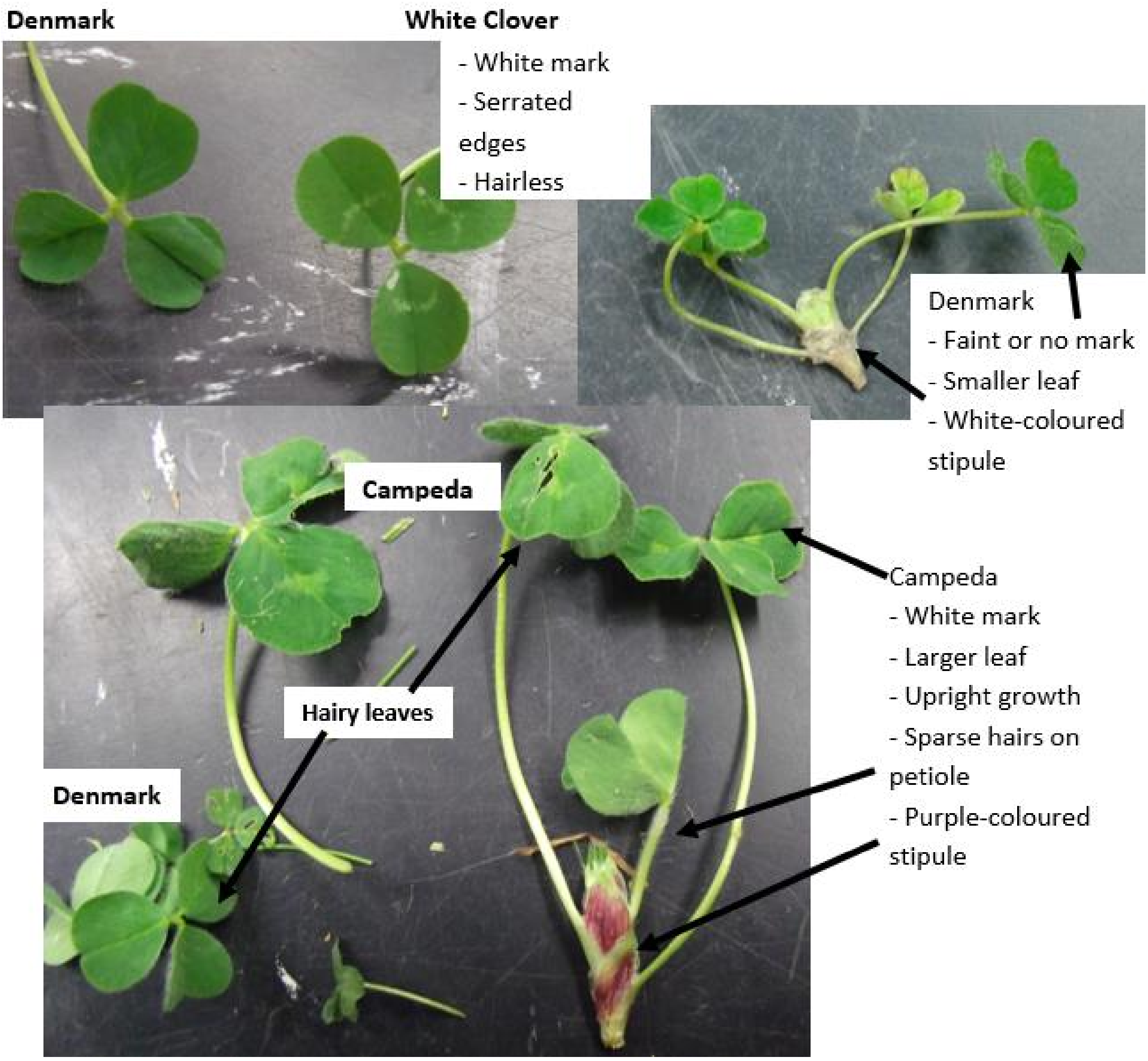

Plate 3.2 'Denmark' and 'Campeda' subterranean clover and white clover plant identification features.

Herbage mass (kg DM/ha) was measured pre and post grazing using 50 rising plate metre readings in a zigzag transect across each plot, keeping 1 m away from the fence lines. This ensured a fair representation of the plot and the variable pasture cover from the urine and stock camps were taken into consideration. In addition to the plate meter readings a 5 m mown strip was cut per plot pre and post grazing to calibrate the rising plate meter. Once a fair representation of the plot was selected a 5 m chain was measured and 10 rising plate meter readings recorded along the strip. The strip was then mown to a height of 30-40 mm using a rotary mower with a width of 0.46 m and all the fresh herbage mass collected into a bag. Once collected the fresh herbage mass was recorded and a 100 g sub-sample dried for 48 hours at 65°C. The dry weight was then measured to determine the dry matter percentage (DM %) and the samples were stored for further analysis.

3.5.3 Nutritive value

Metabolisable energy (ME) and crude protein (CP) contents of the pre-grazing mixed herbage samples were analysed to determine nutritive value. Sub-samples each pre-grazing mown strip were ground with a centrifugal grinder (Retsch ZM 200) through a 1 mm sieve and collected in small vials individually labelled with a code that corresponded to the treatment and grazing rotation (64 in total). The samples were analysed for ME (MJ/kg DM) and CP (%) by near infra-red spectroscopy (NIRS) using a calibrated NIRS Systems 5000 Rapid content Analyser.

3.5.4 Dry matter yield

Accumulated DM yield (kg DM/ha) was measured from stock exclosure cages (0.6 x 0.8 m) in each plot. A 1 x 1 m area was mown to 30 mm and the cage placed on the area with two stakes placed either side to secure it in place (Plate 3.3). A 0.2 m^2 quadrat was harvested with electric shears to 30 mm on from 7 March, 9 April, 25 May, 12 August to 15 September 2014 (spring harvests) (Plate 3.3). After each cut a new area (1 x 1 m) was mown to a height of 30 mm and the cage moved and secured to the new site. All the herbage in the quadrat was collected and a sub-sample separated into botanical composition of the sward (tall fescue, white clover, subterranean clover, weed and dead material). The separated sub-sample and bulk sample were then dried for 48 hours at 65°C and weighed to determine DM yield and botanical composition.

Plate 3.3 Cage harvest from 0.2 m^2 quadrat with electric shears on 15 September 2014 at the tall fescue experiment at Lincoln University.

3.6 Rising plate meter calibrations

To calibrate the rising plate meter readings (RPM) of herbage mass (kg DM/ha) from the pre- and post-grazing 5 m mown strips were plotted for each rotation using a simple linear regression analysis (Table 3.4).

Table 3.4 Calibrations of rising plate meter readings (MR) to determine herbage mass (HM) of tall fescue/clover pastures from 17 March-27 May 2014 at Lincoln University. MR and HM range is shown with the equation of the calibration where y = HM and x = MR.

Rotation number	Rotation period	n	MR range	HM range	R^2	Equation
1	17 Mar-16 Apr	64	6-22	695-2512	75.2	y=101.35x-204.4
2	16 Apr-27 May	64	4-12	266-969	80.3	y=113.95x14

3.7 Soil analysis

Soil samples were collected on 6 August 2014 to analyse a range of soil values. From every plot, twenty 15 cm cores were collected, cut in half (0-7.5 cm (A) and 7.5-15 cm (B)) and bagged up into the corresponding bags giving a total of 64 bulk samples. One random core was taken from each sample and bagged up into either high fertility 'A', high fertility 'B', low fertility 'A' or low fertility 'B' according to the treatment which added up to 16 cores for each group. A standard suite analysis was conducted on these four groups (Table 3.1). The 64 bulk samples were measured for the anaerobic mineralisable N content, total N content, total C content and C:N to determine whether there was an interaction with these three variables against the legume DM content.

3.8 Statistical analysis

Factorial analysis of variance (ANOVA) was used to test significant ($\alpha = 0.05$) treatment effects and their interactions using GenStat 16th Ed. (VSN International, 2014). For liveweight gain each animal group was not replicated and was considered the experimental unit therefore there was only one replicate for the three-way interaction. The three-way interaction was considered insignificant and used as experimental error to test for each main effect (n=4 replicates) and two way interaction (n=2 replicates). All other variables (pre- and post-grazing herbage mass, botanical composition, ME and CP, DM yield, soil anaerobically mineralisable N, total N, total C and C:N ratio) were analysed according to the complete 2^3 experimental design with four replicates. From the rising plate meter calibrations, once a linear relationship was observed a straight line was fitted to the data and treatment effects on the line were tested with linear regression with group procedure in GenStat 16th Ed.

4 Results

4.1 Sheep liveweight gain

There were no significant effects of any of the treatments on sheep growth rate (Figure 4.1). However, the hoggets grew on average 36.8 g/day on subterranean clover pastures compared with (P=0.066) 14.0 g/day on the white clover pastures.

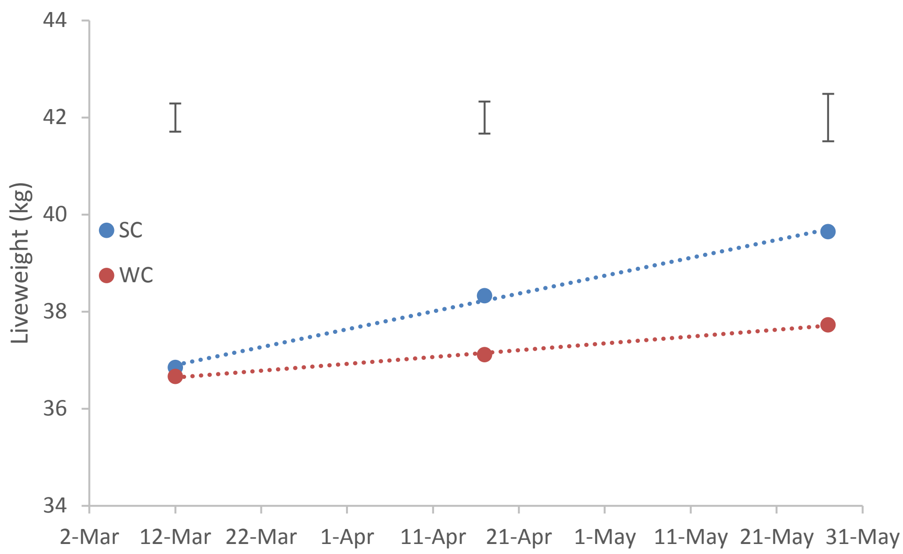

Figure 4.1 Average liveweight of hoggets grazing tall fescue/subterranean clover (SC) and tall fescue/white clover (WC) pastures grazing from 12 March to 27 May 2014 at Lincoln University, Canterbury. Error bars are standard errors of differences.

The hoggets gained an average of 83.7 kg/ha on the tall fescue/subterranean clover swards compared with (P=0.066) 30.4 kg/ha on the tall fescue/white clover swards from 12 March to 27 May 2014. Liveweight gain per hectare was not affected by tall fescue cultivar and soil fertility. Stocking rates were also not significantly different between treatments.

Table 4.1 Average growth rate, stocking rate and liveweight gain per hectare of hoggets grazing tall fescue/clover pastures in response to tall fescue cultivar, clover species and soil fertility from 12 March to 27 May 2014 at Lincoln University, Canterbury.

Treatment	Growth rate (g/day)	Stocking rate (sheep/ha)	Liveweight gain (kg/ha)
Tall fescue (T)			
'Advance'	24.2	30.9	53.6
'Flecha'	26.6	31.7	60.4
SED	13.7	0.8	31.6
Clover (C)			
Subterranean	36.8	31.9	83.7
White	14.0	30.6	30.4
SED	10.2	0.7	23.0
Soil fertility (F)			
High	28.2	31.6	63.4
Low	22.7	30.9	50.6
SED	13.6	0.9	31.2
Significance			
T	NS	NS	NS
C	P=0.066	NS	P=0.06
F	NS	NS	NS

NS = not significantly different.

4.2 Pre- and post-grazing herbage mass

There were no treatment effects for the pre-and post-grazing herbage mass (kg DM/ha) in autumn (Table 4.2).

Table 4.2 Pre- and post-grazing herbage mass of tall fescue/clover pastures in response to tall fescue cultivar, clover species and soil fertility for two grazing rotations from 17 March to 25 May 2014 at Lincoln University, Canterbury.

Treatment	Pre-grazing herbage mass (kg DM/ha)	Post-grazing herbage mass (kg DM/ha)
Tall fescue (T)		
‘Advance’	1360	741
‘Flecha’	1445	715
Clover (C)		
Subterranean	1442	760
White	1362	696
Soil fertility (F)		
High	1486	773
Low	1318	683
SED	189.9	106
Significance		
T	NS	NS
C	NS	NS
F	NS	NS

NS = not significantly different.

4.3 Botanical composition

There was 14.7% more ($P<0.001$) tall fescue in the ‘Advance’ pastures (55%) than the ‘Flecha’ pastures (40.3%) and 6.7% more ($P<0.05$) tall fescue in the subterranean clover swards (51%) than in white clover swards (44.3%) (Table 4.3). Subterranean clover pastures contained 8.5% clover which was 2.8% more ($P<0.05$) than in white clover pastures (5.6%). There was 13.1% more

(P<0.001) weeds in ‘Flecha’ (20%) than ‘Advance’ (33.1%) pastures and 8.3% more (P<0.05) weeds in the white clover pastures (30.7%) than the subterranean clover swards (22.4%).

Table 4.3 Botanical composition of pre-grazing herbage mass of tall fescue/clover swards in response to tall fescue cultivar, clover species and soil fertility from 17 March to 25 May 2014 at Lincoln University, Canterbury.

Treatment	Tall fescue	Clover	Weed	Dead
		% of pre-grazing herbage mass		
Tall fescue (T)				
‘Advance’	55.0	7.3	20.0	17.7
‘Flecha’	40.3	6.8	33.1	19.8
Clover (C)				
Subterranean	51.0	8.5	22.4	18.1
White	44.3	5.6	30.7	19.3
Soil fertility (F)				
High	48.2	6.3	25.8	19.7
Low	47.1	7.8	27.3	17.7
SED	2.7	1.2	3.8	2.8
Significance				
T	***	NS	***	NS
C	*	*	*	NS
F	NS	NS	NS	NS

* = P<0.05, *** = P<0.001, NS = not significantly different.

4.4 Clover composition in the subterranean clover pastures

The composition of ‘Denmark’ and ‘Campeda’ subterranean clovers and adventive white clover (presumably ‘Huia’) in the subterranean clover pastures was not affected by tall fescue cultivar or soil fertility (Figure 4.2). ‘Denmark’ subterranean clover was the dominant cultivar where it composed an average of 5.1% of the total pre grazing herbage mass, followed by adventive white clover (3.2%) then ‘Campeda’ (0.3%).

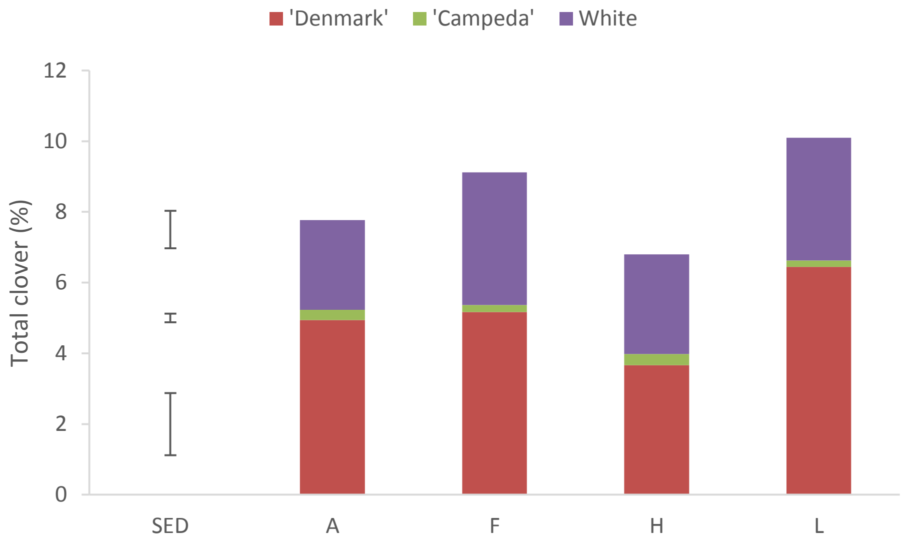

Figure 4.2 Percentage of ‘Denmark’ and ‘Campeda’ subterranean clover and adventive white clover in tall fescue/subterranean clover pastures in response to tall fescue cultivar (‘Advance’ (A) and ‘Flecha’ (F)) tall fescue and soil fertility (high (H) and low (L)) from 17 March to 25 May 2014, at Lincoln University, Canterbury.

4.5 Nutritive value

Metabolisable energy and the crude protein contents of pre-grazing herbage of the tall fescue/clover swards were not significantly affected by tall fescue cultivar, clover species and soil fertility (Table 4.4). The overall mean ME content was 10.3 MJ/kg DM and CP was 18.6%.

Table 4.4 Metabolisable energy and crude protein contents of pre-grazing herbage of tall fescue/clover swards in response to tall fescue cultivar, clover species and soil fertility from 17 March to 25 May 2014, at Lincoln University, Canterbury.

Treatment	Metabolisable energy (MJ/kg DM)	Crude protein (%)
Tall fescue (T)		
'Advance'	10.4	18.3
'Flecha'	10.2	18.9
Clover (C)		
Subterranean	10.4	19.4
White	10.2	17.8
Soil fertility (F)		
High	10.3	18.4
Low	10.4	18.8
SED	0.2	1.1
Significance		
T	NS	NS
C	NS	NS
F	NS	NS

NS = not significantly different.

4.6 Dry matter yield

The total accumulated yield of the tall fescue/clover swards from 28 November 2013 to 15 September 2014 was affected by tall fescue cultivar clover species (Figure 4.3). 'Flecha' pastures yielded (6455 kg DM/ha) compared with ($P<0.05$) 5787 kg DM/ha for 'Advance' pastures, and subterranean clover pastures yielded 6562 kg DM/ha compared with (P<0.01) 5679 kg DM/ha for white clover pastures.

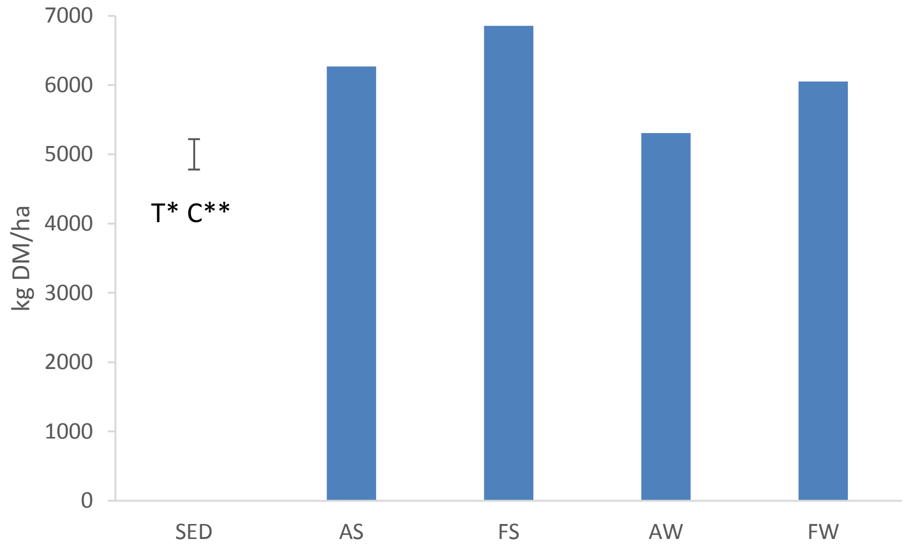

Figure 4.3 Total accumulated yield of 'Advance' tall fescue/subterranean (AS), 'Flecha' tall fescue/subterranean clover (FS), 'Advance' tall fescue/white clover (AW) and 'Flecha' tall fescue/white clover (FW) swards from 28 November 2013 to 15 September 2014, at Lincoln University, Canterbury. Significant main effects of tall fescue cultivar (T) and clover species (C) are indicated (* = P<0.05 and ** = P<0.01).

There was an interaction (P<0.05) between clover species and soil fertility in their effects on total accumulated yield (Figure 4.4). Subterranean clover pastures yielded 108 kg DM/ha more (P<0.05) herbage than the white clover pastures (6072 kg DM/ha) at high fertility, but 1659 kg DM/ha more than white clover pastures (5286 kg DM/ha) at low fertility.

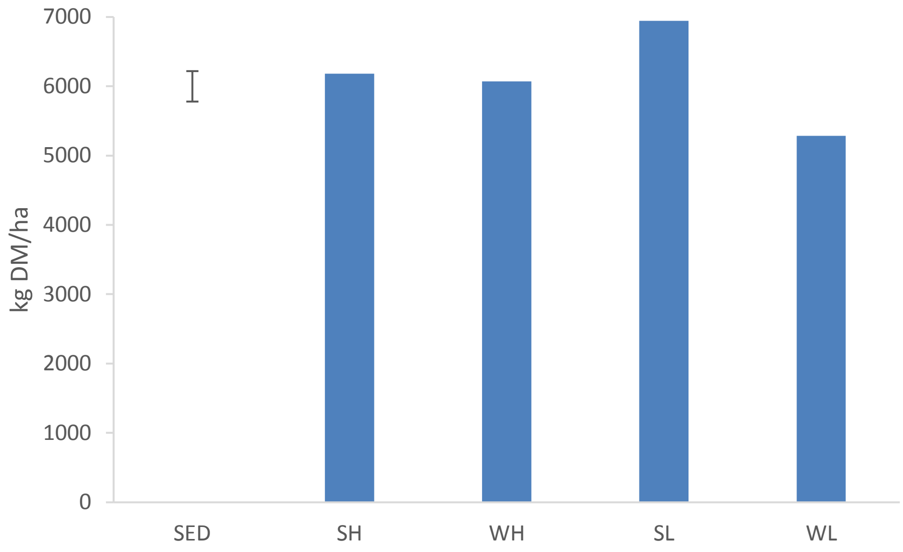

Figure 4.4 Total accumulated yield of tall fescue/subterranean clover (S) and tall fescue/white clover (W) swards at high (H) and low fertility (L) soil fertility from 28 November 2013 to 15 September 2014, at Lincoln University, Canterbury.

'Advance' tall fescue pastures contained 50% more ($P<0.001$) tall fescue (45.6%) than 'Flecha' pastures (30.4%) and subterranean clover pastures contained more ($P<0.01$) tall fescue (42.1%) than white clover pastures (33.9%) (Figure 4.5). There was a higher proportion of clover ($P<0.01$) in the subterranean clover pastures (12.4%) than the white clover pastures (5.7%). 'Flecha' swards contained 48.5% weeds, which was 14.7% more ($P<0.001$) than 'Advance' swards and white clover swards contained 48.6% weeds, which was 14.9% more ($P<0.001$) than subterranean clover swards.

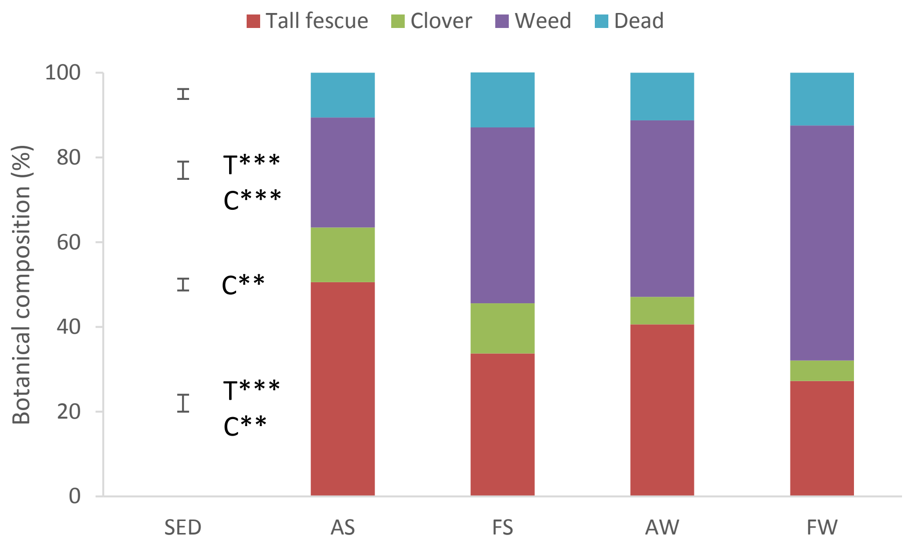

Figure 4.5 Botanical composition of total accumulated yield of 'Advance' tall fescue/subterranean (AS), 'Flecha' tall fescue/subterranean clover (FS), 'Advance' tall fescue/white clover (AW) and 'Flecha' tall fescue/white clover (FW) swards from 28 November 2013 to 15 September 2014, Lincoln University, Canterbury. Significant main effects of tall fescue cultivar (T) and clover species (C) on the separated components are indicated (** = P<0.01 and *** = P<0.001).

The DM yields at each harvest are shown on Figure 4.6. On 7 March there was no effects of treatments and total yield averaged 1050 kg DM/ha. On 9 April, the subterranean clover swards produced 1590 kg DM/ha compared with (P<0.01) 1195 kg DM/ha for white clover swards. On 28 May, 'Flecha' tall fescue pastures yielded an average of 1405 kg DM/ha compared with 1156 kg DM/ha for the 'Advance' tall fescue pastures. On 12 August, the 'Flecha' pastures 1283 kg DM/ha compared with (P<0.001) 875 kg DM/ha for the 'Advance' pastures and the subterranean clover pastures yielded 1171 kg DM/ha (P<0.05) compared with 988 kg DM/ha for the white clover pastures. Also on 12 August, total yield was affected by an interaction (P<0.001) between clover species and soil fertility (Figure 4.7). Yield was 13.5% greater for white clover (1140 kg DM/ha) than subterranean clover (1004 kg DM/ha) pastures, but it was 60.2% more than white clover (835 kg DM/ha) pastures at low fertility. On 15 September, yield was not affected by treatments and total yield averaged 1319 kg DM/ha.

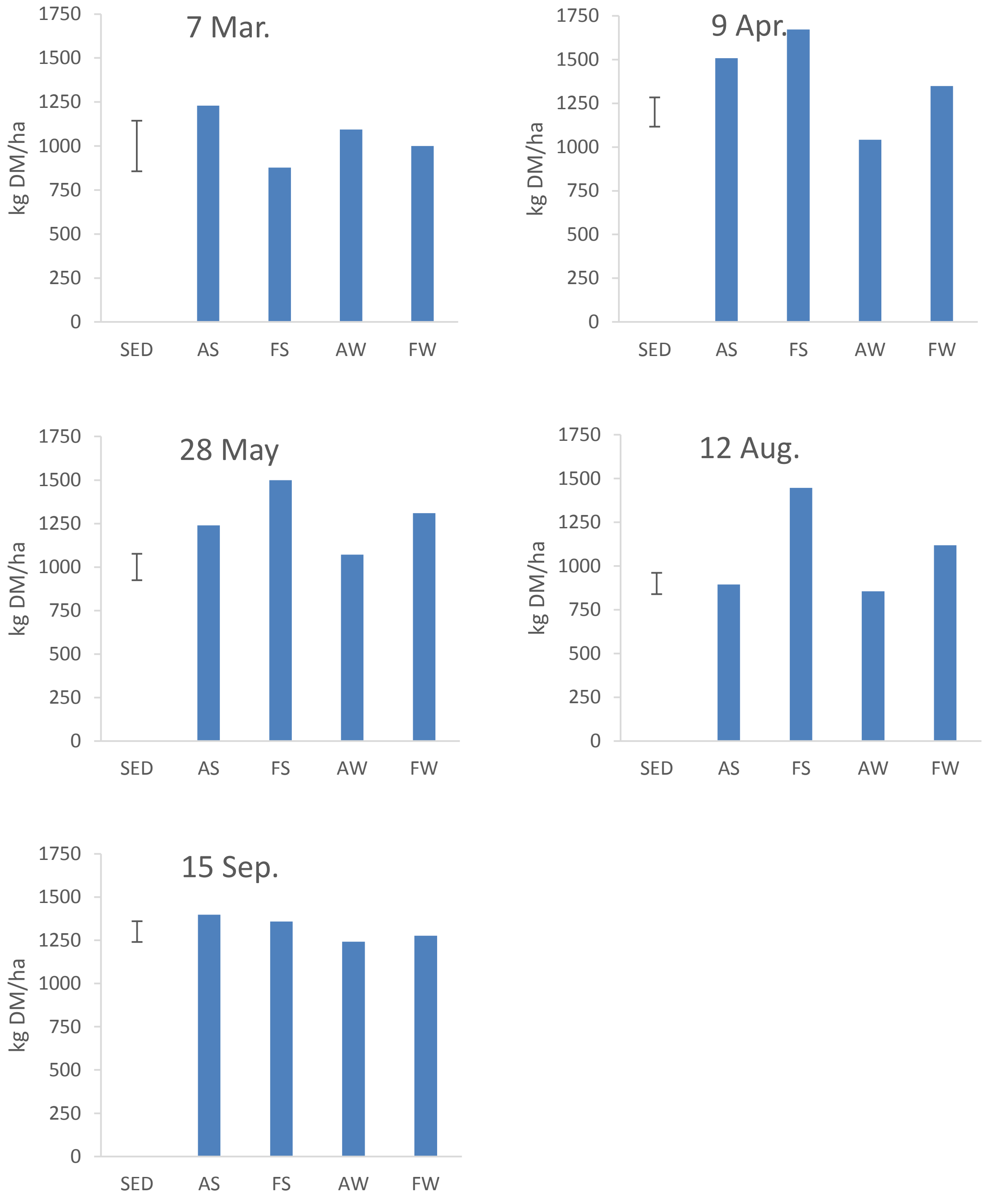

Figure 4.6 Total yield of 'Advance' tall fescue/subterranean clover (AS), 'Flecha' tall fescue/subterranean clover (FS), 'Advance' tall fescue/white clover (AW) and 'Flecha' tall fescue/white clover (FW) swards on five harvest dates during autumn and early spring at Lincoln University, Canterbury.

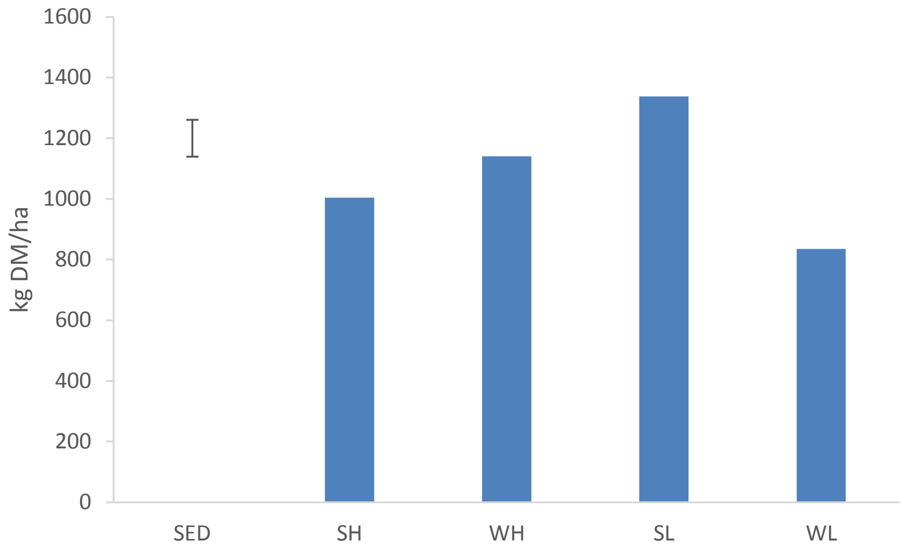

Figure 4.7 Total yield of tall fescue/subterranean clover (S) tall fescue/white (W) swards at high (H) and low (L) soil fertility on 12 August 2014, Lincoln University, Canterbury.

The botanical composition of the yields from each harvest are given in Figure 4.8. On 7 March, 'Advance' pastures contained 62.6% tall fescue which was 36.5% more (P<0.001) than the 'Flecha' pastures. There was 1.4% more (P<0.001) weeds in the 'Flecha' pastures (8.3%) than the 'Advance' pastures (6.9%) with subterranean clover and 11.4% more weeds in 'Flecha' pastures (19.6%) than 'Advance' pastures (8.2%) with white clover. 'Flecha' pastures contained 69.3% dead material which was 40.3% more (P<0.05) than 'Advance' pastures (29%) with subterranean clover. There was 20.4% more (P<0.05) dead material in 'Flecha' pastures (44%) than 'Advance' pastures (23.6%) with white clover.

On 9 April, 'Advance' pastures had 14.3% more (P<0.01) tall fescue (48.1%) than the 'Flecha' pastures (33.8%) (Figure 4.8). There was 8.9% more (P<.0.01) clover in the subterranean clover swards (18.9%) than the white clover swards (10%). 'Flecha' pastures contained 13.9% more weeds (P<0.05) than 'Advance' pastures (35.6%). White clover pastures contained 18.7% more (P<0.01) weeds than subterranean clover pastures (33.2%).

On 28 May, ‘Advance’ pastures contained 13.3% more ($P<0.05$) tall fescue than ‘Flecha’ pastures (35.1%), subterranean clover pastures contained 9.7% clover which was 5.2% more ($P<0.05$) than white clover pastures and ‘Flecha’ swards contained 53.9% weeds which was 16.6% more ($P<0.01$) than ‘Advance’ swards (Figure 4.8). White clover swards contained 52.7% weeds which was 14.2% more ($P<0.01$) than the subterranean clover pastures and ‘Advance’ swards contained 3.1% more ($P<0.05$) dead material than ‘Flecha’ pastures (4%).

On 12 August, subterranean clover pastures contained 49.3% tall fescue which was 23.8% more ($P<0.001$) than white clover pastures (25.5%) (Figure 4.8). White clover pastures contained 62% weeds which was 24% more ($P<0.001$) than the subterranean clover pastures (38%).

On 15 September, there was 18.7% more ($P<0.01$) tall fescue in ‘Advance’ pastures (33.6%) than ‘Flecha’ pastures (Figure 4.8), 14.4% more ($P<0.001$) clover in the subterranean clover pastures (19.4%) than white clover pastures (5%) and 12.1% more ($P<0.01$) clover in low fertility pastures (18.3%) than high fertility pastures (6.2%). There were 23.5% more ($P<0.001$) weed in ‘Flecha’ swards (64.6%) than ‘Advance’ swards (41.4%) and 13.9% more ($P<0.05$) weed in white clover swards (59.8%) than subterranean clover swards (45.9%).

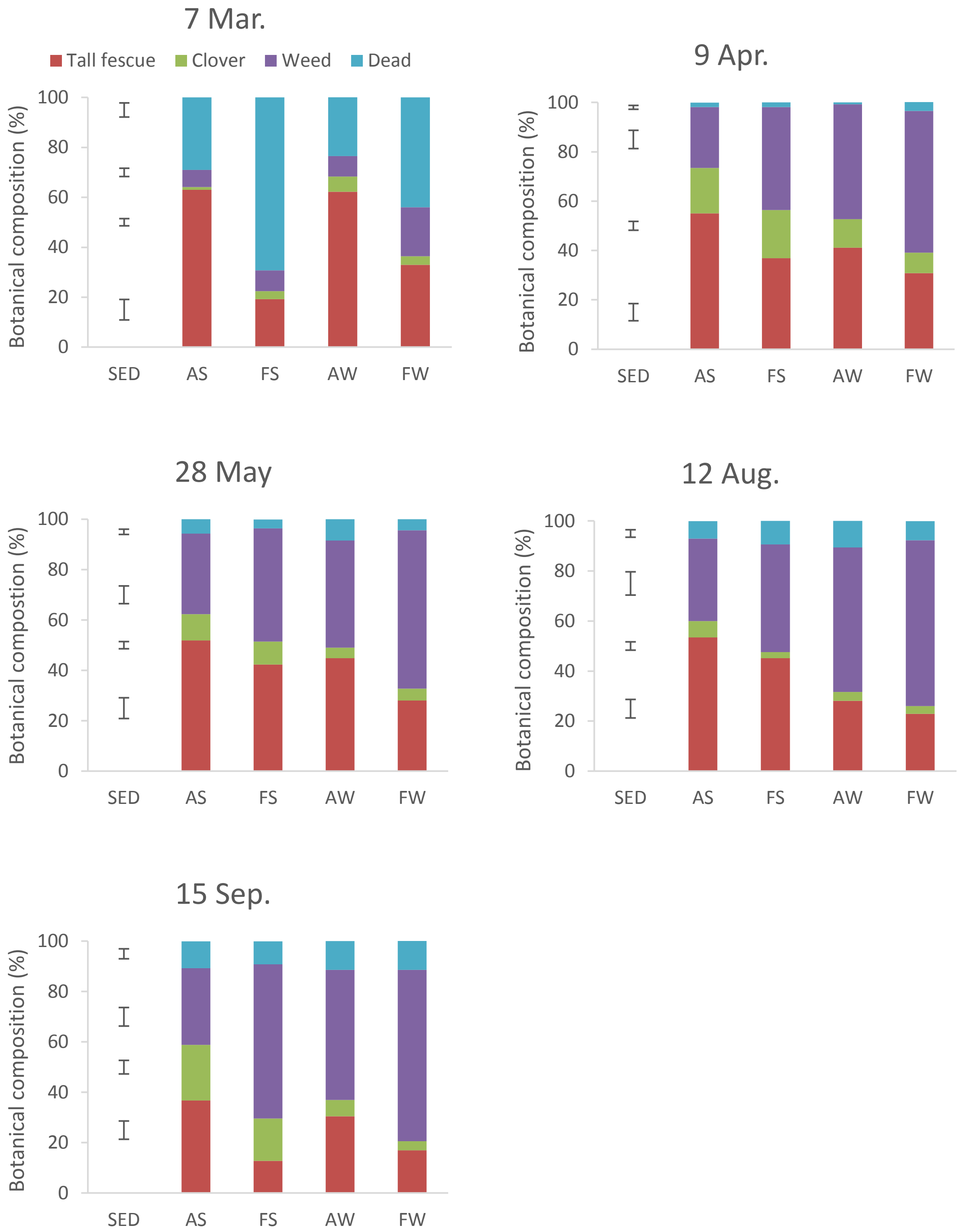

Figure 4.8 Botanical composition of the total yield of 'Advance' tall fescue/subterranean (AS), 'Flecha' tall fescue/subterranean clover (FS), 'Advance' tall fescue/white clover (AW) and 'Flecha' tall fescue/white clover (FW) swards on five dates during autumn and early spring 2014 at Lincoln University, Canterbury.

4.7 Soil N and C contents

On 6 August, the anaerobically mineralisable N content of soil in the top 7.5 cm was 110.2 kg N/ha for 'Advance' tall fescue swards compared with 101.8 kg N/ha for 'Flecha' (Table 4.5). Soil mineral N was 15.8 kg N/ha higher ($P<0.05$) for 'Advance' than 'Flecha' at high soil fertility, but similar for both tall fescue cultivars at low fertility (Figure 4.9). Total N was 0.008% w/w high ($P<0.05$) in subterranean clover (0.226%) than white clover (0.218%) pastures in the top 7.5 cm of soil (Table 4.5). There were no effects of treatments on soil N and C contents in the 7.5-15 cm layer of soil.

Table 4.5 Anaerobically mineralisable N, total N, total C and C:N of tall fescue/clover soils in response to tall fescue cultivar, clover species and soil fertility at 0-7.5 cm and 7.5-15 cm on 6 August 2014, at Lincoln University, Canterbury.

Treatment	Anaerobically min N (kg N/ha)	Total N (%)	Total C (%)	C:N ratio
		0-7.5 cm		
Tall fescue (T)				
Advance	110.2	0.220	2.63	11.94
Flecha	101.8	0.224	2.62	11.88
Clover species (C)				
Subterranean	108.1	0.226	2.64	11.81
White	103.9	0.218	2.60	12.00
Soil fertility (F)				
High	107.9	0.225	2.65	12.00
Low	104.1	0.219	2.59	11.81
SED	3.3	0.0035	0.044	0.09
T	*	NS	NS	NS
C	NS	*	NS	NS
F	NS	NS	NS	NS
TF	*	NS	NS	NS
		7.5-15 cm		
Tall fescue (T)				
Advance	62.2	0.186	2.147	11.69
Flecha	60.8	0.185	2.139	11.63
Clover species (C)				
Subterranean	60.4	0.188	2.149	11.63
White	62.6	0.183	2.138	11.69
Soil fertility (F)				
High	62.3	0.186	2.158	11.69
Low	60.7	0.185	2.129	11.63
SED	2.0	0.0032	0.035	0.18
T	NS	NS	NS	NS
C	NS	NS	NS	NS

F	NS	NS	NS	NS

* = P<0.05, NS = not significantly different.

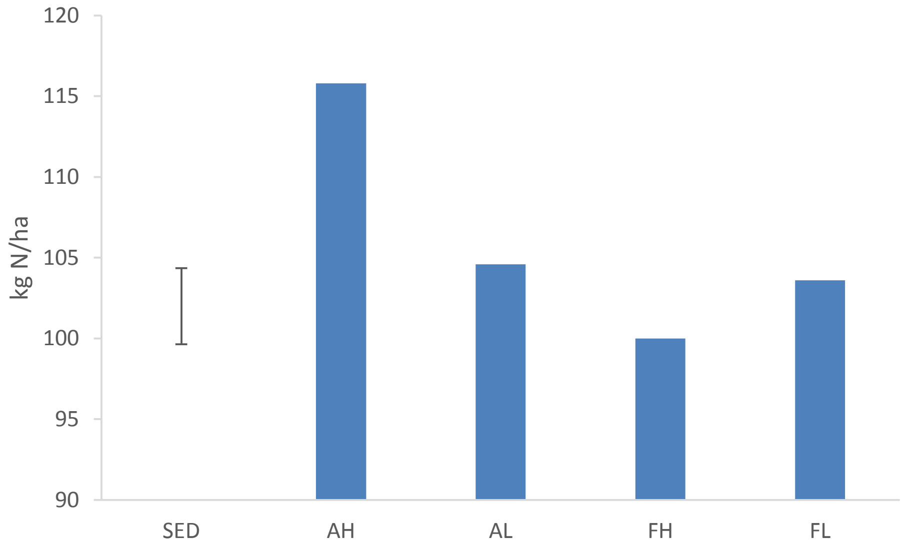

Figure 4.9 Anaerobically mineralisable N content of 'Advance' (A) and 'Flecha' (F) tall fescue/clover soils at high (H) and low (L) soil fertility at 0-7.5 cm on 6 August 2014, at Lincoln University, Canterbury.

5 Discussion

The main aim of this study was to assess strategies to improve sheep liveweight gains and DM production of dryland tall fescue/clover swards. The strategies tested were: 1) using a Mediterranean type cultivar of tall fescue ('Flecha') instead of a more conventional continental type cultivar ('Advance'), and 2) growing subterranean clover with the tall fescue instead of the traditional white clover. Both strategies were designed to attempt to improve sheep and pasture production during the cool season autumn, winter and early spring months, when soil moisture is favourable, but temperatures are normally limiting pasture growth. The Mediterranean type cultivar of tall fescue was purported to be more productive in the cool season than most continental types of tall fescue, and subterranean clover, which is also a species of Mediterranean origin, has been shown to perform better than white clover on dryland pastures in the past (Moot, 2012). The study also tested if the relative performance of the pastures was consistent across contrasting levels of soil fertility, and the abundance of clover cultivars on the subterranean clover pastures after 6 years.

5.1 Strategy 1: Mediterranean instead of continental tall fescue

There was no effect of tall fescue cultivar on sheep growth rate, stocking rate and sheep liveweight gain per hectare (Figure 4.1 and Table 4.1). These results were associated with similar levels of pre- and post-grazing herbage mass (Table 4.2), clover content in the pre-grazing herbage mass (Table 4.3) and nutritive values (Table 4.4). However, the 'Advance' pastures did contain more tall fescue (55%) and less weeds (20%) than the 'Flecha' pastures (40% and 33%, respectively) in the pre-grazing herbage mass. These differences in botanical composition did not influence the nutritive value of the tall fescue/clover pastures, suggesting that the tall fescue and weed (mostly annual grasses) fractions were of similar nutritive value. However, these results did show an important difference in the persistence of the two tall fescue cultivars after 6 years of dryland conditions. Both cultivars were approaching the end of their productive lives, as seen by the low tall fescue content and ryegrass of weeds into all pastures. But this found that there was more tall fescue and less weeds in the 'Advance' swards than the 'Flecha' swards which suggests that the continental type is perhaps a better, more persistent option for dryland pastures in this environment.

While there was no effects of tall fescue cultivar on sheep liveweight gains, herbage mass and nutritive values, there were differences between the two cultivars in herbage yield (Figure 4.3). The accumulated total DM yield from the caged areas was greater for 'Flecha' than 'Advance', but this difference was probably because of the higher weed content in the caged areas of the 'Flecha' swards (49% compared with 34%, respectively) (Figure 4.5). These differences on yield and botanical composition were consistent across most harvests, but particularly in April, May and August (Figure 4.6 and 4.8) when the 'Flecha' swards yielded more than the 'Advance' swards. These seasonal yield differences are difficult to explain due to the high proportion of weeds. However, the apparent yield advantage was likely due to both better growth rate of surviving ' Flecha' compared with 'Advance' tall fescue, and faster growth of weeds, which were mainly annual grasses, compared with tall fescue. There was also a much higher dead content in the 'Flecha' than 'Advance' swards in March, which is consistent with the high content of annual grasses (mostly dead at that time of year) and the summer dormancy of 'Flecha' (Figure 4.8).

The results from this study period (autumn 2014) were consistent with the previous year (Peter, 2013). In the previous autumn (2013), the 'Advance' tall fescue pastures carried more sheep than the 'Flecha' pastures which was associated with more tall fescue and less dead material in the 'Advance' pastures. In that autumn, the greater dead material in 'Flecha' pastures caused total pre- and post-grazing herbage masses to be greater than 'Advance' pastures. Consequently, 'Flecha' pastures had a lower ME value (7.5-8.3 MJ/kg DM) compared with the 'Advance' swards due to the greater grass weed and dead material contents.

Greater DM yields from 'Flecha' than 'Advance' pastures were also found in the 2011/12 season (Dellow, 2012) when 'Flecha' pastures produced 1839 kg DM/ha more herbage compared with 'Advance' pastures (13534 kg DM/ha). This was due to the 'Flecha' pastures containing more weeds (51%) and less tall fescue (36%) than the 'Advance' pastures (25% and 61%).

The higher weed content in the 'Flecha' pastures could be due to 'Flecha' tall fescue's slower growth rate than 'Advance' in summer (Schiller & Lazenby, 1975) and partly because it lies dormant over summer (Pecetti *et al*., 2011). In contrast, 'Advance' performed better in autumn 2014 because of a wetter than average autumn (327 mm compared with 149 mm), which resulted in a wetter than average year (707 mm compared with 599 mm). Over summer (7 March 2014 harvest), there were more weeds in 'Flecha' pastures than 'Advance' pastures (Figure 4.8). However, there was also more dead material in 'Flecha' than the 'Advance' pastures, presumably due to the summer dormancy of 'Flecha'.

'Advance' pastures had a greater tall fescue yield for each harvest except in winter (28 May to 12 August 2014) where the yields were similar to 'Flecha' pastures (Figure 4.6). This was in agreement with Schiller & Lazenby (1975) who stated that continental cultivars had greater yields in spring, summer and autumn than Mediterranean cultivars which rapidly declined in daily growth rates in late spring and early summer. However, Reed *et al.* (2004) reported that Mediterranean cultivars' winter production outperforms continental cultivars during winter.

There was no effect of tall fescue cultivar on the cultivar composition of the clover content in the subterranean clover pastures in autumn 2014. This result was different to that found in the previous autumn, when 'Advance' pastures contained more 'Campeda' subterranean clover than the 'Flecha' pastures. That result was possibly due to a lower herbage mass in 'Advance' swards and greater competition from 'Flecha' pastures which may have reduced the growth of subterranean clover.

5.2 Strategy 2: Subterranean clover instead of white clover

Clover species had no significant effect on stocking rate (Table 4.1), which was associated with similar pre- and post-grazing herbage masses (Table 4.2) and nutritive values (Table 4.4) between the two clover treatments. However, the liveweight gains of the hoggets were better on the subterranean clover than the white clover pastures (Figure 4.1 and Table 4.1). This result was consistent with the differences found by Peter (2013) in the previous autumn year.

The botanical composition results showed that the subterranean clover pastures contained more tall fescue and clover and less weeds than the white clover pastures (Table 4.3). These differences could help explain the higher liveweight gains on the subterranean clover pastures. The greater clover content in the subterranean clover pastures could have been due to the early autumn rains received in 2014 (81 mm from 3 to 6 March), which resulted in a wetter than average autumn that could have allowed the subterranean clover to germinate earlier.

The clover composition within the subterranean clover pastures was mostly made up of 'Denmark' subterranean clover (60%) followed by adventive white clover (37%) and 'Campeda' subterranean clover (3%) (Figure 4.2). Smetham (2003) stated that small-leaved and dense cultivars of subterranean clover (e.g. 'Denmark') were found to be more persistent and successful than erect, larger leaved cultivars (e.g. 'Campeda') under grazing by sheep in New Zealand. Another reason for the abundance of 'Denmark' after 6 years may be due to its more prostrate growth habit making it less subjected to selective grazing than 'Campeda', which has a more upright growth habit (Wurst *et al.,* 2004). The earlier flowering date (September to late October) of the 'Campeda' cultivar could coincide with grazing by sheep in spring causing it to reduce its seed set compared with 'Denmark', which has a longer growing season and later flowering date (October to mid-November) (Ru and Fortune, 2000). Therefore this could cause the constant reduction in 'Campeda' yield over time reducing its persistency compared with 'Denmark'.

The subterranean clover pastures were also occupied by adventive white clover plants which could have helped to increase the tall fescue component in the subterranean clover pastures as a greater clover yield can lead to an increased amount of N fixed resulting in more total soil N. However, as Hyslop *et al.* (2000) stated, there was no relationship between increasing white clover content and liveweight gain on white clover based swards in autumn (Figure 2.5).

In the 2011/12 season, clover was also the only factor to affect liveweight production as hoggets grazing on the subterranean clover swards gained 122 g/head/day and 878 kg/ha whereas hoggets grazing on the white clover swards gained an average of 76 g/head/day and 437 kg/ha over the spring and autumn.

The total accumulated DM yield of the subterranean clover pastures was 6563 kg DM/ha compared with 5679 kg DM/ha for the white clover pastures (Figure 4.3). This clover effect was also visible at the harvests on 9 April and 12 August 2014 (Figure 4.6) and in the 2011/12 season (Dellow, 2012). In that year, the subterranean clover swards produced 16003 kg DM/ha compared with 12894 kg DM/ha from the white clover swards. The subterranean clover swards contained more tall fescue (51%) and clover (20%) and less weeds (29%) compared with white clover (46%, 7% and 47%, respectively). This comparison shows that the subterranean clover and white clover yields have declined by 59 and 56% in 2 years.

The lack of clover in the swards in March 2014 (Figure 4.8) was probably due to the high temperatures and PET and lack of rainfall then. Over summer, subterranean clover lies dormant as seed. White clover prefers moist conditions, requiring at least 40 mm/month for survival and 60 mm/month for performance (Brock, 2006). At every harvest throughout the year the subterranean clover pastures contained more clover. This result was also seen in the previous autumn, which was drier than autumn 2014.

The white clover pastures contained the most weeds at every harvest (Figure 4.8). The fast establishing annual grass weeds, such as vulpia hair grass (*Vulpia spp*.), soft brome (*Bromus hordeaceus*) and annual poa (*Poa annua*), after the autumn rains and cooler temperatures, arrived in both the current and previous years (Peter, 2013). This would have competed against the white clover and germinating subterranean clover seedlings.

In spring, Peter (2013) found that sheep growth rates and liveweight gains were greater in the subterranean clover pastures (129 g/head/day and 301 kg/ha, respectively) than white clover pastures (97 g/head/day and 209 kg/ha, respectively), which allowed higher stocking rates. The clover yield was low as it contained less than 9% of green material; however, the high liveweight gains were achieved with reasonably high stocking rates (>38 sheep/ha). Similarly, Ates *et al.* (2006) stated that lambs from twin bearing ewes at high (20 ewes/ha) and low (10 ewes/ha) stocking rates achieved 307-374 g/head/day on subterranean clover swards that contained less than 13% subterranean clover (Table 2.4). This suggests that the relationship described by Hyslop *et al.* (2000) is unreliable if it anticipates sheep to gain >200 g/head/day grazing pastures containing 30% white clover in tall fescue/white clover pastures in spring (Figure 2.4) when sheep can gain larger weights in swards with <10% in tall fescue/subterranean clover pastures.

5.3 Soil fertility effects

The two levels of soil fertility had no effect on sheep production (Table 4.1), herbage mass (Table 4.2) botanical composition (Table 4.3) and nutritive values of the tall fescue/clover pastures (Table 4.4). This finding agreed with previous data (Dellow, 2012; Peter, 2013). However, it would have been expected that there would be more clover at the high fertility level. Brock (1973) found greater clover yields when applied with 112 kg P/ha each year compared with 22 kg P/ha only in the establishing year due to more N being fixed. It would also have been anticipated that the low fertility treatment would be invaded by more weeds than the high fertility treatment (Kemp *et al.,* 1999a).

In contrast to the seasonal DM yields of the current year (Figure 4.6), Peter (2013) found that the first cage harvest on 27 February 2013 contained more weeds in subterranean clover than white clover pastures at high fertility, but more in white clover than subterranean clover pastures at low fertility. In the second cage harvest (10 April 2013) there was 9% more weed grass in the high fertility than the low fertility pastures. These differences between the 2 years may have been due to the heavy autumn rains which occurred in the current year and below average rainfall in 2013.

The accumulated DM yields were similar for the subterranean clover and white clover pastures at high fertility, but greater for the subterranean clover than white clover pastures at low fertility (Figure 4.4). This demonstrates that subterranean clover is more productive than under low and high soil P levels (Caradus, 1980). However, on 12 August, white clover pastures produced 14% more herbage at high fertility, but yielded 60% less than the subterranean clover pastures at low fertility (Figure 4.7). The lift in yield in the white clover/high fertility swards was from a higher weed content as there were more weeds in the white clover pastures (62%) compared with subterranean clover pastures (38%). There was no effect of soil fertility on the botanical composition at that harvest.

Peter (2013) found that there was 26% more white clover in the high (70%) than low (44%) soil fertility treatments in winter 2013. This showed that white clover is responsive to a higher Olsen P (18 mg/L) (Caradus, 1980) in late winter/early spring which was supported by more total white clover in the high fertility swards. The current year also found that the low fertility pastures contained more clover compared with the high fertility pastures (18% and 6%, respectively) at the 15 September 2014 harvest. However, a soil fertility effect was observed in the 2011/12 season where the high fertility treatments total yield was 11% greater than the low fertility treatments (13707 kg DM/ha), but there was no soil fertility effect on pasture composition (Dellow, 2012).

This may suggest that the higher fertility level (18 mg/L) is not quite high enough to gain greater benefits than the low fertility (8 mg/L) swards.

5.4 Soil N and C contents

In addition to the usual sheep and pasture production measurements taken each year on this experiment in 2014, this study also tested the effects of the long-term tall fescue cultivar, clover species and soil fertility treatments on the N and C contents of the soil. Total C contents of 2-4%, 4-10% and 10-20% are referred to as low, medium and high values, respectively, (Blakemore *et al.*, 1987). Low, medium and high levels of anaerobically mineralisable N are <100, 100-150 and >150 kg N/ha (Moir *et al.*, 1997), 0.1-0.3%, 0.3-0.6% and 0.6-1.0% for total N (Blakemore *et al*., 1987) and 10-12, 12-16 and 16-24 for C:N (Blakemore *et al*., 1987).

Lambert *et al.* (2000) averaged the values across two fertiliser treatments and found that the total C, total N and C:N ratio of soil in a grass/clover pasture were 5.91%, 0.47% and 12.8:1, respectively. From the same site, in an earlier study, Lambert (1987) found that low fertility and high fertility treatments produced a total 6240 and 9230 kg DM/ha, respectively, which included 755 and 1846 kg DM/ha of legumes. In contrast, the current study found low and high soil fertility treatments yielded 6116 and 6126 kg DM/ha, respectively. However, both treatments produced less clover (676 and 445 kg DM/ha) than the pastures reported by Lambert (1987). Comparatively, 2 years prior, this study produced 13319 and 14524 kg DM/ha of total herbage and 1716 and 1866 kg DM/ha clover on the low and high soil fertility treatments, respectively (Dellow, 2012).

This study found that, after 6 years of treatments, there were medium and low levels of anaerobically mineralisable N (Table 4.5) in the 0-7.5 cm and 7.5-15 cm layers of soil, respectively. In the top 7.5 cm of soil, the anaerobically mineralisable N content was greater in 'Advance' pastures (116 kg N/ha) than 'Flecha' pastures (100 kg N/ha) at high fertility, but similar for both pastures at low fertility (Figure 4.9). This difference was not associated with any differences in clover yields which were similar for the two tall fescue cultivars at 453 and 436 kg DM/ha, respectively. Total N, total C and C:N ratio were all low at both soil depths. One reason for this could have been that the total yields were relatively low on this dryland environment compared with the DM yields achieved at high soil fertility by Lambert (1987). This demonstrates that producing more herbage accumulates more C, and the more clover grown accumulates more N due to more N being fixed over the long term. Furthermore, subterranean clover pastures had more total N (0.226%) in the top 7.5 cm of soil than white clover pastures (0.218%) which could have been due to more N being fixed (Lambert, 1987). There was no effect of clover on N and C contents in the 7.5-15 cm layer of soil, which was presumably due to reduced N fixation rates at lower soil depths.

5.5 Practical implications

The results from this study illustrate that sowing 'Advance' tall fescue had the greatest performance in its seventh year of growth under dryland Canterbury conditions in tall fescue/clover swards. This is because it is a summer active cultivar and contained more tall fescue, showed greater weed suppression and yielded more DM than the 'Flecha' tall fescue pastures. 'Flecha' pastures failed to provide greater cool season yields of tall fescue than the continental cultivar after 6 years of growth and contained consistently more weeds than 'Advance' pastures throughout the year.

Subterranean clover pastures consistently yielded more total herbage and clover and less weeds compared with white clover pastures, which resulted in a higher rate of sheep liveweight gain over autumn. Growth of subterranean clover increases after the autumn rains arrive. The earlier the rains come in autumn the higher the annual production and seed set of subterranean clover will be. The greater yield of total clover from subterranean clover compared with white clover pastures will provide more herbage for lactating ewes and assist with lamb growth rates.

‘Denmark’ subterranean clover was more productive and persistent than ‘Campeda’ subterranean clover. This could have been due to its smaller leaf size and prostrate growth habit. ‘Campeda’ subterranean clover was less persistence in these grazed tall fescue pastures, possibly due to its erect growth habit.

Of the pasture mixtures tested in this study, the most suitable mix was ‘Advance’ tall fescue sown with ‘Denmark’ subterranean clover, as this pasture mix was the most persistent and productive after 6 years. Although there was no effect of soil fertility on herbage mass and composition and liveweight gain in the sixth year, there was evidence that high soil fertility would be preferable for that pasture mix. Also in the soil in the ‘Advance’ tall fescue pastures at high fertility contained more mineralisable N and the soil in the subterranean clover pastures at high fertility contained more total N than at low fertility.

To maintain pasture production and quality and achieve target liveweight gains, tall fescue and subterranean clover pastures require the correct grazing management as described in section 2.5.

5.6 Future research

Future research could be made on the botanical composition of pastures between different soil fertility levels, due to the unexpected similarity between the high and low soil fertility treatments and the occasionally greater clover yields in the low fertility treatments. The loss of soil fertility after a few years may not be noticed straight away. However, when signs start to appear, it takes time to build the soil fertility back up to a productive status. This can be seen where there was more anaerobically mineralisable N in the ‘Advance’/high fertility pastures compared with the ‘Advance’/low fertility pastures. However, a study using lower (<8 mg/L) and higher (>18 mg/L) fertility treatments could assist dryland farmers determine whether applying capital fertiliser is necessary when sowing tall fescue/clover pastures.

The nutritive quality of the pastures did not differ between treatments in the autumn. Reasons for why this occurred should be discovered as it is suggesting that the two tall fescue cultivars and clover species have a similar nutritive value as the weeds because there was no difference whenever there was a significantly greater weed yield. Therefore some of these weeds may have beneficial qualities as there was no decline in liveweight gain. However, the fluctuations in CP and ME contents of the pasture over the last 3 years needs to be looked into as it would be expected that the pasture quality would decline with age which would explain the decline in animal performance. Therefore the factors which influence the nutritive values of tall fescue/clover swards also needs to be further examined.

5.7 Conclusions

1. In previous years of this 7 year experiment, it has been shown that sheep liveweight gains were greater in spring than in autumn due to a greater clover content and higher stocking rate.
2. In autumn 2014, sheep liveweight gains per head per day and per hectare were 163% and 175% greater in subterranean clover pastures than in white clover pastures which was associated with a 52% higher clover content which was mostly 60% 'Denmark' subterranean clover.
3. 'Advance' tall fescue swards contained more tall fescue in spring (34%), summer (63%) and autumn (48%) than 'Flecha' swards (15%, 26% and 35%, respectively). However, 'Flecha' swards had a greater total accumulated yield than 'Advance' tall fescue swards due to their greater weed content (49% compared with 34%).
4. Subterranean clover at high fertility provided a greater total herbage yield (6180 kg DM/ha) than white clover at high fertility (6072 kg DM/ha). However, subterranean clover pastures yielded more DM at low fertility (6945 kg DM/ha) than at high fertility, suggesting that the soil fertility levels were not the main regulators of DM yield.

5. Soil fertility had an unexplained interaction with tall fescue cultivar on the anaerobically mineralisable N content causing 16 kg N/ha more mineral N in the ‘Advance’/high fertility pastures (116 kg N/ha) compared with the ‘Flecha’/high fertility pastures (100 kg N/ha) as both pastures produced similar clover yields.
6. Subterranean clover pastures contained greater total N values (0.226%) than white clover pastures (0.218%) in the top 7.5 cm which is likely due to more N being fixed.

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