Grazing Management of Subterranean Clover (*Trifolium subterraneum L.*) in South Island (New Zealand) Summer Dry Pastures

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Serkan Ates

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Grazing management of subterranean clover (*Trifolium subterraneum L.*) in South Island (New Zealand) summer dry pastures

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This study consisted of two sheep grazed dryland pasture experiments. Experiment 1 compared sheep production from 3-year-old cocksfoot based pastures grown in combination with white, Caucasian, subterranean or balansa clover with a ryegrass-white clover pasture and a pure lucerne forage. Sheep liveweight gain per head from each pasture treatment and the pure lucerne stand was recorded in the 2006/07 and 2007/08 seasons. The cocksfoot-subterranean clover pasture provided equal (381 kg LW/ha in 2006) or higher (476 kg LW/ha in 2007) animal production in spring and gave the highest total animal production (646 kg LW/ha) averaged across years of the five grass based pastures. However, total annual liveweight production from lucerne was higher than any grass based pasture mainly due to superior animal production during summer when lucerne provided 42-85% higher animal production than any of the grass based pastures.

In Experiment 2, the effect of stocking rate (8.3 (low) and 13.9 (high) ewes + twin lambs/ha) and time of closing in spring on lamb liveweight gain, pasture production and subterranean clover seedling populations was monitored over 2 years for a dryland cocksfoot-subterranean clover and ryegrass-subterranean clover pasture in Canterbury. In both years, twin lambs grew

faster (g/head/d) in spring at low (327; 385) than high (253; 285) stocking rate but total liveweight gain/ha (kg/ha/d) was greater at high (7.26; 7.91) than low (5.43; 6.38) stocking rate. Ewes also gained 0.5 and 1.5 kg/head at the low stocking rate in 2006 and 2007 respectively but lost 0.2 kg/head in 2006 and gained 0.3 kg/head at high stocking rate in 2007.

Mean subterranean clover seedling populations (per m^2) measured in autumn after grazing treatments in the first spring were similar at both low (2850) and high (2500) stocking rate but declined with later closing dates in spring (3850, 2950, 2100 and 1700 at 2, 4, 6, 8 weeks after first visible flower). Seedling populations measured in autumn after grazing treatments in the second spring were also unaffected by stocking rate (low 1290, high 1190) but declined with later closing dates in spring (1470, 1320 and 940 at 3, 5 and 8 weeks after first flowering, respectively).

The effect of stocking rate and closing dates in spring on pasture and clover production in the following autumn was similar to the effects on seedling numbers in both years. However, clover production in the following spring was unaffected by stocking rate or closing date in the previous year at the relatively high seedling populations generated by the treatments. This was presumably due to runner growth compensating for lower plant populations in pastures that were closed later in spring. Subterranean clover runner growth in spring may not compensate in a similar manner if seedling numbers in autumn fall below $500/m^2$.

Mean annual dry matter production from cocksfoot and ryegrass pastures grown with and without annual clovers pasture production ranged from 6.4 to 12.4 t DM/ha/y but stocking rate (8.3 vs. 13.9 ewes/ha) during spring did not affect annual pasture production. Pastures overdrilled with annual clovers yielded 23-45% more dry matter production than pastures grown without annual clovers.

The study confirms the important role of subterranean clover in improving pasture production and liveweight gains of sheep in dryland cocksfoot and ryegrass pastures. Lowering stocking rate from 13.9 to 8.3 ewes/ha was a less effective method of increasing seed production of subterranean clover in dryland pastures although it did lead to increased liveweight gain per head.

Keywords: cocksfoot, *Dactylis glomerata*, closing date, liveweight gain, *Lolium perenne L., Medicago sativa L,* seedling population, sheep grazing, stocking rate, subterranean clover, *Trifolium repens, Trifolium subterraneum, Trifolium ambiguum L, Trifolium michelianum L.*

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List of Abbreviations

Abbreviation	Description	Units
LTM	long term mean	
PET	potential evapotranspiration	mm
TDR	time domain reflectometry	
LAI	leaf area index	dimensionless
PSWD	potential soil water deficit	mm
R^2	coefficient of determination	
SWC	soil water content	mm
SWD	soil water deficit	mm
T_b	base temperature	°C
T_m	maximum temperature	°C
T_o	optimum temperature	°C
Tt	thermal time	°Cd
SEM	standard error of the mean	
LSD	least significant difference	
SD	standard deviation	
LW	liveweight	kg/head
LWG	liveweight gain	g/head/d
NIRS	near infra-red spectroscopy	
CP	crude protein	g
DM	dry matter	kg/ha
ME	metabolisable energy	MJ/kg
NDF	neutral detergent fibre	%
DMD	dry matter digestibility	%
ADF	acid detergent fibre	%
DOMD	digestible organic matter in dry matter	%
ASW	argentine stem weevil	

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Chapter 1
General Introduction

1.1 Background Information

Pastures containing a mixture of grasses and legumes form the basis of low cost animal production systems in temperate regions of the world (Caradus *et al.*, 1996). Pasture legumes have the ability to fix atmospheric nitrogen (N) through their symbiotic relationship with rhizobia bacteria (McKenzie *et al.*, 1999; Ledgard & Steele, 1992). Nitrogen recycled through the grazed grass-legume system improves grass quality and dry matter production. Also, the seasonality of legume growth complements grass growth and therefore increase the total quality and quantity of herbage produced (Thomas, 1992). Pasture legumes are also forage of high feeding value relative to grasses, reflecting both high nutritive value and intake potential (Waghorn & Clark, 2004). Thus, the ability to sustain a high proportion of legume in the pasture is an important goal in pastoral systems.

Rainfall is one of the most important environmental factors defining the adaptation and distribution of legumes (McGuire, 1985). In New Zealand, the average annual rainfall ranges from about 275 mm in Central Otago to 9000 mm on western faces of the Southern Alps (Daly, 1990). The most commonly sown pasture is a mixture of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) and these are productive in the regions with more than 1200 mm of annual rainfall (Brock & Hay 2001). However, where conditions are summer dry (<800 mm rainfall) both may fail to thrive and lack persistence. For example, Brock (2006) indicated that white clover needs rainfall of 40 mm/month for persistence. Stoloniferous plants, like white clover, that do not retain a tap root throughout their entire life (Thomas, 2003) are consequently susceptible to droughts (Brock & Caradus, 1996). Knowles *et al.* (2003) concluded that white clover is generally not tolerant of drought conditions, with poor post-drought recovery.

About 2.8 M hectares of land or 10.7% of total land area in New Zealand receives less than 800 mm of annual rainfall (Brown & Green, 2003). These areas are consistently prone to dry conditions during summer when potential evapotranspiration is high. The lack of persistence and production of white clover and ryegrass under these conditions may limit sheep performance and farm profitability (Chapter 3; Brown *et al.*, 2006; Mills *et al.*, 2008a), particularly during the crucial early spring period, before the summer dry sets in. Therefore, alternative grass and legume combinations are sought to provide persistent pastures and high quality feed. Practically on-farm, it is particularly important that these species grow in the late winter and early spring period to feed lactating ewes and their lambs, and to ensure that lambs are finished before the onset of summer dry conditions (Grigg *et al.*, 2008).

In these dry environments, annual legumes such as subterranean clover, which avoid summer dry conditions by flowering and producing seed before the onset of drought, may be more productive than white clover (Chapman *et al.*, 1986). Subterranean clover is the most important annual clover species in New Zealand that is adapted to summer dry environments (Smetham, 2003a). It has the ability to grow substantially faster than lucerne and perennial grasses in winter and early spring and is therefore capable, under proper management, of producing more high quality forage in late winter and early spring (Smetham & Jack, 1995; Hyslop *et al.*, 2003; Moot *et al.*, 2003).

However, subterranean clover may require specific grazing management in spring to optimize the trade-off between animal production and the persistence and production of the legume. Specifically. hard grazing throughout spring may maximise livestock production (Reeve & Sharkey, 1980; Lloyd Davies & Southey, 2001; Ates *et al.*, 2006). However, this may limit flowering and seed production due to consumption of runners, flowers and seeds. In turn, this may adversely affect seedling recruitment the following autumn and the amount of clover herbage on offer to lambing ewes in the following spring (Smetham & Dear, 2003; Ates *et al.*, 2006). Conversely, where grazing is lax or animals are removed early in spring to promote flowering, seed production and seedling recruitment may be enhanced. However, this may come at the expense of animal performance.

Most of the research on subterranean clover is based on Australian farming systems. This is often in a Mediterranean type of climate and sometimes with ungrazed (mechanical defoliation) pure swards or as part of cropping rotations (e.g. Hogan, 1972; Dear & Loveland, 1984; Lodge *et al*., 2003; Stockdale, 2005). It is thus difficult to apply some of the research to New Zealand where the climate is more temperate and pastures are grazed mixtures of grasses and legumes, with legume contents ranging from 10% to 80%. Research on subterranean clover in New Zealand has focused on summer dry hill country systems, fertilizer response and cultivar choice for these environments (e.g. Dodd & Orr, 1995; Dodd *et al*., 1995; Hoglund, 1990; Sheath & MacFarlane, 1990; Smetham, 2003a). There remains a need for research on how to fit subterranean clover into dry New Zealand regions. In particular, best management for adequate seed production and consequently successful re-establishment of new seedlings each autumn needs to be defined.

1.2 Research aim and objectives

The aims of this research are (i) to compare pasture and animal performance of dryland sheep pastures that are based on annual or perennial legumes growing with cocksfoot and perennial ryegrass and (ii) to develop grazing management guidelines in spring that optimize stock performance and subterranean clover persistence and production. The research addressed four specific objectives:

1. To quantify the contribution of annual versus perennial legumes to the seasonality and quantity of pasture and livestock production in a dryland cocksfoot pasture.
2. To quantify how stocking rate in spring affects pasture nutritive value, pasture

composition, pasture production and lamb liveweight gain of subterranean clover-cocksfoot dominant pastures.

3. To quantify how stocking rate and closing time in spring affects flowering, seed production, seedling establishment and pasture production of subterranean clover-cocksfoot dominant pastures.
4. To quantify pasture production of cocksfoot and perennial ryegrass based pastures growing with and without annual clovers grazed at two different stocking rates.

1.3 Thesis structure

The thesis consists of seven chapters and the outline of the thesis structure is shown in Figure 1.1. Chapter 2 reviews the literature with particular reference to grazing management effects on subterranean clover. Chapter 3 to 6 are experimental chapters, examining animal production from dryland pastures, lamb liveweight gain, persistence and production of subterranean clover and dryland pasture production. Chapter 7 is a general discussion that draws results together and attempts to provide practical implications to farmers.

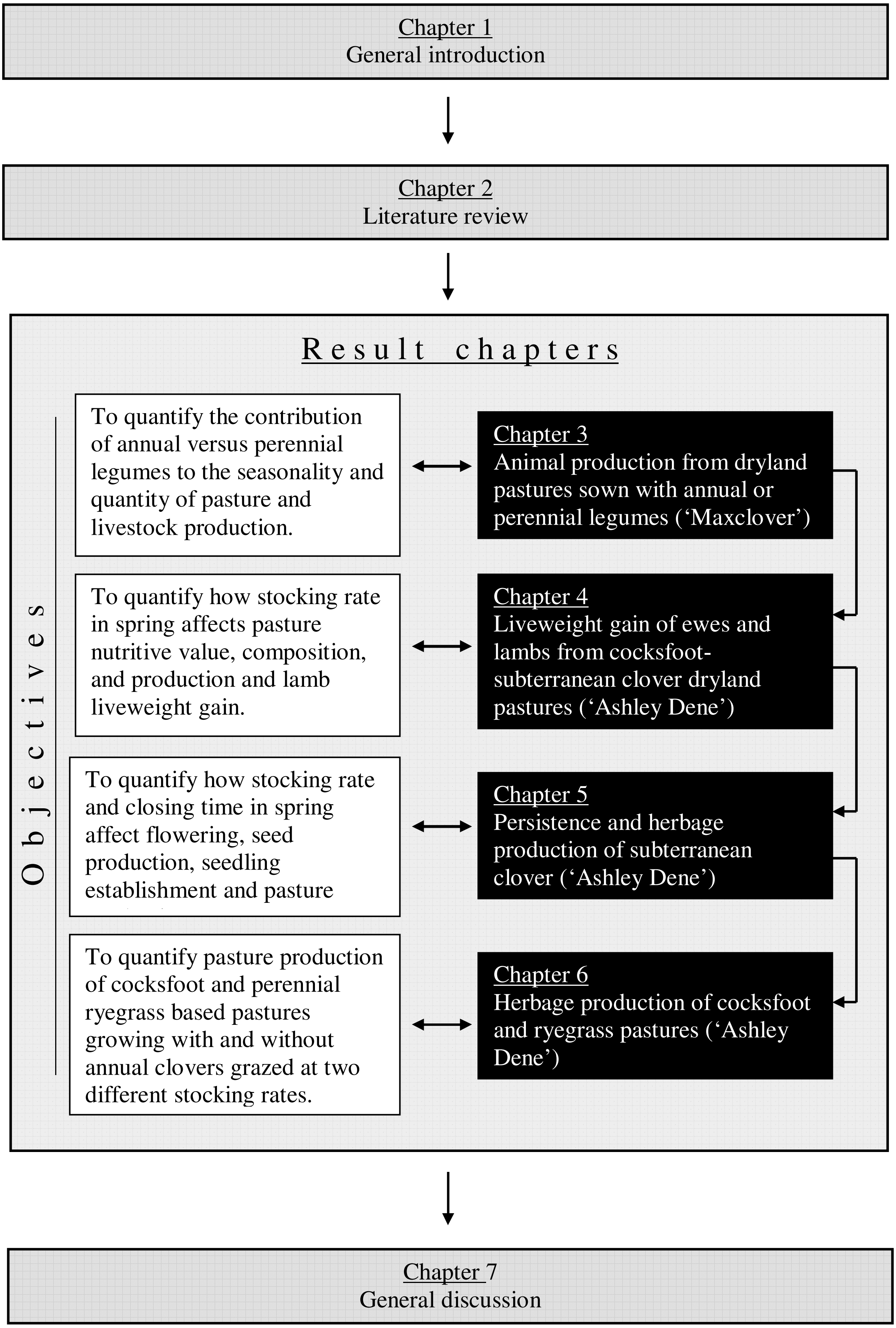

Figure 1.1 Flow diagram of thesis structure

Chapter 2
Literature Review

The following review investigates the ecology and use of subterranean clover in association with grasses in dryland pastures. The review provides general information about the biological, physiological and morphological characteristics and seasonal grazing management requirements of subterranean clover in dryland environments.

2.1 Subterranean clover

2.1.1 General description

Subterranean clover is a cool season active annual legume of Mediterranean origin with a prostrate growth habit. It is also known as subclover and well named due to its characteristic of burying its seeds below ground in burrs (Langer, 1990). Subterranean clover primarily comprises three subspecies which are: *Trifolium subterraneum, sub spp subterraneum, sub spp yanninicum* and *sub spp brachycalycinum.* The former is the most commonly grown species and is best suited to well drained, slightly acid soils (Dear & Sandral, 1997).

There are about 35 registered commercial cultivars of subterranean clover available for farmers but half of those are no longer in widespread use (Dear & Sandral, 1997). Cultivars are typically classified according to variation in flowering and maturation time, concentrations of oestrogenic substance and degree of hardseededness (Smetham, 2003b). Subterranean clover cultivars and strains differ in subtle or distinct morphological characteristics such as leaf shape and markings, presence or absence and prolificacy of hairs on stem and the colour of floret that enable cultivar identification (Dear & Sandral, 1997).

Subterranean clover has a central taproot with many fibrous supporting roots and develops prostrate, non-rooting runners in spring. Subterranean clover leaves are generally heart shaped with some major morphological differences among the subspecies and cultivars (Frame *et al.*, 1998). The inflorescences of plants are not easily visible in taller growth but they are more apparent in grazed pastures. Self fertile flowers are held erect on peduncles arising from leaf axils and consist of three to six florets per head (McGuire, 1985). Following fertilization, the peduncle elongates and bends toward the soil surface as a burr develops around the seed pods. The burrs are then partly or wholly buried in the soil where the seeds mature (Frame *et al.*, 1998).

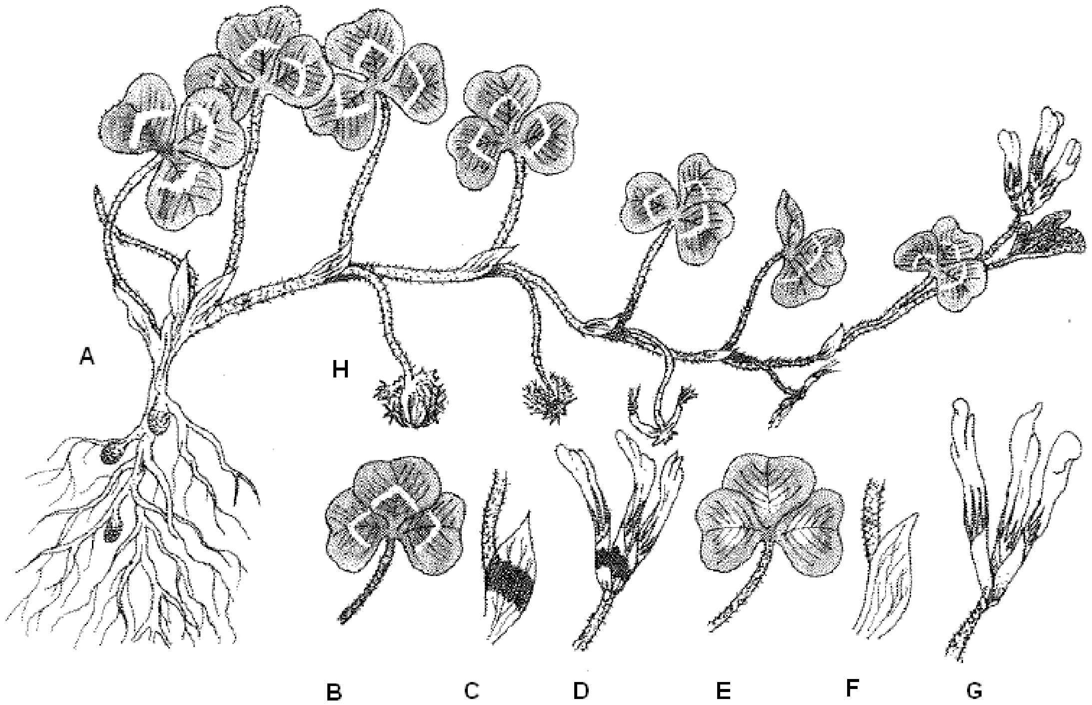

Figure 2.1 Morphology and the characteristics of subterranean clover. A = Growth habit in spring; B, C, D = Leaf, stipule and flower of 'Mt. Barker'; E, F, G = Leaf, stipule and flower of 'Tallarook' H = seedhead (burrs) (McGuire, 1985).

2.1.2 Origin and geographic range

Subterranean clover originates from the Mediterranean region and exists naturally in the countries encircling the Mediterranean sea (e.g. Spain, Italy, Greece, Turkey), the Middle East (e.g. Syria, Israel) and in other areas with marginal Mediterranean climates (e.g.Ethiopia, Afghanistan) (Smetham, 2003b). In the early 1900s, subterranean clover was introduced to

Australia and soon became the most important annual clover in areas of temperate Australia (Gladstones, 1966). In New Zealand, subterranean clover was recognized to the north of Auckland in the early 1900s and initially identified as Mangare clover (Saxby, 1956). Most subterranean clover cultivars have been developed and tested in Australia for pastoral use and soil improvement (Frame *et al.*, 1989).

Subterranean clover is adapted to areas with hot, dry summers and moist winters with annual rainfall of 350-700 mm (Frame *et al.*, 1998) or hill slopes with a sunny aspect and consequently lower effective rainfall (Kemp *et al.*, 2004). It is common in hill pastures on the east coast of both the North and South Islands of New Zealand (Kemp *et al.*, 2004), where it makes a significant contribution to pasture production (Smetham, 2003a). South Africa, the USA and some South American countries including Chile, Uruguay and Argentina also sow subterranean clover commercially (Smetham, 2003b).

2.2 Growth and development of subterranean clover

2.2.1 Germination

Several environmental variables and individual plant characteristics within a species play critical roles in regulating the germination process of subterranean clover. Seedling germination is regulated by a hardseededness mechanism which may promote persistence to plants growing in climatic areas where on occasions there is sufficient summer rain to promote germination but insufficient to sustain seedling growth on into autumn and winter (Smetham, 2003a). Hardseededness is caused by the prevention of water uptake through the seed coat and seeds with a water impermeable seed coat are termed as ‘hard’ seeds. The loss of hardness of the seed is described as ‘seed softening’ (Norman *et al.*, 2002).

The hardseededness mechanism may prevent seedlings from germinating for a period of time varying from weeks to years after maturation (Taylor *et al.*, 1984). This enables subterranean clover to persist in an environment where adequate seed production was not attained or seedlings were lost due to drought or predators (Quinlivan & Nicol, 1971). There are differences among subterranean clover cultivars in hardseededness. Quinlivan and Millington (1962) reported that 97% of the seed produced by 'Geraldton' subterranean clover was hardseeded in early summer while 'Mount Barker' produced only 60% hard seed in Western Australia.

Diurnal temperature variation may cause alternate expansion and contraction of the tissues, breaking hard seed coats and allowing water to enter the seed (Quinlivan, 1961). Blumenthal and Ison (1994) also noted that hot fluctuating temperatures within the range of 15 to 60 ^{o}C at the soil surface were more effective in breaking hardseededness than were constant temperatures in the field. Thus, removal of dry residues through hard summer grazing before the initiation of autumn rains increases the temperature fluctuations near the soil surface which in turn aids adequate seedling germination and early seedling vigour in mixed pastures (Leigh *et al*., 1995).

Another important characteristic of subterranean clover seed is the embryo dormancy that is governed by temperature, inhibitory substances in the seed coat and carbon dioxide. Unlike hardseededness, embryo dormancy is not influenced by the seed coat permeability (Kendall & Stringer, 1985). Quinlivan and Nicol (1971) reported that embryo dormancy of subterranean clover is broken primarily by hot temperatures during summer under field conditions or in the laboratory by temperature treatments. Temperatures in the range of 40 to 60 ^{o}C for at least 5 weeks or 3 to 11 ^{o}C for 3 days are reported to be effective for breaking embryo dormancy (Kendall & Stringer, 1985).

Germination is also dependant on a combination of adequate soil moisture and favorable temperatures. In areas of New Zealand where subterranean clover grows, the onset of germinating autumn rains is quite erratic and may range from January to May (Moot *et al.,* 2003). Young *et al.*, (1970) reported that subterranean clover cultivars show variations in germination with soil matric potential. They also found that the germination of subterranean clover in relation to matric potential was dependent on the texture of the soil substrate. Germination terminated or was close to zero at -0.6, -0.8, and -0.12 MPa, respectively, on sand, loam, and clay substrates.

Temperature is an important factor in defining the time and the rate of germination of clover seeds when water and nutrients are non-limiting (McKenzie *et al.*, 1999; Hampton *et al.*, 1987). Subterranean clover seeds show a distinct germination response to temperature. McWilliam *et al.* (1970) reported that germination of 'Woogenellup' was at a maximum at 15 ^{o}C but reduced dramatically as temperature rose from 20 to 30^{o}C. There is also a great variation in optimum germination temperature among subterranean clover cultivars. Hampton *et al.* (1987) reported that germination of 'Mt Barker' was reduced at 20 ^{o}C, whereas the germination of 'Woogenellup' was depressed at 5 ^{o}C, when tested at constant temperatures of 5, 10, 15, 20 ^{o}C and a fluctuating temperature of 5/10 ^{o}C.

In a more detailed analysis, Moot *et al.* (2000) measured the thermal time requirements for germination of temperate herbage species using a linear model of development rate against temperature. Thermal time requirements of subterranean clover for germination and emergence were measured as 45 ^{o}Cd and 120 ^{o}Cd respectively, while these values were 45 ^{o}Cd and 150 ^{o}Cd, respectively, for white clover.

2.2.2 Seedling growth

The morphological development pattern of subterranean clover at the early seedling stage (heterotrophic) is similar to other clover species (Thomas, 2003). Seed germinates and produces two large fleshy cotyledons and a strong radicle (Frame *et al.*, 1998). After germination, the seedling rapidly grows a central taproot, with 1-20 prostrate, non-rooting runners developing from the taproot in mid winter, depending on the level of competition from surrounding vegetation (Smetham, 2003a).

Seedlings at the early growth stage are dependant on their cotyledons for their source of energy to sustain their growth (Kendall & Stringer, 1985). Taylor (1972) reported that larger seeds of subterranean clover give higher early growth rates and this provides an advantage to the plant at the establishment phase. Similarly, Silsbury and Hancock (1990) reported that 'Clare' with a mean seed weight of 12.2 mg had 57 mm^2 of cotyledon area, whereas 'Geraldton' with a mean seed weight of 5.3 mg had only 20 mm^2 14 days after planting. They noted that the swards established from large seeds of 'Clare' grew faster than the swards established from the smaller seeds of 'Geraldton' at a period of 60 days.

Inter- and intra-species competition also play a key role in determining the seedling growth rates during establishment (Donald, 1954; Dear & Cocks, 1997). In early work with subterranean clover, Donald (1954) showed that at lower plant populations ($12.5/m^2$) the dry matter yield of individual 'Mt Barker' plants was 31 g/plant compared with the 0.04 g/plant at higher plant populations ($18725/m^2$) in a period from mid-April to December. Similarly, in a study with a range of subterranean clover plant populations (1000, 2000 and $4000/m^2$), Silsbury and Fukai (1977) obtained the highest sward growth rates at the lowest population. They noted that the recorded maximum growth rates of 10-15 g DM/m^2 decreased with an increase in population and the effect of sowing rate on the growth rate was persistent throughout the whole season from May to December in Australia. Dear and Cocks (1997) showed the impact of competition with perennials on subterranean clover at early seedling growth. They noted that seedling weights of subterranean clover were reduced severely when grown with lucerne (0.56 mg/plant) or phalaris (0.99 mg/plant) compared with pure subterranean clover stands (2.02 mg/plant) soon after emergence.

Physiologically, temperature is an important factor that affects the potential growth and development of subterranean clover (McWilliam *et al.*, 1970). Moot *et al.* (2003) calculated the thermal time to quantify the important stages in the seedling development using a base temperature of 0 ^{o}C. The appearance of first trifoliate leaf was estimated at 230 ± 20.0 ^{o}Cd for several subterranean clovers, compared with 309 ± 10.0 ^{o}Cd for 'Grasslands Demand' white clover. They calculated the phyllochron (^{o}Cd/leaf) for main stem leaves of subterranean clover as 68 ± 6.5 ^{o}Cd compared with 89 ± 5.4 ^{o}Cd for the main stem leaves of white clover, and therefore subterranean clover has potential for faster inital growth rates than white clover.

2.2.3 Reproductive development

The reproductive phase of the subterranean clover life cycle commences with the initiation of flowering in winter and terminates with the seed production (Kendall & Stringer, 1985; Aitken, 1955). The time of flowering is determined by the amount of cold required to commence flower initiation and then occurs as a response to photoperiod and/or temperatures (Aitken, 1955). There is a wide range in the time of flowering among subterranean clover cultivars (Dear & Sandral, 1997).

Early flowering ecotypes require little cold requirement for vernalization and therefore flower in early spring, while late flowering ecotypes need exposure to temperatures below 10 ^{o}C for 6-10 weeks before initiation occurs. Therefore, they do not commence flowering until early summer (Smetham, 2003b). In New Zealand, early flowering cultivars such as 'Dalkeith' and 'Seaton Park' start flowering as early as mid September while late flowering cultivars such as 'Denmark' and 'Leura' commence flowering in mid to late October (Table 2.1, Widdup & Pennell, 2000). Sheath and MacFarlane (1990) noted that the optimum flowering time in New Zealand to obtain maximum seed and seedling numbers is late October to early November so that subterranean clover can produce and mature a sufficient amount of seed for persistence before the onset of summer drought.

Table 2.1 Flowering time, plant morphology and year of release of some Australian bred subterranean clover cultivars, planted at Templeton, Canterbury in New Zealand (Widdup & Pennell, 2000).

Cultivars	Year of release	Subspecies	Flowering time*	Plant morphology**
'Dalkeith'	1983	*subterraneum*	Early 13 Sept	2.0
'Seaton Park'	1967	*subterraneum*	Early 24 Sept	1.75
'Trikkala'	1976	*yanninicum*	Early 26 Sept	2.5
'Gosse'	1992	*yanninicum*	Mid 8 Oct	2.25
'Junee'	1984	*subterraneum*	Mid 10 Oct	3.0
'Woogenellup'	1960	*subterraneum*	Mid 10 Oct	1.75
'Clare'	1955	*brachycalycinum*	Mid 10 Oct	1.5
'Mt Barker'	1920	*subterraneum*	Mid-late 12 Oct	2.75
'Goulburn'	1991	*subterraneum*	Mid-late 12 Oct	3.75
'Karridale'	1984	*subterraneum*	Mid-late 14 Oct	2.5
'Nangeela'	1930	*subterraneum*	Late 16 Oct	2.5
'Denmark'	1991	*subterraneum*	Late 16 Oct	3.5
'Larisa'	1970	*yanninicum*	Late 20 Oct	2.5
'Leura'	1991	*subterraneum*	Late 23 Oct	3.25
'Tallarook'	1930	*subterraneum*	Late 26 Oct	3.75

*Date of flowering at Templeton in Canterbury in 1993
**1=open large leaved, 5= dense small leaved

Subterranean clover generally buries its seeds below ground which provides protection against ingestion by grazing animals (McGuire, 1985). The inflorescence contains 3-6 fertile and a number of sterile flowers. After self pollination, the peduncle bends over and grows towards the soil by which time the sterile flowers have formed a network of barbs which anchor the whole structure, called a burr, below the soil surface (McGuire, 1985). Subterranean clover seeds are among the largest of the common forage legumes and 1000-seed weights range between 6.7 to 8 g (Frame *et al.*, 1998). Buried burrs are also larger than those left on the soil surface, contain more and larger seed which have superior viability, and tend to produce more hardseed (Frame *et al.*, 1998). In contrast the burrs that are not buried generally produce fewer and smaller seeds with lower viability (Taylor, 1976).

2.3 Productivity

2.3.1 Herbage production

Considerable variation exists in the herbage and seed production of subterranean clover pastures. Factors such as environmental conditions, cultivars, sward conditions and grazing management play a critical role in DM yields and seasonal production of subterranean clover. Mills *et al*. (2008b) reported that subterranean clover averaged approximately 3.7 t DM/ha/y herbage in combination with cocksfoot where total pasture production was 9.9-12.9 t DM/ha/y over a five year period in Canterbury. Average annual DM production of Caucasian, white or balansa clover when sown with cocksfoot in the same experiment were 1.1, 1.9, 2.0 t DM/ha/y, respectively. Smetham and Jack (1995) recorded approximately 5000 kg DM/ha annual herbage production from hard grazed pure subterranean clover swards in Canterbury. In a study with winter annual clovers in Hastings, North Island, Hyslop *et al*. (2003) reported that Persian (*Trifolium resupinatum*), subterranean and balansa clovers were highly preferred by grazing sheep and total ungrazed subterranean clover production was over 6000 kg DM /ha between early April and late October. White and Meijer (1978) reported that a laxly grazed pure 'Woogenellup' sward produced over 6000 kg DM/ha on hill country in Canterbury.

2.3.1.1 Time of germination

The total herbage production of subterranean clover during autumn is strongly related to the timing of emergence and size of the seedling population. Early germination of subterranean clover in autumn provides a quick establishment of leaf area, leading to greater production before the initiation of cooler and shorter days (Moot *et al*., 2003).

A field study at Lincoln University, Canterbury showed that in a pure sward, subterranean clover that emerged on 7 March produced 44 kg DM/ha/d for 158 days, yielding approximately 7000 kg DM/ha by mid-September. In contrast, subterranean clover that emerged on 7 May produced 15 kg DM/ha/day for 120 days to yield only 1800 kg DM/ha by mid September (Moot *et al*., 2003). Similar results were reported by Dear and Loveland (1984) in Australia, where total annual dry matter production of subterranean clover ranged from 10.3 t DM/ha when sown in early March to 3.2 t DM/ha when sown in early May. They reported that seasonal production of swards was strongly influenced by sowing time and stated that if germination did not occur until mid April, autumn production was penalized severely and growth during winter was reduced in a cool tableland environment in south eastern Australia.

2.3.1.2 Seedling population

Seedling populations of greater than 1000 established plants/m^2 in autumn are considered an 'agronomically successful' establishment in a pure subterranean clover sward and necessary for highest winter and spring herbage production (Silsbury & Fukai, 1977; Smetham, 2003b). Smetham and Jack (1995) reported a strong relationship of r^2=0.75 between DM production and seedling numbers in autumn in pure swards. They recorded the greatest total annual DM production of 4100-5200 kg DM/ha from the seedling populations above 1700/m^2, while the lowest DM production of 942 kg DM/ha was obtained at a seedling population of 310/m^2 from May to November in New Zealand. However the increase in seedling population up to a maximum of 6130/m^2 did not cause any further increase in total annual DM production. In another study, Rue *et al*. (1997) reported that increasing subterranean clover population from 460 to 4600 m^2 increased herbage production from 885 to 3628 kg DM/ha in pure swards over a 60 day growth period in Australia.

Prioul and Silsbury (1982) reported that higher subterranean clover populations in pure swards had the highest growth rate soon after emergence but the relative importance of plant population declined as the season progressed. Low population subterranean clover communities showed an increasing crop growth rate during the season so that final yields were similar for pure swards of 428 and 4760 plants/m^2. This was mainly attributed to longer petioles, smaller leaf area and less dry weight for individual leaf blades and less branching of plants at high population.

2.3.1.3 Flowering time

In New Zealand, total pasture production of subterranean clover-grass pastures is closely related to spring rainfall (Smetham, 2003b). Subterranean clover produces most of its herbage yield in early and mid-spring and potential yield is particularly affected by flowering time of the cultivar (Scott, 1969; Widdup & Pennell, 2000). Widdup and Pennell (2000) recorded a linear increase of herbage production from 2580 kg DM/ha for early ('Dalkeith') to 7660 kg DM/ha for late ('Nangeela') flowering cultivars in Canterbury from June to November. Early flowering cultivars (e.g. 'Seaton Park' and 'Dalkeith') with high seed yields and larger hard seed contents may be able to maintain larger soil seed reserves, which would improve long-term persistence and give greater autumn-winter production due to high plant populations than late flowering cultivars. Early flowering cultivars yield less than late flowering cultivars but improve the reliability of seed set of clover pastures, particularly in years when the growing season finishes before later mid-season cultivars can set sufficient seed (Silsbury & Fukai, 1977).

Scott (1969) reported that later flowering subterranean clover cultivars (e.g. 'Denmark' and 'Leura') always produce greater herbage production if soil moisture is present. Within subterranean clover pastures, sowing cultivars together in mixtures that differ in flowering time may be useful in exploiting and coping with variable spring rainfall. For example, early flowering cultivars exploit winter rainfall and ensure high quality feed. If later spring rainfall occurs, late flowering cultivars would be well placed to exploit this prior to the onset of flowering and subsequent death (Dear & Sandral, 1997).

2.3.2 Seed production

Smetham (2003b) calculated that for an agronomically successful establishment (1000 plant/m^2) of subterranean clover in a pure sward, without the consideration of hardseededness, the minimum amount of seed that needs to be set was 336 kg/ha for early, 288 kg/ha for mid and 218 kg/ha for late flowering cultivars. Dear and Sandral (1997) reported that a pure stand of subterranean clover can potentially produce 1500 kg/ha seed under ideal growing conditions. McGuire (1985) measured typical seed production of subterranean clover which ranged from 500 to 1000 kg/ha with a yield potential up to 2000 kg/ha.

Dear and Loveland (1984) measured the seed production of four subterranean clover cultivars. They found that early flowering cultivars had greater seed yields in a cool tableland environment in Australia where the seed yield ranged from 290 kg/ha for a 'Mount Barker' sward to 1203 kg/ha for a 'Seaton Park' sward. Francis and Gladstone (1974) found that seed production of 24 subterranean clover cultivars ranged between 490 and 1340 kg/ha. Seed yield was not related to time or duration of flowering but positively correlated with the rate of inflorescence production, number of inflorescences, burr and seed numbers and seed size.

Scott (1969) reported that 'Geraldton' had the highest seed yields, whereas 'Woogenellup' and mid season flowering subspecies 'Clare' produced over 500 kg/ha in North Canterbury. Smetham (1980) reported that in North Canterbury hill country, 'Seaton Park' had the greatest seed yield but early flowering 'Geraldton', 'Northam A' and 'Woogenellup' all produced 130-450 kg/ha seed. Widdup and Pennell (2000) evaluated the suitability of mid to late flowering subterranean clover lines in Canterbury. They reported that mid season flowering 'Junee', late-mid season flowering 'Goulburn' and 'Karridale' produced large amounts of seed ranging from 350 to 600 kg/ha and they suggested that late flowering small leaved and densely branched types were best adapted to the Canterbury environment.

2.4 Grazing management of subterranean clover

Pastures containing subterranean clover as the main legume component need to be managed carefully in spring and autumn, in particular, to ensure the persistence and production of the subterranean clover. Seasonal grazing management objectives must include adequate seed production in spring, and a successful re-establishment in autumn.

2.4.1 Summer ‘clean up’ and autumn grazing management

Autumn is a critical season for subterranean clover in terms of re-establishment of the annual plant population. Establishing seedlings in mixed swards are generally subjected to competition for moisture, light and nutrients from the perennial grass component of permanent pastures. Theferore, grazing management should aim to minimise such competition to ensure successful re-establishment of newly geminating subterranean clover seedlings (Dear & Cocks, 1997). In addition, dry plant residues need to be removed over summer to assist in the breakdown of hard seed and reduce shading on emerging seedlings after autumn rains (Leigh *et al.*, 1995). The blanketing effect of dry plant residues can be eliminated by either topworking subterranean clover-grass pastures using grubber, discs or heavy harrows in mid summer (Calder, 1954) or by hard “clean up” grazings in summer and autumn (Smetham, 2003a). However, special attention must be paid during the summer grazing period to avoid excessive consumption of subterranean clover burrs. The fraction of large subterranean clover seeds that survive through the animal digestive track is as low as 1% (de Koning, 1990).

Subterranean clover sward production in spring is reliant on the succesful establishment of adequate seedling populations in autumn. Grazing management, therefore, has an important impact on the survival of clover seedlings and the achievement of the target of 1000 seedlings/m^2 (Smetham, 2003b). Spelling subterranean clover paddocks during germination in autumn with appropriate management is crucial to obtain successful establishment (Smetham, 2003a). The general grazing management practice recommended to farmers on subterranean clover pastures in autumn is not to graze subterranean clover seedlings until the plant has 4-6 trifoliate leaves (Costello & Costello, 2003; Grigg *et al*., 2008).

Moot *et al*., (2003) also reported that subterranean clover pastures should be spelled until the seedlings are pulled down into the ground and sufficiently developed to survive grazing. Moot *et al*. (2003) quantified that the time for seedlings to produce 6 leaves was 434 ^{o}Cd. They observed minimal seedling failure at the six-leaf stage and proposed that root and shoot growth were adequate to sustain grazing (Table 2.2). However, in wet autumn seasons, it may also be necessary to graze the pasture to prevent subterranean clover seedlings being smothered by competitive grasses, in which case the subterranean clover gets little chance to re-establish (Costello & Costello, 2003).

Table 2.2 Chronological time (days) to safe grazing of subterranean clover at several New Zealand sites with varying dates of opening autumn rains (Moot *et al*., 2003). Based on thermal time requirement of 434 ^{o}Cd.

Location	Time of opening rain			
	February 1	March 1	April 1	May 1
Lincoln	26	29	37	53
Alexandra	26	30	46	102
Blenheim	25	27	34	47
Napier	23	25	30	39

2.4.2 Spring grazing management

2.4.2.1 General issues

Subterranean clover production is highest in spring, and therefore their contribution to animal production in dryland systems is greatest in that season. Grigg *et al*. (2008) reported, in an on-farm study, that the number of prime lamb sales was positively related to the amount of subterranean clover in the sward in spring. However, pastures based on subterranean clover are potentially unstable and year to year variation is quite common depending on the success of re-establishment and spring rainfall (Costello & Costello, 2003).

Also of note is that flowering of subterranean clover occurs with the main flush of herbage production of the species in spring and coincides with high feed demand from lactating ewes. This situation represents a challenge for farmers of how to effectively manage their pastures to achieve the conflicting objectives of seed production and livestock performances (Smetham, 2003a). Building up a large seed bank increases the resilience of subterranean clover based pastures in this environment. Therefore grazing in spring should be optimized for both satisfactory animal performance and seed production.

During moist spring conditions, experienced farmers recommend set stocking of subterranean clover dominant pastures so that a herbage mass of 2000 kg DM/ha is maintained to ensure adequate seed production (Costello & Costello, 2003). However, when spring rainfall is less than average, ewes and lambs may rapidly reduce herbage mass to less than 1400 kg DM/ha and differential grazing of paddocks may then be necessary. Grazing intensity can then be increased to sacrifice subterranean clover seed production in paddocks known to have high seed reserves while it may be possible to graze newly establish pastures less intensively so that moderate seed production of subterranean clover is achieved (Smetham, 2003b; Ates *et al.*, 2006). Although this is a common practice on dryland farms where subterranean clover is the main legume species of the pastures (Grigg *et al.*, 2008), decisions for differential managements of paddocks to protect annual clovers are not well supported by quantified data in New Zealand. Thus, this study aims to develop an understanding on how to graze subterranean clover pastures in a sustainable manner in dryland farms.

2.4.2.2 Grazing pressure/intensity of grazing

McGuire (1985) reported that subterranean clover develops, produces and regenerates successfully with at least moderate grazing pressure and utilization. During the vegetative growth in spring the effect of grazing may be mainly to remove the leaves with little damage to shoot apices because of the prostrate growth form of subterranean clover (Collins & Aitken, 1970). Rossiter (1961) reported that defoliation during vegetative growth up to first flower appearance generally increased seed production by up to 30% in a pure subterranean clover sward. However, grazing or defoliation after first flower appearance and during the flowering period (Rossiter, 1961; Collins, 1978; Collins *et al.*, 1983) decreased the seed yield even though grazing or cutting was adjusted to avoid removal of flowers.

Smetham and Dear (2003) showed that continuous grazing to a LAI of 0.6 (1400 kg DM/ha) and LAI of 1.0 (1600 kg DM/ha) or ungrazed with a leaf area index (LAI) of 4.6 resulted in a significant difference in seed production of pure subterranean clover pastures. The seed yields of swards in the study were recorded at 70, 320 and 1250 kg/ha, respectively. They suggested that continuous grazing during flowering and seed maturation should be controlled to leave at least 1600 kg DM/ha of residual herbage mass. This was equivalent to an LAI of 1.0, for adequate seed to be produced and ensure the establishment of a high producing sward in the following growing season.

Fukai and Silsbury (1976) found that intermittent grazing at a LAI of 2.7-3.4 in winter, early and late spring did not affect the seed yield except for 'Clare' which had 50% lower seed production. Young *et al.* (1994) reported a similar result with rotational grazing at 21-52 day intervals during flowering and up to pod formation that reduced seed yield by up to 50%. Similarly, in a grazing study from Oregon, the USA, Steiner and Grabe (1986) reported that optimum grazing period for highest seed production of subterranean clover is from just prior to the start of flowering until the time of early burr fill.

Carter and Lake (1985) investigated the effect of five stocking rates (7.4, 12.4, 14.8, 17.3, 22.2 sheep/ha) on subterranean clover seed production in an annual ryegrass-subterranean clover pasture in a five year experiment at the Waite Institute, Southern Australia. They reported that increasing stocking rate from 7.4 to 22.2 ewes/ha decreased both hard (399 vs. 49 seeds/m^2) and total seed (516 vs. 73 seeds/m^2) reserves of subterranean clover. However, de Koning (1990) found no effect of stocking rate (7, 11, 15 sheep/ha) on the seed yield of five subterranean clover cultivars in an experiment conducted at the Waite Institute, Southern Australia, but high stocking rate reduced the seed size due to stress of grazing on seed development or large burrs being eaten by sheep.

In another experiment, Stockdale (2005) reported the effect of two heights of defoliation, (2.8 and 7.0 cm) and four intervals of harvest (4, 6, 9 and 12 weeks) at each height of defoliation on productivity of a subterranean clover sward (predominantly 'Trikkala'), with particular emphasis on flowering and seed production. The total herbage production ranged from 5.7 to 8.7 t DM/ha, with variations in response due to both height and frequency of defoliation. Harvested yield increased from 6.2 to 7.4 t DM/ha as the interval between harvests was extended, and plots harvested to 2.8 cm above ground level yielded more (7.7 t DM/ha) than those harvested to 7.0 cm (6.0 t DM/ha). Seed production increased as the interval between harvests increased, and was heaviest at the higher defoliation height. However, nutritive characteristics (DM digestibility, crude protein, neutral detergent fibre) of harvested herbage were similar in all treatments throughout the year.

2.4.2.3 Grazing method

Several studies have compared the effects of grazing management on the productivity of subterranean clover and animal performance. Sheath and Hodgson (1989) reported that set stocking prior to and during flowering periods, enables the development of a stable grazing height, to which the subterranean clover plants adapt. In contrast, rotational grazing encourages elevation of the flowers into the subsequent grazing zone. Frame *et al*. (1998) reported that subterranean clover cultivars with prostrate growth habit are more suited to continuous grazing by sheep, while the upright cultivars are well suited to rotational grazing.

Grazing management until commencement of flowering may also influence the potential number of growing points available during the subsequent phases, determining the potential sites for leaf growth, flowers, burrs and subsequent seed production, since flowers develop from buds in the leaf axils (Collins & Aitken, 1970).

In a grazing management study on phalaris-subterranean clover based pastures in Australia (Chapman *et al.*, 2003), subterranean clover herbage production in spring was restricted under rotational grazing compared with set stocking over the five years. Rotational grazing resulted in significantly higher phalaris herbage production than set stocking (mean 3680 vs. 2120 kg DM kg/ha) but significantly lower subterranean clover herbage production (1440 vs. 2490 DM kg/ha). Rotational grazing supported higher stocking rates than set stocking treatments at higher P fertilization rate (mean 14.9 vs. 13.7 ewes/ha) but decreased pasture feeding value due to the lower legume content under rotational grazing.

In a study at Whatawhata on a steep hill country with 1600 mm of a low effective rainfall in New Zealand, the mid-season 'Howard' and the late mid-season 'Mt Barker' and late flowering 'Tallarook' produced nearly 200 seedlings/m^2 under continuous close grazing management. However, under rotational grazing early mid-season 'Woogenellup' and 'Clare' and late flowering 'Nangeela' and 'Larissa' mostly exceeded the optimum number of plants/m^2 for hill country (200 seedlings/m^2) and produced more herbage than 'Mt Barker' and 'Tallarook' (Sheath & Macfarlane, 1990).

2.5 Feeding and nutritive value

The feeding value of a pasture is a key determinant of the performance of stock (Cosgrove & Edwards, 2007). Waghorn and Clark (2004) defined feeding value as a function of intake and nutritive value. A high legume composition in the pasture is viewed as being a strong indicator of high pasture feeding value as legumes generally have higher intake and nutritive value than grasses (Waghorn & Clark, 2004). Furthermore, an increased growth of pasture legumes may also improve the nutritive value and preference of grasses. For example, sheep show a low preference for herbage of low N content relative to grass of high N content (Edwards *et al*., 1993). Thus, any improvement in the N content of grasses by transfer of N from legumes that have reached a high abundance in the pasture may increase preference. This may be particularly the case for pastures based on cocksfoot which often have a low N concentration (Turner *et al*., 2006).

2.5.1 Plant maturity

In dryland pastures, there are often marked changes in nutritive value over the spring summer period reflecting plant maturity, and the onset of reproductive development. For example, Walsh and Birrell (1987) reported that the nutritive value (CP, DMD) of subterranean clover along with phalaris and perennial ryegrass decreased towards summer, with an accelerating rate after flowering in a grazed pasture where subterranean clover was 20% of the pasture in Australia. Although subterranean clover had lower dry matter digestibility (72-75%) and crude protein (23-26%) than phalaris and perennial ryegrass, it retained its digestibility 4-6 weeks longer than the grass species in the experiment. Mulholland *et al.* (1996) reported a similar effect of plant maturity on the nutritive value of subterranean clover. They found that during the vegetative and early flowering stages, the concentration of effective rumen degradable protein exceeded the supply of fermentable metabolisable energy required for microbial protein synthesis, while in mature clover (at the end of flowering) the concentration of effective rumen degradable protein was low and limiting microbial protein synthesis.

2.5.2 Plant parts

Differences in plant maturity may reflect changes in the relative proportion of leaf, stem and petioles throughout spring, although there is conflicting evidence on the nutritive value of different plant parts of subterranean clover, probably owing to different sampling techniques and/or management factors (grazing or cutting). Several authors (e.g. Stockdale, 1992;

Mulholland *et al*., 1996) reported that the DMD and water soluble carbohydrate concentration of the stem and the petiole fraction of subterranean clover plants were greater than those of the leaf fraction even though the leaf had a higher lignin content in the cell wall. However, Ru (1996) reported that leaves of subterranean clover ('Dinninup', 'Seaton Park' and 'Mount Barker') were more digestible than stems under different grazing intensities in both pure and mixed swards and dry matter digestibility of leaf and the whole plants decreased with an increase in grazing intensity.

In a more recent study, Ru and Fortune (2000a) evaluated the variation in the nutritive value of plant parts with 26 subterranean clover cultivars at different physiological stage during spring and under 2 different grazing intensities. They found that the leaves of 26 cultivars had higher nitrogen concentration (4.78-5.21%) than the stems (2.72-3.36) and the petioles (2.41-2.74%) and a similar DMD (73.2-75.9%) with the stems (73.0-75.5%) and petioles (73.8-76.8%) at the same vegetative stage. The DMD of leaves remained similar after the cessation of flowering (68.3-70.8%). However, the DMD of stems (57.7-59.7%) and the petioles (60.8-65.6) declined significantly compared with the vegetative stages of the plants.

2.5.3 Stocking rate effect

Ru and Fortune (2000b) also showed grazing intensity influenced nutritive value of subterranean clover and interacted with cultivar maturity. Heavy grazing depressed DMD by 5% in October for early maturity cultivars but increased DMD by 3% in September for mid maturity cultivars in Australia. The influence of grazing intensity on nitrogen content was small. Heavy grazing did not affect acid detergent fibre (ADF) for the early maturity group, but depressed it for the mid maturity group throughout the season. Acid detergent lignin remained comparable for all cultivars during the season. Mineral content of subterranean clover showed variable response to grazing treatments.

2.6 Animal performance

Animal performance on subterranean clover based dryland pastures in spring often exceeds that of other pasture mixtures. Mills *et al.* (2008a) reported that cocksfoot-subterranean clover pastures gave the highest sheep liveweight production in spring (approximately 400-700 kg/ha) when compared with other binary mixtures of clover species (Caucasian, white and balansa clovers) with cocksfoot or with ryegrass-white clover pastures in a five year study in Canterbury. This was mainly attributed to the superior spring growth of subterranean clover. These results were consistent with the earlier findings, reported by Brown *et al.* (2006) from the same experiment. However, while these studies measured liveweight gain over the entire spring period, they did not measure liveweight gain within a season and no attempt was made to match performance to changes in pasture quality.

High lamb liveweight gains from subterranean clover based pastures have also been reported in other parts of New Zealand. Muir *et al.* (2000) obtained high lamb growth rates of 343 and 292 g/head/d for single and twin lambs respectively from birth to 15 weeks of age from ryegrass-subterranean clover based pastures in Hawke's Bay, where they evaluated the relative importance of pasture and milk for lamb growth during lactation under a high performance lamb production system. Similarly, in another study in Hawke's Bay, Muir *et al.* (2003) reported average lamb growth rates of 437, 407 and 380 g/head/day with single, twin and triplet lambs, respectively from birth to 12 weeks of age from a pasture where the main legumes were subterranean and white clover.

There is evidence that stocking rate in spring may be a key determinant of livestock performance in pastures where subterranean clover is the main legume. In a continuous grazing experiment on a dryland tall fescue (*Festuca arundinacea* L.)-subterranean clover pasture in Canterbury, twin lambs grew at 374 g/day at 10 ewes/ha and 307 g/day at 20 ewes/ha (Ates *et al.*, 2006). However, lamb liveweight gain/ha over the entire 46 day grazing period was greater at high (12.3 kg/ha/d) than low (7.5 kg/ha/d) stocking rate. Of note was that these high lamb growth rates occurred in a dry spring from sparse (30% cover) tall fescue pastures. They concluded that the high performance was due to sheep selectively grazing the subterranean clover to the detriment of future production. Seed production and seedling numbers in the subsequent spring were found to be inadequate at both high (285 seedlings/m^2) and low (223 seedlings/m^2) stocking rates.

In another study, Sharrow and Krueger (1979) compared the effect of continuous and rotational grazing on sheep performance from improved hill pastures that consisted of subterranean clover as the sole clover component in the U.S.A. They noted that final liveweights of lambs were 10% higher under rotational (35 kg/head) compared with (31 kg/head) continuous grazing in spring (May-July), due to an observed increase in subterranean clover, in diets of sheep grazing rotationally. Sharrow and Kruger (1979) suggested that rotational grazing can be effective in increasing forage available to livestock and improving animal performance during spring, when plants are actively growing.

Waller *et al.* (2001) studied the effects of tactical rotational and continuous stocking in perennial ryegrass-subterranean clover pastures on sheep liveweight gain in south-west Victoria, Australia. They found the live weights of the ewes were similar across all treatments during autumn and winter but tactically stocked ewes were 3-6 kg lighter than continuously stocked ewes during spring and summer. The lower liveweight was attributed to the lower herbage quality on the rotationally stocked pastures in spring. Herbage production was reported as similar between the treatments but tactical stocking increased herbage mass during the growing season compared with continuous stocking (500-900 kg DM/ha higher). Both DMD and CP concentration were about 4% lower with rotational stocking in spring. This lower quality was associated with the higher herbage mass on the tactically stocked pastures which presumably had a higher stem: leaf ratio and showed reproductive growth earlier than the continuously stocked pastures.

2.7 Coexistence of subterranean clover

2.7.1 Coexistence with other legumes

Subterranean clover is one of a suite of legumes growing in dryland pastures in New Zealand. Other sown (e.g. white and red clover) and adventive, annual clover species such as striated (*Trifolium striatum*), suckling (*Trifolium dubium*), cluster (*Trifolium glomeratum*), and haresfoot clover (*Trifolium arvense*) may also be present. Compared with subterranean clover, adventive clover species are viewed as having lower herbage production and are unlikely to be sown in New Zealand (Boswell *et al*., 2003). However they may still have a useful role in dryland pastures due to their nutritional value and complementary effects to grasses through N fixation (Boswell *et al*., 2003).

Boswell *et al*. (2003) reviewed the agronomic and nutritive value characteristics of adventive clovers. In dry hill environments, haresfoot clover yielded between 850 and 3300 kg DM/ha, and production of suckling clover ranged from 3100 to 5100 kg DM/ha. It was suggested that in dry sub-humid grassland a combination of four adventive clovers with subterranean clover may be more productive than subterranean clover alone due to increased total resource use (niche differentiation) or through positive interactions among neighboring plants (see also Skinner *et al*., 2004). In support of this concept, Dear (2003) suggested that by sowing three or more different legume species, such as balansa clover, subterranean clover and gland clover (*Trifolium glanduliferum Boiss.*), in a mixture with perennial pasture legumes or grasses may provide more resilient and adaptable swards.

Norman *et al*. (2005) also noted that sowing annual clovers together with different reproductive strategies (e.g. many small versus few large seed) may reduce the risks of failure of legumes in pastures, as there is always one species capable of exploiting the climatic and grazing management conditions. Most annual clover species produce small but many hard seeds for persistence. This is in contrast to subterranean clover which produces relatively few and larger buried seeds. However, when seeds of different sizes are sown together and grown into seedling stage, plants from the small seeds tend to die as a result of excessive competition (possibly shading) from plants (Donald, 1954). Subterranean clover has relatively larger cotyledons which may provide a competitive advantage to subterranean clover over small seeded annual clovers such as white and balansa clover at the establishment and early growth stage (Hill & Glesson, 1990). However, Hill and Glesson (1990) reported that white clover severely depressed the seed production of subterranean clover grown in binary mixtures at proportions of 100:0, 90:10, 50:50, 10:90, owing to lower maximum temperatures and less erratic rainfall distribution in late summer and autumn in New South Wales, Australia. Whether these interactions are altered by variation in grazing management is not clear.

2.7.2 Coexistence with grasses

Managing the interaction between perennial grasses and annual legumes is an important part of dryland pasture management. Grasses are the dominant contributor to pasture production in dryland pastures and transfer of N from legumes to grasses is important. Donald (1954) noted that the balance between clover and grass in mixed swards is susceptible to environmental factors and affected by nutrient status and grazing management.

Annual legumes such as subterranean clover appear to be vulnerable to competition during the seedling establishment phase in autumn (Dear, 2003). Perennial plants reduce the availability of mineral N, light and water and affect the growth and the number of established seedling (Dear & Cocks, 1997; Dear *et al.*, 1998; Dear, 2003). For example, lucerne and cocksfoot may respond rapidly to late summer-early autumn rain when temperatures are still relatively high and rapidly dry out the soil surface when subterranean clover is germinating, decreasing seedling turgor, size and survival. Dear and Cocks (1997) reported that only 1, 13 and 57% of seedlings established from the whole germinated subterranean clover seedlings in autumn when growing with cocksfoot, danthonia (*Danthonia richardsonii*) and phalaris (*Phalaris aquatica*), respectively.

In spring, perennial species may reduce seed production of annual legumes due to increased competition for soil water during flowering and seed set or shading at varying degrees depending on the perennial plant population and biomass (Dear *et al.*, 2000). Dear *et al.* (2001) reported that seed production of subterranean clover in mixtures with grasses reduced by up to 50% compared with pure annual swards. However, Dear *et al.* (2000) showed that perennials with deep tap roots such as lucerne and phalaris have little impact on drying the top soil (0-40 cm) profile which is exploited by annual clovers. Therefore, Dear (2003) suggested that shading can be minimized through grazing management to ensure high annual clover seed production and long term legume content in the swards.

2.8 Conclusions

The following conclusions can be drawn based on the literature on subterranean clover:

- Subterranean clover persists and provides high quality forage for lactating ewes and lambs in dryland environments where white clover fails to persist. Higher production of subterranean clover in early spring due to its lower temperature requirement compared with white clover supports early lambing.
- DM production of subterranean clover in New Zealand ranges from 3 to 10 t DM/ha depending on the environmental conditions, sward type (pure or mixed), flowering time, and degree of competition.
- Grazing management affects subterranean clover production and persistence. Grazing until the initiation of flowering increases the inflorescence rate, while grazing midway through to flowering or at/after burr formation decreases the seed production.
- Subterranean clover can provide high twin lamb growth rates of 300 g/head/d in spring. However, grazing management decisions such as stocking rate impact on individual lamb liveweight gain and animal production per hectare.
- Research on subterranean clover in New Zealand has focused on summer dry hill country systems, fertilizer response and cultivar choice for these environments. Further research is needed to define the best management for the adequate seed production and successful re-establishment of new seedlings each autumn while maintaining animal production in spring.

Four main objectives were developed based on these conclusions which are presented in Section 1.2 and Figure 1.1.

Chapter 3
Animal production from cocksfoot based dryland pastures in combination with annual or perennial legumes

3.1 Introduction

High quality pasture is essential to provide high lamb growth rates during spring/early summer as this is a critical lactation period in many animal production systems. This is particularly the case in pastures exposed to water deficit in late spring/early summer, where lambs are targeted to be sold before the onset of summer drought (Grigg *et al*., 2008). There are many studies showing high legume content leads to increased liveweight gain in sheep (e.g. Hyslop *et al*., 2000; Litherland & Lambert, 2000). Therefore, the ability to sustain high proportions of legume in pasture and diet is of vital importance.

The most commonly sown pasture mixture in New Zealand is perennial ryegrass with white clover. However this combination often fails in dry environments where low summer rainfall limits production and persistence (Fraser, 1994; Knowles *et al*., 2003). An alternative for dryland pastures is the use of annual clovers. These avoid summer dry conditions by dying in early summer after seed setting and have an added advantage of growing earlier in spring so providing high quality feed in early lactation (Smetham, 2003b). Conversely a deep rooted perennial legume such as Caucasian clover may compete successfully with dryland grasses due to its deep taproot. However, a lack of early spring growth may limit its usefulness in early lactation on dryland farms (Black *et al*., 2003).

The aim of the experiment reported in this chapter was to compare liveweight gain of sheep from cocksfoot based pastures grown in combination with white, Caucasian, subterranean or balansa clover with a ryegrass-white clover pasture and a monoculture of lucerne. This study builds on previous reports of pasture production from these mixtures (Brown *et al.*, 2006; Mills *et al.*, 2008a,b) with the main focus of this chapter on change in liveweight gain and pasture nutritive value within and between seasons. The specific objectives were:

1) Determine the effect of each of the five pasture mixtures and lucerne on liveweight gain per head and per hectare in years 4 and 5 of the experiment.
2) Determine how liveweight gain varied between and within seasons in each pasture type.
3) Determine the effect of pasture type on the nutritive value of the feed on offer.

3.2 Material and methods

3.2.1 Site description

The experiment was carried out within the 'Maxclover' experiment which is located in paddock H19 of the Field Service Centre research area at Lincoln University, Canterbury, New Zealand (43° 38'S, 172° 28'E, 11 m a.s.l.). The site is bounded by poplar trees (*Populus deltoides*) on the western boundary and willow trees (*Salix alba*) on south and east boundaries.

3.2.2 Soil characteristics

The soil is a Templeton silt loam soil (*Udic Ustochrept*, USDA Soil Taxonomy) with 0.85–1.45 m of fine material overlying alluvial gravels (Cox, 1978). The parent material of the soil is sandy and silty alluvium derived from greywacke (Watt & Burgham, 1992). Templeton silt loam soils are described as free draining and well suited to cropping with an average 100-120 mm available water holding capacity in the top 1.0 m (Webb *et al.*, 2000). Actual depth to the gravels in an adjacent paddock (H17) to the north ranged from 0.6-1.5 m (Gyamtsho, 1990).

3.2.3 Meteorological conditions

The meteorological data for the experimental period are presented in Figure 3.1 (rainfall and potential evapotranspiration) and Figure 3.2 (temperature and solar radiation). Long term mean (LTM) monthly data are the average of 45 years from 1960 to 2005 collected from the Broadfields Meteorological Station which is located 2 km north of the experimental site. The long term annual average rainfall is 635 mm and total annual potential evapotranspiration (PET) is 1033 mm for the experimental site. The annual mean temperature is 11.4 ^{o}C with the coldest month July (5.9 ^{o}C) and the warmest January (16.6 ^{o}C).

3.2.3.1 Rainfall and evapo-transpiration

Total rainfall was 20% higher in spring 2006 than the long term mean (LTM), with the wetter period extended until January 2007 (Figure 3.1). However the rainfall in the following months except June, July and October was lower than LTM resulting in the year of 2007 being drier than average (120 mm less annual rainfall). Total rainfall in spring 2007 was similar to long term data. In general, the seasonal distribution of rainfall was erratic and did not follow the long term data during the experimental period. Penman PET (Penman, 1971) followed a similar pattern to the LTM except in summer 2006 when PET was lower than the LTM (Figure 3.1). The minimum monthly PET was 31 mm in July 2007, while the maximum was 157 mm in January 2008.

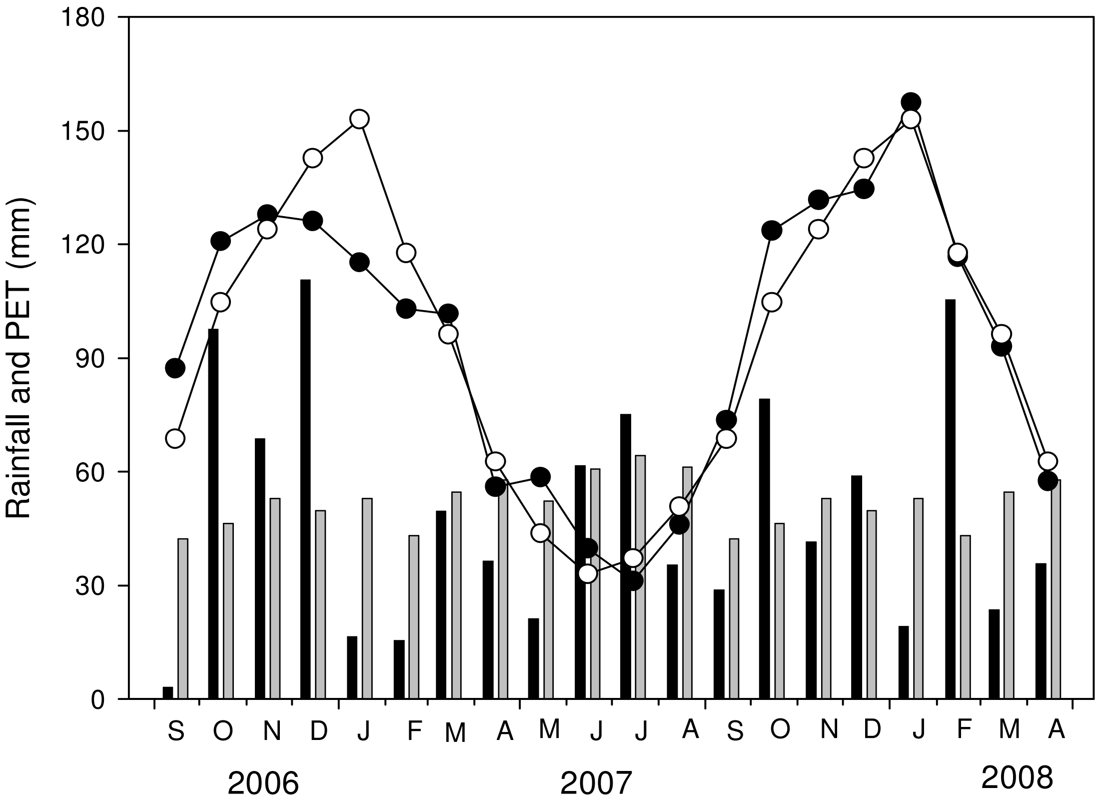

Figure 3.1 Monthly rainfall (■) and potential evapotranspiration (PET) (●) from 1 September 2006 to 30 April 2008. Long term means of rainfall (□) and PET (○) are for the period 1960-2005. Data were collected from the Broadfields Meteorological Station located 2 km north of the experimental site.

3.2.3.2 Temperature and solar radiation

The mean daily temperature and mean daily total solar radiation were almost identical to the LTM during the experimental period (Figure 3.2). The exception was that the mean monthly air temperature was lower than the LTM in September and December 2006 and January and May 2007. The highest monthly mean temperature was 16.2 ^{o}C in January 2007 and the lowest monthly temperature was 6.0 ^{o}C in July 2007. Mean daily solar radiation ranged from 5.1 MJ m^2/d in July 2007 to 23.5 MJ m^2/d in November 2007 (Figure 3.2).

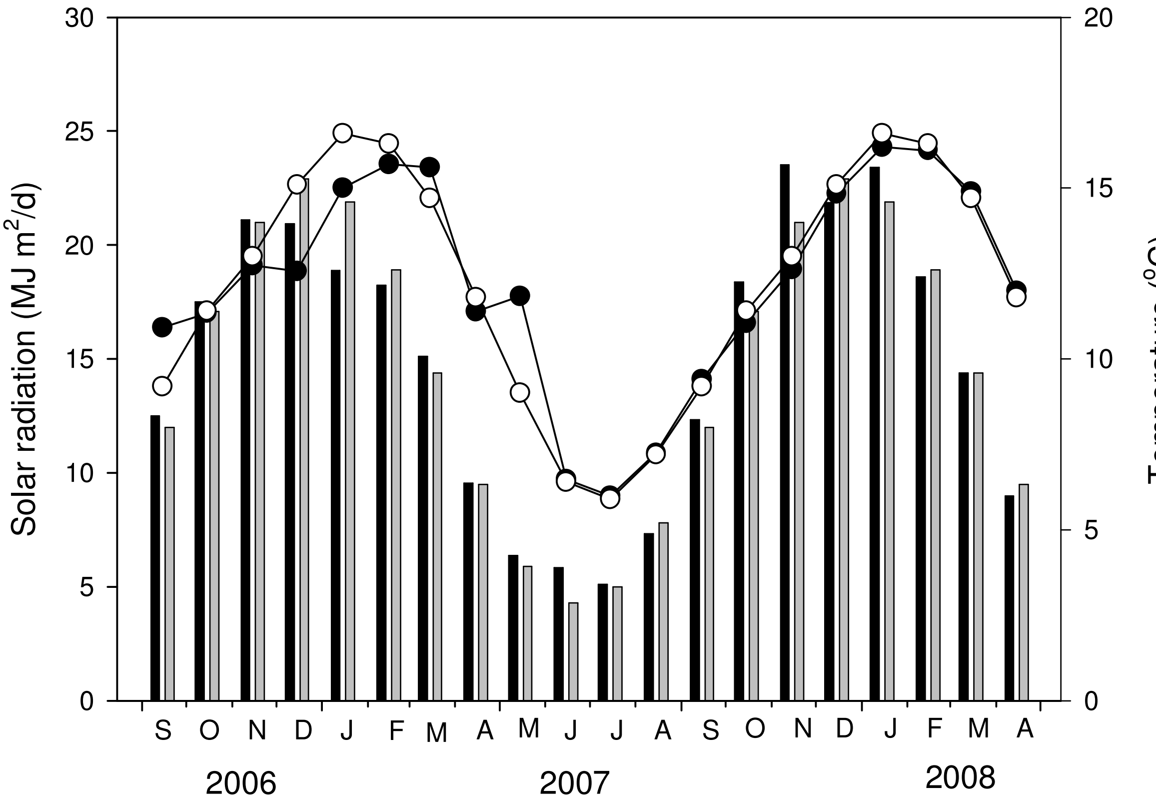

Figure 3.2 Monthly mean air temperature (●) and daily mean solar radiation (■) from 1 September 2006 to 30 April 2008. Long term means of air temperature (○) and daily mean solar radiation (□) are for the period 1960-2005. Data were collected from the Broadfields meteorological station located 2 km north of the experimental site.

3.2.4 Pasture establishment

The 2.0 ha paddock (H19) was split into four blocks and sown with six pasture treatments on 18 February 2002 in a randomized complete block design. Two further blocks were established in autumn 2003, giving a total of six blocks. Each block contained six fenced 22 × 23 m plots (0.05 ha) opening onto an adjoining race. The six pasture treatments were: 'Vision' cocksfoot sown in combination with 'Denmark' subterranean clover, 'Bolta' balansa clover, 'Endura' Caucasian clover or 'Grasslands Demand' white clover, 'Aries AR1' perennial ryegrass sown with 'Grasslands Demand' white clover and 'Kaituna' lucerne. All legume species were inoculated with appropriate Rhizobium strains before sowing: Group B (TA1) for white clover, ICC148 for Caucasian clover, Group C for subterranean and balansa clovers and Group AL for lucerne. The sowing rates of pasture treatments are presented in Table 3.1.

Table 3.1 Treatment details and sowing rates of pasture species of the experiment located in H19. Symbols in the table are used to differentiate pasture treatments in figures throughout this chapter, unless stated otherwise in figure captions.

Pasture mixtures	Sowing rate (kg/ha)		Nomenclature	Symbol
	Grass	Legume		
Cocksfoot/balansa clover	4.0	6.0	(Cf/bal)	■
Cocksfoot/subterranean clover	4.0	10.0	(Cf/sub)	●
Cocksfoot/Caucasian clover	4.0	8.0	(Cf/Cc)	□
Cocksfoot/white clover	4.0	3.0	(Cf/wc)	○
Perennial ryegrass/white clover	10.0	3.0	(Rg/wc)	△
Lucerne	-	8.0	(Luc)	▽

3.2.5 Soil fertility

Soil fertility was monitored over the two year period described in this thesis. A total of 10 soil cores were taken to a depth of 75 mm from each treatment on 28 April 2006, 26 July 2007 and 7 May 2008 (Table 3.2). A bulked sample was analysed using Ministry of Agriculture and Fisheries Quick Test (MAF QT) procedures. Data from each season are presented in Table 3.2. A total of 200 kg/ha 'Sulphur Super 20' (20.8% S, 18% Ca and 8.1% P) was applied to all treatments on 2 August 2007. No fertilizer was applied in 2006 and 2008 on the basis of satisfactory test results. Over the two years of this study, pH, Olsen P, SO_4^-S, Mg and Na levels fluctuated within the optimum range. However, the soil Ca level of 6-9 meq/100 g was lower than the optimum of 10-15 meq/100 g, while the soil K level was twice as high as the optimum levels for grazed pastures (McLaren & Cameron, 1996). The low value of 3 for SO_4^-S concentration in 2007 appeared to be anomalous. The application of 'Sulphur Super 20' after receiving the 2007 soil test resulted in satisfactory SO_4^-S values in 2008.

Table 3.2 Soil test results from H19 at Lincoln University from 2006 to 2008.

Year	Treatments	pH (H_2O)	Olsen P (μg/ml)	SO_4^-S (μg/g)	Ca^{++}	K^+	Mg^{++}	Na^+
					-------------(meq/100 g)-------------			
2006	Cf/bal	6.2	18	12	7	13	16	9
	Cf/sub	6.2	19	9	8	13	16	9
	Cf/Cc	6.2	23	13	7	13	17	9
	Cf/wc	6.2	20	14	6	12	16	9
	Rg/wc	6.2	15	11	7	9	16	9
	Lucerne	6.0	21	24	6	15	14	7
2007	Cf/bal	6.4	17	3	8	13	19	10
	Cf/sub	6.4	22	3	9	19	17	9
	Cf/Cc	6.4	24	3	9	17	20	9
	Cf/wc	6.4	22	3	8	16	18	8
	Rg/wc	6.4	25	3	9	18	20	10
	Lucerne	6.5	27	3	9	17	22	10
2008	Cf/bal	6.4	24	7	8	15	20	9
	Cf/sub	6.2	24	10	8	15	21	12
	Cf/Cc	6.3	22	7	8	15	21	11
	Cf/wc	6.3	20	7	8	15	20	10
	Rg/wc	6.3	18	11	8	12	20	12
	Lucerne	6.2	25	17	8	17	19	8
Optimum levels*		6-6.5	12-20	8-16	10-15	5-8	20-30	5-10

* McLaren and Cameron (1996) for pasture growth.

3.2.6 Grazing management

The grazing management was designed to optimize the quantity and quality of herbage for both pasture and animal production, and the persistence for the species in each pasture type. Thus, grazing management was different for each pasture mixture. In general, the two cocksfoot pastures with annual clovers (Cf/sub and Cf/bal) were managed similarly. The three pastures with perennial clovers (Cf/wc, Cf/Cc and Rg/wc) had a longer grazing rotation. Lucerne plots required regrowth periods of approximately 5 weeks after 1 week grazing duration. Six groups of ewe hoggets or ewe lambs grazed rotationally within the six replicates of each treatment to compare pasture and animal production.

A "put and take" grazing system was used during each grazing period when sheep were weighed. Each treatment had a core group of 3–12 animals (testers) with spare sheep (regulators) which helped to match feed demand with changing supply. Spare sheep grazed in races or nearby paddocks when not involved with the experiment and were of similar age and breed to core animals. The number of animals in each plot was adjusted, according to changing pasture growth rates which were obtained from exclosure cage cuts (Mills *et al*., 2008a). The rotation length was approximately 14, 21 and 42 days for short, medium and long rotations, respectively. The average grazing duration ranged from 5 to 10 days in each plot.

Coopworth ewe hoggets were stratified according to their liveweights (mean LW=47 kg ±SD=4.1 in 2006 and 52 kg ±SD=4.7 in 2007) and allocated to their treatment groups on the basis of their liveweights and they grazed their respective plots for each spring period. Hoggets were replaced in late spring-early summer with weaned lambs (LW=31 kg ±SD=3.2 in 2006 and 27 kg ±SD=3.5 in 2007). The lambs grazed throughout the summer and autumn as long as feed quality and quantity allowed. 'Clean up' grazings were done in mid and late summer with hoggets or dry ewes as lax and selective grazing with lambs resulted in grass dominated areas in the stock camps and patches of tall, dead reproductive grass stems and mature low nutritive value herbage. For this, a stocking density of up to 400 ewes/ha was applied to plots to remove the low quality herbage and reduce herbage mass to approximately 800 kg DM/ha. This was particularly important to provide space for annual clover seedlings with the onset of autumn rains.

Full details of grazing management for each treatment are given in Tables 3.3 and 3.4. In 2006/07, annual clover treatments were grazed with a combination of short (3 flocks of sheep grazing 2 plots each rotationally) and medium rotations (2 flocks of sheep grazing 3 plots each rotationally) until flowering and seed set in mid spring (Table 3.3). The Cf/sub plots were then grazed with long rotations (one flock of sheep grazing 6 plots rotationally) until the end of spring. The Cf/bal plots were spelled in early November until mid December 2006 to allow some flowering to replenish balansa clover soil seed reserves. The low quality herbage that accumulated in Cf/bal plots due to the 6 week reseeding spell was removed by ewes.

Table 3.3 Seasonal grazing periods, class of animals, rotation type and clean up grazing days of the pasture treatments and lucerne in 2006/07 in block H19, Lincoln University.

Pasture	Season	Dates	Management	Class	Rotation	'Clean up' grazing*
Cf/bal	Spring	12 Sep-8 Nov	Grazing	Hoggets	Short/Medium	27 Dec-9 Feb
	Spring	9 Nov-18 Dec	Spell	-	-	27 Feb-9 Mar
	Summer	19 Dec-21 Feb	Grazing	Lambs	Long	10 May-16 Jun
	Autumn	22 Feb-8 Mar	Grazing	Lambs	Long	
	Autumn	9 Mar-11 Apr	Spell	-	-	
	Autumn	12 Apr-10 May	Grazing	Lambs	Long	
Cf/sub	Spring	12 Sep-18 Dec	Grazing	Hoggets	Short/Medium	3 Jan-1 Feb
	Summer	19 Dec-21 Feb	Grazing	Lambs	Long	27 Feb-17 Mar
	Autumn	22 Feb-8 Mar	Grazing	Lambs	Long	10 May-16 Jun
	Autumn	9 Mar-11 Apr	Spell	-	-	
	Autumn	12 Apr-10 May	Grazing	Lambs	Long	
Cf/Cc	Spring	12 Sep-18 Dec	Grazing	Hoggets	Medium	21 Dec-7 Feb
	Summer	19 Dec-21 Feb	Grazing	Lambs	Long	2 Mar-30 Mar
	Autumn	22 Feb-3 Apr	Grazing	Lambs	Long	29 May-16 Jun
	Autumn	4 Apr-11 Apr	Spell	-	-	
	Autumn	12 Apr-10 May	Grazing	Lambs	Long	
Cf/wc	Spring	12 Sep-18 Dec	Grazing	Hoggets	Medium	30 Jan-31 Jan
	Summer	19 Dec-21 Feb	Grazing	Lambs	Long	10 May-16 Jun
	Autumn	22 Feb-3 Apr	Grazing	Lambs	Long	
	Autumn	4 Apr-30 Apr	Spell	-	-	
	Autumn	1 May- 10 May	Grazing	Lambs	Long	
Rg/wc	Spring	12 Sep-18 Dec	Grazing	Hoggets	Medium	19 Dec-10 Feb
	Summer	19 Dec-21 Feb	Grazing	Lambs	Long	1 Mar-28 Mar
	Autumn	22 Feb-13 Mar	Grazing	Lambs	Long	10 Apr-13 Jun
	Autumn	14 Mar-11 Apr	Spell	-	-	
	Autumn	12 Apr-10 May	Grazing	Lambs	Long	
Luc	Spring	21 Sep-18 Dec	Grazing	Hoggets	Long	26 Dec-12 Jan
	Summer	19 Dec-25 Feb	Grazing	Lambs	Long	16 Jun-23 Jun
	Autumn	26 Feb- 5 Apr	Spell	-	-	
	Autumn	6 Apr-8 May	Grazing	Lambs	Long	

* Ewes or hoggets were used for 'clean up' grazings when needed between the dates in the table.

In 2007/08, annual clover treatments were grazed with short and medium rotations throughout the entire spring grazing period. In both years, all perennial clover treatments were grazed with medium rotations until mid December (Table 3.4). Lucerne was grazed with long rotations throughout the whole grazing experiment in both years. Lucerne was spelled to allow flowering to build up root reserves from 26 February to 5 April 2007 and from 17

January to 21 February 2008. Pasture treatments were grazed with medium and long rotations from December until the end of the autumn grazing period in each year. After the summer 'clean up' grazings, sheep were removed to accumulate feed for autumn grazing and allow annual clovers to re-establish in early March until mid April in 2007. Moderate intensity grazing was applied to annual clover treatments from mid February to mid March 2008 to reduce shading by companion grasses on the new generation of clover seedlings. Grazing intensity on the individual treatment plots varied according to the rotation length of each treatment plot. The grazing intensity with short, medium and long rotations were 60, 80-100, 160-240 sheep/ha, respectively in both years (Appendices 1 and 2).

Plate 3.1 A view from the grazing experiment on paddock H19 at Field Service Centre research area at Lincoln, Canterbury on 5 October 2006.

Table 3.4 Seasonal grazing periods, class of animals, rotation type and clean up grazing days of the pasture treatments and lucerne in 2007/08 in block H19, Lincoln University.

Pasture	Season	Dates	Management	Class	Rotation	Clean up' grazing*
Cf/bal	Spring	29 Aug-1 Nov	Grazing	Hoggets	Short/Medium	9 Nov-30 Nov 17 Apr-10 May
	Spring	2 Nov-27 Nov	Grazing	Lambs	Medium	
	Summer	28 Nov-16 Jan	Grazing	Lambs	Medium/Long	
	Summer	17 Jan-20 Feb	Spell	-	-	
	Autumn	21 Feb-16 Apr	Grazing	Lambs	Medium/Long	
Cf/sub	Spring	29 Aug-1 Nov	Grazing	Hoggets	Short	9 Nov-29 Nov 17 Apr-10 May
	Spring	2 Nov-27 Nov	Grazing	Lambs	Medium	
	Summer	28 Nov-14 Jan	Grazing	Lambs	Medium	
	Summer	15 Jan-20 Feb	Spell	-	-	
	Autumn	21 Feb-16 Apr	Grazing	Lambs	Medium/Long	
Cf/Cc	Spring	29 Aug-1 Nov	Grazing	Hoggets	Medium	9 Nov-30 Nov 17 Apr-10 May
	Spring	2 Nov-27 Nov	Grazing	Lambs	Medium	
	Summer	28 Nov-16 Jan	Grazing	Lambs	Medium/Long	
	Summer	17 Jan-20 Feb	Spell	-	-	
	Autumn	21 Feb-16 Apr	Grazing	Lambs	Long	
Cf/wc	Spring	29 Aug-1 Nov	Grazing	Hoggets	Medium	9 Nov-30 Nov 17 Apr-8 May
	Spring	2 Nov-27 Nov	Grazing	Lambs	Medium	
	Summer	28 Nov-16 Jan	Grazing	Lambs	Medium/Long	
	Summer	17 Jan-20 Feb	Spell	-	-	
	Autumn	21 Feb-16 Apr	Grazing	Lambs	Long	
Rg/wc	Spring	29 Aug-1 Nov	Grazing	Hoggets	Medium	9 Nov-30 Nov 17 Apr-10 May
	Spring	2 Nov-27 Nov	Grazing	Lambs	Medium	
	Summer	28 Nov-14 Jan	Grazing	Lambs	Medium/Long	
	Summer	15 Jan-20 Feb	Spell	-	-	
	Autumn	21 Feb-16 Apr	Grazing	Lambs	Long	
Luc	Spring	21 Sep-1 Nov	Grazing	Hoggets	Long	12 Apr-10 May
	Spring	2 Nov-27 Nov	Grazing	Lambs	Long	
	Summer	28 Nov-16 Jan	Grazing	Lambs	Long	
	Summer	17 Jan-21 Feb	Spell	-	-	
	Autumn	22 Feb-9 Apr	Grazing	Lambs	Long	

* Ewes or hoggets were used for 'clean up' grazing when needed between the dates in the table.

3.2.7 Liveweight gain measurement periods

Liveweight gain and pasture nutritive values were evaluated in spring, summer and autumn grazing periods in both years (Table 3.3 and 3.4). In 2006/07, spring grazing commenced in mid September and continued until 18 December. The summer period started when weaned lambs were put on the paddocks on 19 December. The autumn period ended when pasture growth was insufficient to meet feed demand of animals at various days for each pasture type in May. In 2007/08, the spring grazing period started earlier on 28 August to gain a better assessment of the early growth of annual clover treatments relative to perennial clover treatments. Lucerne was first grazed from 21 September. Hoggets were replaced by weaned lambs on 2 November and then grazed pastures until mid January before spelling. Autumn grazing started in late February and continued until mid April. Plots were not grazed during winter except for the clean up grazings by ewe hoggets in June.

3.2.8 Measurements

3.2.8.1 Liveweight gain per head and per hectare and number of grazing days

Sheep were fasted overnight and weighed empty the next morning at each measurement date. After weighing, they were then drafted into their treatment groups and returned to their respective plots. Sheep were weighed at intervals of 2-6 weeks (range 17 to 42 days). The number of grazing days was calculated by multiplying the number of tester plus regulator sheep per plot by the number of days each plot was grazed. Liveweight gain per head of tester sheep was calculated from the change in weight between each measurement date. Liveweight gain per hectare (kg/ha/d) was calculated by multiplying liveweight gain/head of testers by the number of tester plus regulator sheep/ha. Total seasonal liveweight gain per hectare was calculated by multiplying liveweight gain per hectare (kg/ha/d) by the total number of calendar days that the plot was grazed.

3.2.8.2 Herbage mass

Herbage mass was measured with a rising plate meter prior to and following grazing in each plot. A total of fifty plate meter readings were taken across the whole plot on each occasion. The plate meter readings were calibrated with direct measurement of herbage mass estimated by quadrat cuts during spring and early summer in 2006. A total of three 0.2 m^2 quadrats were cut to 10 mm stubble height with electric shears prior to and following grazing of the plots between 18 September and 6 October in early spring and 5 November to 18 December 2006. These periods were chosen to represent changing morphology of plants and sward development during spring. For example, pastures from leafy stage with little dead material in September, to grass stem elongation stage in November. Pre and post grazing herbage masses of lucerne were also measured by cutting five 0.2 m^2 quadrats to a stubble height of 40mm from each plot on the day prior to grazing and within 24 h of the removal of sheep. The herbage samples were dried in an oven at 70 ^oC to a constant weight and then weighed with an electronic scale ± 0.01 g. The data were used to produce linear equations for cocksoot and ryegrass pastures by regression between plate meter readings (pre and post) and herbage mass (Table 3.5). The same linear equations were used for spring 2007. No quadrat cuts were taken during autumn, and spring equations were used for this period (Table 3.5).

Table 3.5 Linear equations for cocksfoot and ryegrass pastures obtained by regression between plate meter readings (x) and herbage mass (y).

Period	Pasture type	Pre grazing	r^2	Post grazing	r^2
September-October	Cocksfoot	y=279.5x	0.95	y=283.4x	0.72
September-October	Ryegrass	y=284.0x	0.99	y=279.2x	0.83
November-March	Cocksfoot	y=298.4x	0.82	y=310.0x	0.85
November-March	Ryegrass	y=299.1x	0.74	y=285.6x	0.89
March-June	Cocksfoot	y=279.5x	0.95	y=283.4x	0.72
March-June	Ryegrass	y=284.0x	0.99	y=279.2x	0.83

3.2.8.3 Herbage on offer and nutritive value

A total of 30-50 snip samples (approximately 200-500g fresh weight) of pasture across each plot were taken prior to each grazing. These samples aimed to be representative of what sheep were eating. A sub sample was sorted to species (sown and volunteer clovers, sown grasses, annual and broadleaf weeds and dead material) and dried in an oven at 70 ^oC to a constant weight to determine the botanical composition of herbage on offer. Samples from the pre grazing quadrat cuts taken from the lucerne plots were retained for chemical analyses. Bulk samples were retained and ground in a mill with a 1 mm stainless steel sieve (Cyclotec Mill, USA). Samples collected from the plots which were grazed by the same flock were combined and prepared for chemical analyses to give an indication of nutritive value over a liveweight gain period in each season. Samples were analyzed for nitrogen content (N %), digestible matter in dry matter (DOMD %), acid detergent fiber (ADF %) and neutral detergent fiber (NDF %) by near infra-red spectroscopy (NIRS-Foss NIR Systems 5000 Rapid Content Analyser) (Adesogan, 2000). Crude protein content was calculated by N% X 6.25 and metabolisable energy (ME MJ kg/DM) content was calculated by DOMD X 0.16 (Nicol, 1989). Analyses were carried out by the Lincoln University Analytical Service.

Herbage macro (N, P, S, Mg, Ca, Na, K) and micro (Fe, Mn, Zn and Co) nutrient concentrations were also determined once at the beginning of the grazing in both spring seasons. All ground snip samples collected from the same pasture treatment from September to November were combined equally for mineral analyses. Analyses were conducted by R.J Hill Laboratories Limited by using Nitric Acid/Hydrogen Peroxide digestion followed by ICP-OES for P, K, S, Ca, Mg, Na, Fe, Mn, Zn and Co and by Dumas combustion for N.

3.2.9 Statistical analyses

Both years were separated into three seasons (spring, summer and autumn) and total liveweight production per hectare was calculated from each plot by multiplying the grazing days by the mean liveweight gain per hd/d of tester sheep from the corresponding treatment during the same season. This gave LW/ha from each of the 36 plots and allowed comparison of spring, summer and autumn production between treatments using ANOVA. Animal liveweight gain (LWG g/hd/d) was calculated for each grazing period (3-6 weeks) but could not always be compared for each period using ANOVA because on some occasions there was only one replicate flock per treatment (e.g. 1 flock rotating around 6 paddocks). Where replicate flocks occurred (e.g. spring period), liveweight gain (LWG g/hd/d) was analysed by ANOVA of unbalanced design due to differences in the number of flocks per treatment. At other times where there was a single flock, no statistical analyses were carried out. To allow further interpretation of stock production in relation to herbage on offer, pre- and post-grazing herbage mass, diet botanical composition and nutritive value of herbage on offer were analyzed by ANOVA. For this ANOVA analysis was based on data that were either bulked (for nutritive value) or averaged (for herbage mass and botanical composition) monthly across the paddocks that a replicate flock was grazing. Replication was thus based on the number of flocks in each pasture treatment. Lucerne was not included in this analyses as it did not have any replicated flocks. Significant means were separated by Fisher's protected LSD at $\alpha = 0.05$.

3.3 Results

3.3.1 Number of grazing days

All grass based pastures and lucerne had a variable number of grazing days depending on the season and the specific requirement of each pasture type (Table 3.5). The total number of grazing days ranged from 1430 (Cf/bal) to 1740 (Cf/Cc) in 2006/07 and 1385 (Rg/wc) to 1673 (Cf/Cc) in 2007/08. There were more grazing days on Cf/Cc than other pastures and Cf/sub had the second most grazing days in both years. The Cf/bal pastures had the lowest number of grazing days in 2006/07 due to a long spell to allow flowering and seed production in late spring. Rg/wc pastures had the lowest total grazing days in 2007/08, reflecting fewer summer and autumn grazing days. Perennial clovers sown with cocksfoot resulted in more autumn grazing days in both years than other pastures. Lucerne had generally fewer grazing days during spring but had more summer grazing days than all grass based pastures in 2007/08 when the summer was drier than 2006/07.

Table 3.6 The number of grazing days of grass based pastures and lucerne in 2006/07 and 2007/08 in block H19, Lincoln University.

Year	Treatments	Spring	Summer	Autumn	Total
2006/07	Cf/bal	434	746	250	1430
	Cf/sub	649	704	343	1696
	Cf/Cc	657	663	420	1740
	Cf/wc	705	497	455	1657
	Rg/wc	719	497	295	1511
	Lucerne	610	663	239	1512
2007/08	Cf/bal	692	426	440	1557
	Cf/sub	827	389	432	1647
	Cf/Cc	745	443	485	1673
	Cf/wc	692	429	481	1602
	Rg/wc	659	347	379	1385
	Lucerne	531	567	350	1448

3.3.2 Liveweight gain per head

Liveweight gain per head over the entire grazing period in spring, summer and autumn of 2006/07 and 2007/07 is shown in Figure 3.3. No statistical analyses were performed on these data because on some occasions there was only one replicate flock per treatment. Average liveweight gain per head was always higher in spring than summer and autumn for all six treatments in both years. Liveweight gain per head was similar in annual clover (Cf/sub and Cf/bal) and Cf/Cc pastures with the hoggets gaining 175-177 g/hd/d in spring 2006. This was approximately 20-35 g/hd/d higher than Rg/wc and Cf/wc pastures, respectively. Liveweight gain per head was 15-33% higher in lucerne than grass-based pastures during the same period. Lucerne also resulted in the highest liveweight gain (141 g/hd/d) in summer, almost twice the next best performing Cf/bal pasture (72 g/hd/d). Liveweight gain per head in summer was lowest in Cf/sub and Cf/Cc pastures with the lambs gaining less than 40 g/hd/d. Perennial clover pastures and lucerne had lower liveweight gain per head in autumn 2007 than the preceding summer 2006/07. In contrast, annual clover pastures supported 15-20% higher liveweight gain per head in autumn than summer.

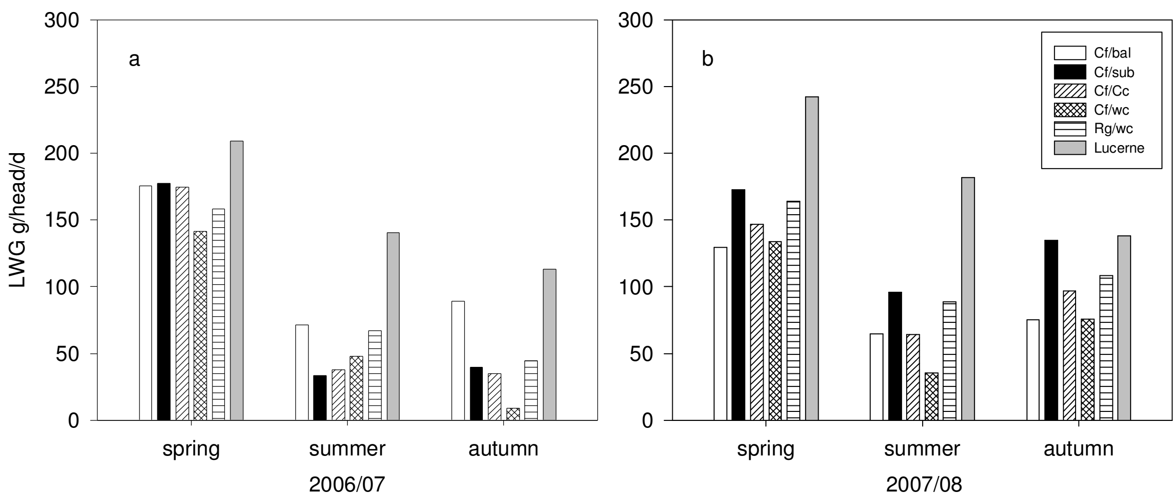

Figure 3.3 Mean seasonal liveweight gain (LWG) per head (g/head/d) in (a) 2006/07 and (b) 2007/08 from five pasture treatments and lucerne at Lincoln University.

In 2007/08, lucerne produced consistently higher liveweight gain per head in spring (29-46%), summer (47-81%) and autumn (3-45%) than any grass based pastures (Figure 3.3b). Cf/sub pastures gave the highest liveweight production among grass based pastures followed by Rg/wc and Cf/Cc pastures, while Cf/bal and Cf/wc pastures supported the lowest animal liveweight gain per head over entire grazing periods. Animal liveweight gains per head were the highest in spring in each pasture ranging from 130 g/hd/d (Cf/wc) to 242 g/hd/d (lucerne). Grass based pasture treatments had the lowest animal production during summer, while animal liveweight gain per head from lucerne was 24% lower in autumn than summer.

3.3.3 Liveweight gain per head within seasons

Figure 3.4 shows liveweight gain per head during each grazing period within a season. Liveweight gain per head in 2006 was the highest during early spring (September to October) in each pasture treatment ranging from 180 g/hd/d (Cf/bal) to 251 g/hd/d (lucerne) (Figure 3.4a). In spring 2006, there was a trend of declining liveweight gain per head from early to late spring. The exception was Cf/sub pastures which had an increased liveweight gain per head from 12 October to 9 November. This meant Cf/sub pastures had significantly higher (P<0.05) liveweight gain per head (188 g/hd/d) than Cf/Cc (122 g/hd/d), Rg/wc (97 g/hd/d) and Cf/wc (73 g/hd/d) during this period. There were no significant differences in liveweight gain per head in early spring. Liveweight gain per head from grass based pastures was highly variable during summer and autumn. In contrast, lucerne gave the highest and more consistent liveweight gains, ranging from 113 to 166 g/hd/d during that period.

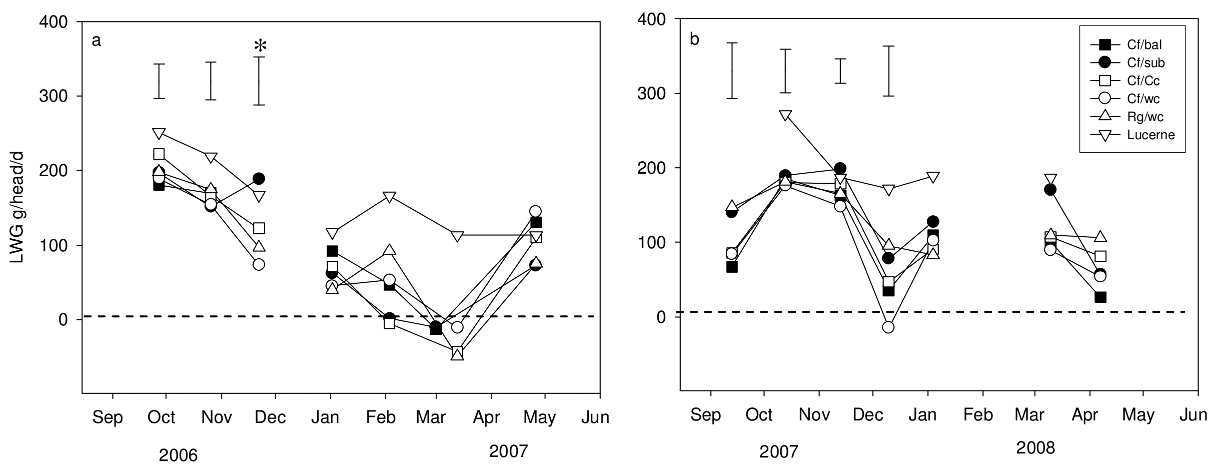

Figure 3.4 Liveweight gain (LWG) per head (g/head/d) in (a) 2006/07 and (b) 2007/08 from five pasture treatments and lucerne at Lincoln University. Bars are LSD above the periods when ANOVA was carried out using the flocks as replicates. Lucerne was not included to the analysis as it did not have any replicate flocks. * = when ANOVA was significant (P<0.05).

In spring 2007, liveweight gain per head increased from the first to the second measurement period, before it declined in all grass pastures in December (Figure 3.4b). Early spring (September-October) animal liveweight gain tended to be greater (P=0.09) in Cf/sub and Rg/wc pastures with the hoggets gaining approximately 150 g/hd/day. Cf/sub gave the highest liveweight gains in mid and late spring (October to November) among grass pastures with a maximum of 200 g/hd/d. However, the difference in liveweight gain per head was not significant (P=0.07). Liveweight gain per head of sheep on lucerne remained over 150 g/hd/d during summer while the liveweight gain per head decreased sharply in all grass pastures to the extent that sheep lost 15 g/hd/d in Cf/wc. The Rg/wc and Cf/sub pastures appeared to have a higher (P=0.06) liveweight gain per head than Cf/wc pastures in December. Liveweight gain per head from Cf/sub pastures and lucerne was approximately 200 g/head/d compared with 100 g/head/d from other pastures in early autumn (March-April). However, only Rg/wc pastures sustained liveweight gain per head over 100 g/hd/d in mid/late autumn (April-May).

3.3.4 Liveweight gain per hectare

In spring 2006, liveweight production (kg/ha) from lucerne (421 kg/ha) was significantly higher (P<0.05) than all grass based pastures, except Cf/sub (Figure 3.5a). However, liveweight production (kg/ha) was similar in Cf/sub, Cf/Cc and Rg/wc pastures (about 380 kg/ha), which were 13-33% greater (P<0.05) than Cf/wc and Cf/bal pastures, respectively. Liveweight production (kg/ha) was comparable among grass based pastures in summer except for Cf/bal pastures which gave approximately 70-100 kg/ha greater production (P<0.01). Liveweight production in autumn 2007 dropped below 100 kg/ha in each pasture, ranging from -2.8 (Cf/wc) to 90.2 (lucerne) kg/ha. Liveweight production was significantly lower (P<0.05) from Cf/wc pastures than lucerne and the other grass based pastures in autumn 2007.

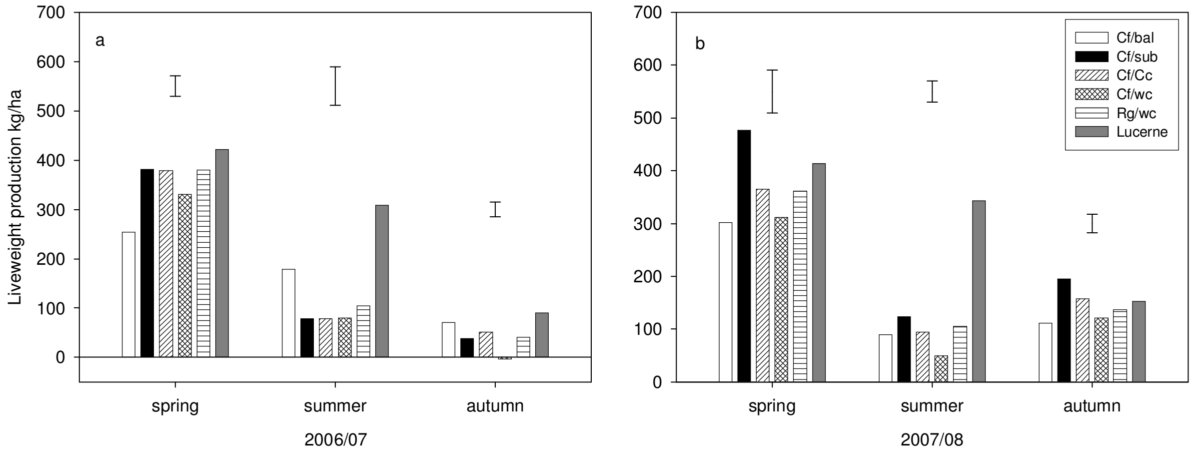

Figure 3.5 Seasonal liveweight production (kg/ha) in (a) 2006/07 and (b) 2007/08 from five pastures and lucerne at Lincoln University. Bars represent LSD above the periods when ANOVA was significant (P<0.05).

In spring 2007, liveweight production (kg/ha) was higher (P<0.05) in Cf/sub than other grass based pastures (Figure 3.5b), but not significantly different from lucerne. The earlier start of spring grazing increased liveweight production per hectare of Cf/sub pastures compared with other grass/clover pastures and lucerne with an average of 13-37% greater production (kg/ha). Similar to summer 2006/07, there was a large reduction in liveweight production per hectare in summer 2007/08 in all grass based pastures, compared with spring. However, lucerne sustained its high liveweight production per hectare with only 72 kg/ha decrease from spring to summer. Liveweight production per hectare in autumn 2008 had a similar pattern to spring except with approximately 60% lower production in each pasture. Cf/sub had 40-80 kg/ha more liveweight production per hectare in autumn and this was significantly higher (P<0.05) than other pastures except Cf/Cc.

3.3.5 Pre grazing herbage mass

Pre grazing herbage mass in grass-clover pastures ranged from 1200 to 2200 kg DM/ha in spring 2006, showing a general increase from September to March and a decline as autumn progressed (Figure 3.6a). Lucerne had a steady pre grazing herbage mass of 3200 kg DM/ha from September 2006 to March 2007 with the exception of 4000 kg DM/ha in October. Pre grazing herbage mass in lucerne then declined to 1000 kg DM/ha and remained similar until June 2007. Rg/wc and Cf/Cc pastures in general had higher pre grazing herbage mass than annual clover pastures and Cf/wc. However, the difference in herbage mass among pasture treatments was only significant (P<0.05) in November 2006. Because of reproductive tiller development by grasses and a wet summer, herbage mass increased to 3000 kg DM/ha in summer. Notably, the long spell to enable seed setting in Cf/bal pastures generated 4500-5000 kg DM/ha of herbage mass. Autumn herbage mass range was approximately 1200 to 2000 kg DM/ha.

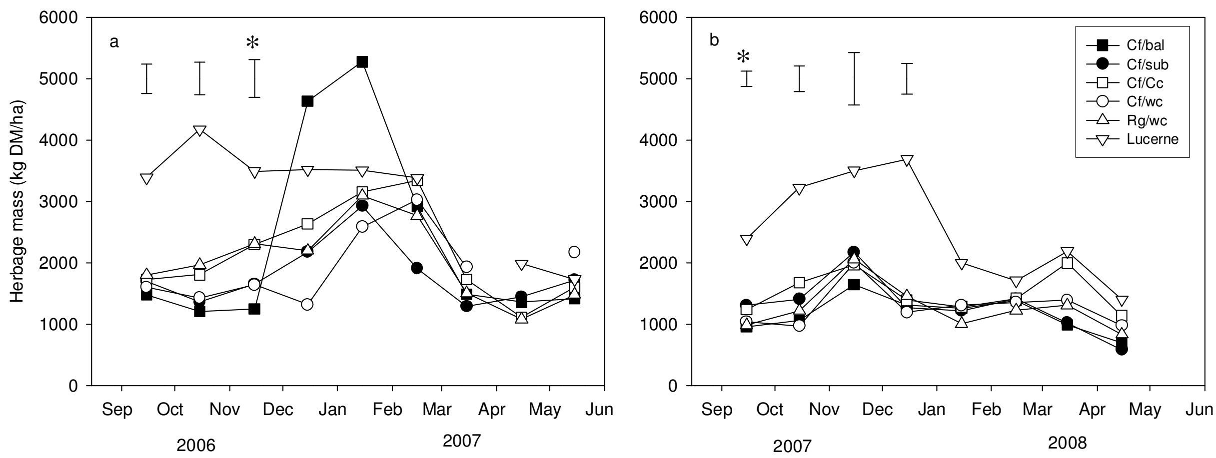

Figure 3.6 Monthly average pre grazing herbage mass in (a) 2006/07 and (b) 2007/08 from five pasture treatments at Lincoln University. Bars represent LSD above the period when ANOVA was carried out using the flocks as replicates. Lucerne was not included to the analysis as it did not have any replicate flocks. * = when ANOVA was significant (P<0.05).

Mean pre grazing herbage mass in grass-clover pastures in 2007/08 averaged 1000-2200 kg DM/ha in spring (Figure 3.6b). During this period Cf/Cc and Cf/sub pastures had 15-42% higher herbage mass than other pastures but the difference was only significant (P<0.05) in September 2007. Herbage mass in summer 2007/08 ranged from 1200 to 1450 kg DM/ha, while autumn 2008 pre grazing herbage mass was maintained between 700 and 1400 kg

DM/ha. Of note, is the high Cf/Cc pasture pre grazing herbage mass which was up to 1000 kg DM/ha greater than other pastures during the autumn period. Pre grazing herbage mass in lucerne increased from 2500 kg DM/ha in September 2007 to 3500 kg DM/ha in December before it declined to 2000 kg DM/ha and remained similar until May 2008.

3.3.6 Post grazing herbage mass

Post grazing herbage mass was maintained at approximately 1200 kg DM/ha in all pastures in 2006/07, except for Cf/bal (Figure 3.7a). Cf/Cc pastures tended to have higher (P=0.09) post grazing herbage mass in spring. Cf/bal pastures had noticeably higher post grazing herbage mass during summer 2007 due to the build up of low quality feed (stems + dead) after the long spell for seed set. This feed was not completely removed by grazing lambs. Therefore dry ewes grazed the pasture to 1500 kg DM/ha, following the lambs. Lucerne had a higher post grazing herbage mass of 1700-1900 kg DM/ha compared with grass-clover pastures during September and October 2006. The post grazing herbage mass in lucerne then declined to below 1500 kg DM/ha and followed a similar trend with grass clover pastures until the end of May 2007.

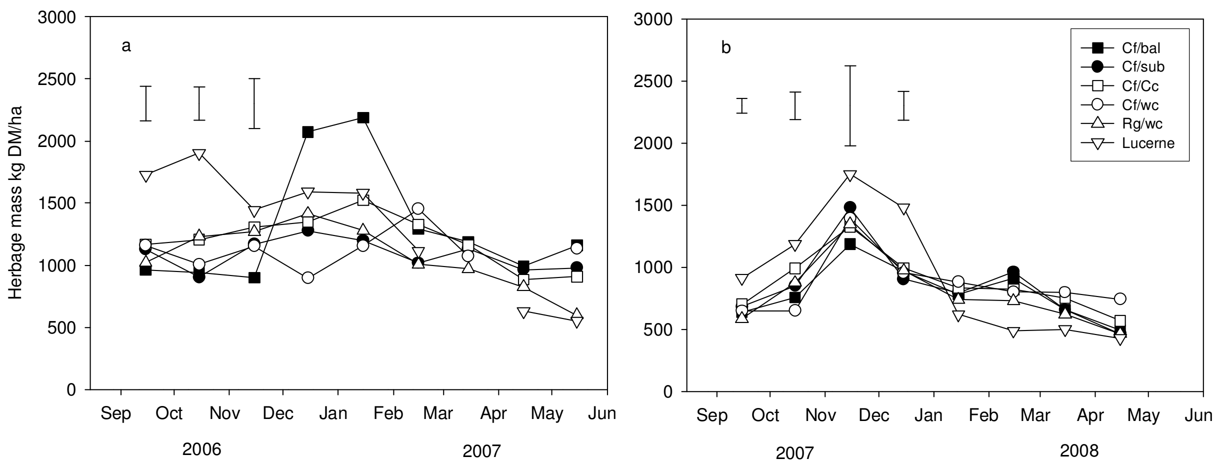

Figure 3.7 Monthly average post grazing herbage mass in (a) 2006/07 and (b) 2007/08 from five pasture treatments at Lincoln University. Bars represent LSD (P<0.05) above the period when ANOVA was carried out using the flocks as replicates. Lucerne was not included to the analysis as it did not have any replicate flocks.

Post grazing herbage mass of grass-clover pastures and lucerne averaged between 600 and 1700 kg DM/ha in 2007/08 (Figure 3.7b). There was an increasing mass towards late spring across all treatments in 2007, after the weaned lambs were introduced. Post grazing herbage mass in lucerne appeared to be 300-600 kg DM/ha higher compared with grass-clover pastures from September until January. Post grazing herbage mass was maintained between 500 and 1000 kg DM/ha during summer and autumn 2007/08. Post grazing herbage mass was variable across all treatments and the difference during spring was not significant (P=0.18).

3.3.7 Botanical composition of herbage on offer to sheep

The average total clover content on offer ranged from 6 to 18% (Figure 3.8e), while the sown clover content accounted for 5-15% in spring (September-December) 2006 (Figure 3.8c). The difference in sown clover content of pasture treatments was only significant (P<0.05) in October 2006 when Rg/wc pastures had 14% clover content (all white clover plants in Rg/wc and Cf/wc pastures were considered to be the sown white clover). This was significantly higher (P<0.05) than all the other pasture treatments. Cf/bal pastures had the lowest (P<0.05) clover (<2%) content during that period, whereas the other pasture treatments had similar sown clover content (6-10%). However, volunteer white clover (17%) was present in Cf/Cc and Cf/bal which accounted for more than half of the clover content of herbage on offer from December 2006 to February 2007 (Figure 3.8e). Total clover content (sown and volunteer) was significantly higher (P<0.05) in Cf/Cc and Rg/wc pastures than other grass based pastures in September and October. Increased clover content in Cf/sub pastures in November was also higher (P<0.05), along with Cf/Cc and Rg/wc pastures than Cf/wc and Cf/bal pastures. A marked increase up to a maximum of 50% (Cf/wc) in both sown and volunteer white clover content in all pastures occurred from December 2006 to February 2007 due to wet summer conditions. All perennial clover pastures had similar mean autumn clover content of approximately 12%, while annual clover pastures only had 5% clover content at this time.

A large increase of clover content was observed in the Cf/sub pasture in spring 2007 (Figure

3.8d). Mean total clover content on offer in Cf/sub over the entire spring period was 38% in spring 2007 compared with 12% in spring 2006. Both total and sown clover content of Cf/sub pastures was higher ($P<0.05$) than other grass based pastures which had similar clover content in September (10-14%) and November 2007 (16-24%). As expected annual clover pastures had less than 5% mean clover content in summer 2007/08, while Cf/Cc pasture had the highest clover content in summer and autumn 2007/08.

Rg/wc pasture had an average of 26% total weed (annual and broadleaf) content compared with 7-13% in cocksfoot based pastures over the entire grazing period in 2006/07 (Figure 3.8g). However, the difference was not significant ($P>0.05$) during spring. Total weed content of cocksfoot based pastures did not change through September to May 2007, while Rg/wc pastures had increasing weed content. Total weed content on offer was higher in each pasture in 2007/08 than 2006/07 with a steady rate through the entire grazing experiment (Figure 3.8h). The average weed content ranged from 17-23% in cocksfoot based pastures while it accounted for approximately half of the Rg/wc pastures. Total weed content of Rg/wc pasture was higher ($P<0.05$) than cocksfoot based pastures in September, October and December 2007.

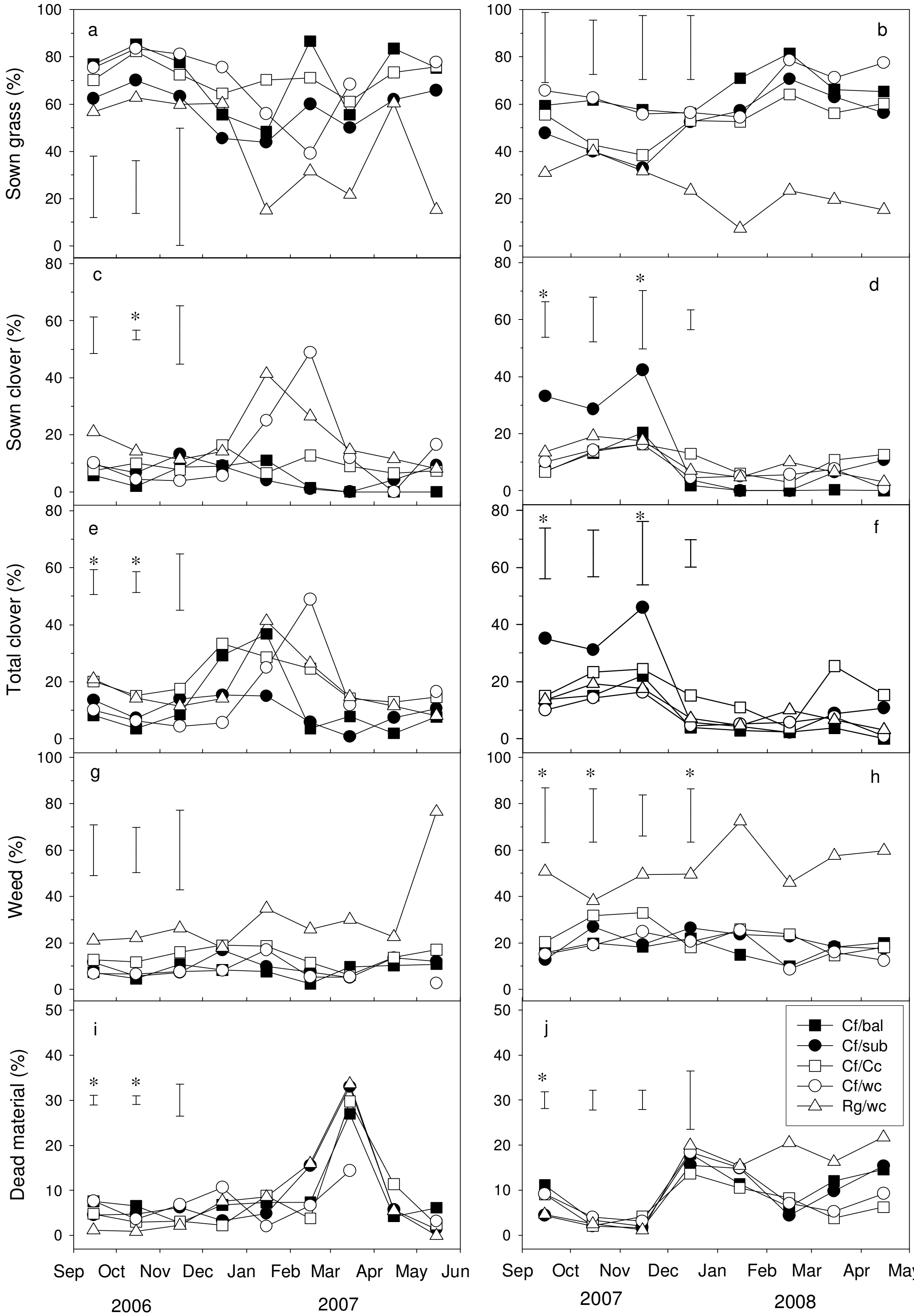

Figure 3.8 Monthly (a, b) sown grass (%), (c, d) total clover (sown+volunteer) (%), (e, f) sown clover (%), (g, h) weed (%) and dead material (i, j) of herbage on offer from five pasture treatments at Lincoln University in 2006/07 and 2007/08. Bars represent LSD above the period stats when ANOVA was performed. * = when ANOVA was significant (P<0.05).

In 2006/07, pasture treatments generally had similar total dead material contents, ranging from 1 to 15%, except in March 2007 when averaged across pastures, dead material content reached 32% (Figure 3.8i). The dead material content of Cf/wc and Cf/bal pastures was 8% in September 2006 and this was higher (P<0.05) than other cocksfoot (5%) and Rg/wc pastures (1%). An average of 7% dead material content in Cf/bal pastures in October 2006 was also higher (P<0.05) than other pastures which had <5% dead material content. The dead material content of Rg/wc pasture was less than 1% and significantly lower (P<0.05) than all cocksfoot based pastures during the same period. In 2007/08, the only significant difference (P<0.05) in dead material content of pastures was in September 2007 when Cf/bal, Cf/wc and Cf/Cc pastures had 9-11% dead material content compared with 4-5% in Cf/sub and Rg/wc pastures (Figure 3.8j).

3.3.8 Nutritive value of herbage on offer

Rg/wc pastures tended to have a higher metabolisable energy (ME) content of herbage on offer than all cocksfoot based pastures in spring 2006 (Figure 3.9a). However, the difference was only significant (P<0.05) in September 2006. The ME content in all grass-clover pastures ranged between 11.5 and 12.3 MJ ME/kg DM during spring months (September-November) with a decreasing trend until March 2007. The decline was more dramatic in annual clover pastures and reached a minimum of 9.5 MJ ME/kg DM in March 2007. Annual clover pastures (Cf/bal and Cf/sub) had generally lower ME content than perennial clover (Cf/Cc, Cf/wc and Rg/wc) pastures from December 2006 to March 2007. The ME content increased in all pastures after March, ranging between 10.8 (Cf/Cc) and 11.9 (Cf/wc) MJ ME/kg DM. The ME content of lucerne ranged between 11.3 and 11.9 MJ ME/kg DM from September 2006 until March 2007 before it dropped to 10.5 MJ ME/kg DM in April 2007. It then increased to 12.0 MJ ME/kg DM in June 2007.

The ME content of herbage on offer was more stable during spring 2007 (September to

November) compared with spring 2006 (Figure 3.9b). The metabolisable energy content of pastures and lucerne ranged from 11.3-12.2 MJ ME/kg DM from September to November followed by a sharp decline to below 10.2 MJ ME/kg DM in each pasture and lucerne in December 2007. Rg/wc pastures had 0.3 MJ ME/kg DM higher (P<0.05) ME content than Cf/bal and Cf/wc pastures in October 2007. ME content was generally stable through January to April 2008 and ranged between 10.9 and 11.4 MJ ME/kg DM in all pastures.

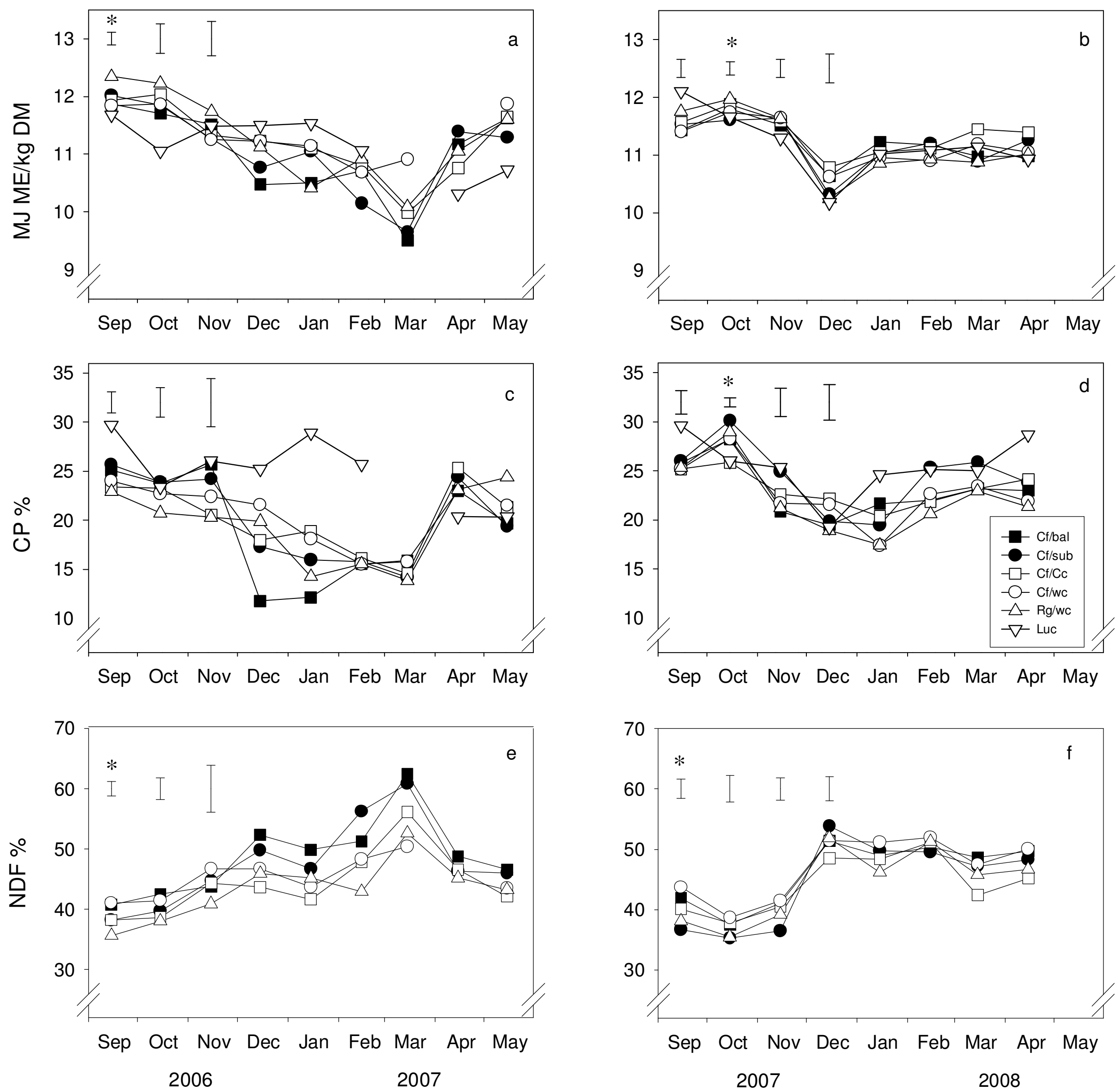

Figure 3.9 Mean monthly metabolisable energy MJ ME/kg DM (a, b), CP % (c, d) and NDF % (e, f) of herbage on offer from five pasture treatments at Lincoln University in 2006/07 and 2007/08. Bars represent LSD above the period stats when a statistical analysis was done. * = when ANOVA was significant (P<0.05).

The CP content of herbage on offer was highest in early spring (September to October) and varied between 23% (Rg/wc) and 26% (Cf/sub) (Figure 3.9c). The CP content of lucerne ranged between 23% and 30% for the same period and remained >25% until March 2007. However there was a constant decrease of crude protein content of grass-clover pastures until March 2007 when average crude protein content of pastures was around 15% before it increased to above 20% in April. Among pasture treatments annual clover pastures (Cf/bal and Cf/sub) tended to have a higher CP content than perennial clover pastures (Cf/Cc, Cf/wc and Rg/wc) through September to December 2006 (Figure 3.9c). However the difference among pastures was not significant (P>0.05) during that period. Annual clover pastures appeared to have lower or similar CP content compared with perennial clover pastures during summer and autumn. Rg/wc pasture tended to have lower CP content from November to March along with Cf/bal pasture which had a 6 week spell in spring 2006.

The CP content of pastures on offer was generally higher in 2007/08 than 2006/07 (Figure 3.9d). Cf/sub pastures and lucerne gave the highest CP content through September to December (25-30%) and from February to March (25-26%) in 2007/08. Cf/sub pastures had significantly higher (P<0.05) CP content than other pasture treatments except Rg/wc while Cf/Cc pastures had the lowest (P<0.05) CP content in October 2007.

Neutral detergent fibre (NDF) content of herbage on offer was the lowest in September 2006 when it ranged between 36% (Rg/wc) and 41% (Cf/wc) (Figure 3.9e). All pastures generally had an increasing NDF content until March 2007 when it reached a peak (50% in Cf/wc-62% in Cf/bal) before it declined sharply until May 2007. Rg/wc pastures appeared to have the lowest NDF content from September to December 2006, while Cf/wc and Cf/bal pastures gave the highest NDF concentrations. Annual clover pastures (Cf/bal and Cf/sub) tended to have higher NDF content than perennial clover pastures from December 2006 to May 2007. Cf/wc pasture gave the highest NDF content (35-39%) through September to November, while Cf/sub had the lowest NDF values (35-36%) during the same period. In 2007/08, both annual and perennial clover pastures had variable NDF contents, ranging from 35-54% from December 2007 to May 2008 (Figure 3.9f). NDF content of pasture was only significantly different ($P<0.05$) at the beginning of experiment in September 2006 and 2007.

3.4 Discussion

The results show that different pasture mixtures and lucerne were superior at different times of the year, with no single pasture combination consistently providing higher animal liveweight gains per head or per hectare than others throughout the 2 year study period. These results are consistent with the previous findings from the 'Maxclover' experiment reported by Brown *et al*. (2006) and Mills *et al*. (2008a). Furthermore, variation from year to year with climatic conditions occurred. This indicates that different pasture mixtures may find a niche on a dryland farm and combinations of species in pastures may be needed to cope with year to year variation and support feed supply on a self contained dryland livestock farm.

3.4.1 Seasonal animal production per hectare from grass/clover pastures

3.4.1.1 Spring

The highest sheep production per hectare was obtained in spring in both years. Averaged over two years, spring production of 365 kg LW/ha accounted for 62% of the total annual animal production. The results from this study support the importance of maximizing liveweight gain per head to increase animal production in spring when rainfall and relatively low evapotranspiration ensure adequate water for plant growth before the onset of summer droughts on dryland sheep farms (O'Connor *et al*., 1968; Korte *et al*., 1987).

The importance of liveweight gain per head during spring was reflected by the higher animal production of ~380 kg LW/ha in Cf/sub, Cf/Cc and Rg/wc pastures compared with Cf/wc and Cf/bal which produced only 320 and 250 kg LW/ha respectively (Figure 3.5). This was despite fewer grazing days on Cf/sub and Cf/Cc than white clover pastures sown with both cocksfoot and ryegrass, reflecting the higher sheep liveweight gain per head (Figure 3.3) from these pastures compensated for fewer grazing days (Table 3.6). In spring 2007, Cf/sub pastures gave superior animal production of 476 kg LW/ha when compared with the next best performing Cf/Cc pasture that produced 365 kg LW/ha. The Cf/sub pastures supported more animals, more grazing days and on occasion higher liveweight gain per head in spring 2007.

3.4.1.2 Summer

Average animal production per hectare from all grass clover based pastures was reduced by more than 70% in summer compared with spring in both years (Figure 3.5). This reflected the restricted pasture growth caused by lack of soil moisture (Salinger, 2003; Moot *et al*., 2008) and lower pasture nutritive value on offer (Figure 3.10). The reduction in animal liveweight production per ha was less severe in the Cf/bal pastures in summer 2006/07. These pastures provided 70-100 kg LW/ha greater animal production than other grass/clover pastures. This reflects the long spell of 7 weeks to allow flowering for seed production. This caused an accumulation of high herbage mass in Cf/bal pastures which consequently provided grazing animals higher pasture allowance and opportunity to selectively graze during summer (Cosgrove & Edwards, 2007). This was not evident in 2007 when spelling did not occur to enhance seed production (Tables 3.3 and 3.4; Figure 3.6).

Of note is that the average animal production per hectare from grass-clover pastures in the dry summer of 2007/08 was similar to the previous summer (2006/07) in spite of an average 195 fewer grazing days. It appeared that an average of 22 g/head/d higher animal liveweight gain per head offset the fewer grazing days in 2007/08. The other important factor leading to similar animal production was probably that dry ewes were used to remove the excess herbage during summer 2006/07 and these were not included in the animal production totals.

3.4.1.3 Autumn

Animal production was highly variable between autumn 2006 and 2007 and there was no distinctive superiority of any pasture treatment during this period in both years (Figure 3.5). However, there were marked differences in animal production per hectare between years, reflecting the impacts of the early onset of autumn rains in 2008. In New Zealand, the initiation of autumn rainfall is highly variable and this affects both animal and herbage production, particularly in pastures where the main legumes are annual clovers (Dear & Loveland, 1984; Moot *et al*., 2003). A rainfall event (63 mm) on 15 February 2008 triggered the germination of annual clover seedlings and provided moisture for plant growth (Figure 3.1). This led to 94 more grazing days and 54 g/head/d higher animal liveweight gain per head compared with the previous autumn when the first significant autumn rainfall started on 14 March 2007 (33 mm). This was despite grazing being completed 24 days earlier in autumn 2008 because of lack of pasture growth caused by low rainfall. The Cf/sub pastures benefited most from early autumn rains which possibly led to higher subterranean clover production (Moot *et al*., 2003) and gave the greatest production of 195 kg LW/ha followed by Cf/Cc (157 kg LW/ha) and then Rg/wc (137 kg LW/ha) and Cf/bal (112 kg LW/ha). The superiority of Cf/sub on providing high liveweight gains per hectare may also been improved in autumn, if grazing had not been delayed to allow subterranean clover seedlings to reach six leaf stage (Tables 3.3 and 3.4). This is recommended to allow successful subterranean clover seedling establishment in autumn (Moot *et al*., 2003) and to support spring production (Smetham, 1990).

3.4.2 Complementarity of lucerne

Lucerne provided the highest animal production per hectare in spring (421 kg LW/ha), summer (308 kg LW/ha) and autumn (90 kg LW/ha) in 2006/07. Similar animal production (414 kg LW/ha) from lucerne in spring 2007 was only exceeded by Cf/sub pastures with 474 kg LW/ha (Figure 3.5). This was despite grazing commencing 24 days later in lucerne than the grass/clover pastures in spring 2007 (Tables 3.3 and 3.4). The higher liveweight gain per hectare from lucerne compared to all grass/clover pastures in both years was mainly due to higher liveweight gain per head (>200 g/head/d) during spring (Figures 3.3 and 3.4). The superiority of lucerne in supporting higher liveweight gains per head was most distinctive during summer when lambs grew 70-110 g/head/d faster than the average grass/clover pastures.

The greater total productivity of lucerne when compared to grass-clover pastures is well known particularly in summer dry environments since lucerne has the ability to grow during dry periods if there is moisture deeper in the soil profile (Reeve & Sharkey, 1980; Brown & Moot, 2004). This allows it to maintain high production due to its deep tap root (Figure 3.6; Brown *et al.*, 2006). The other advantage of lucerne is that lucerne retains its high nutritive value and provides more consistent growth rates during summer months compared with decreasing nutritive value in grass/clover pastures (Figure 3.9; Brown & Moot, 2004). This explains the superior animal production from lucerne during summer compared with grass-clover based pastures in this study. These results are consistent with the previous findings of Brown *et al.* (2006) and highlight the complementarity of lucerne to subterranean clover based pastures in dryland farming where grass-clover pastures can be grazed one month earlier than lucerne. The subterranean clover pastures support high liveweight gain per head in early spring, with lambs to be finished on lucerne. Lucerne may also offer opportunities to spell subterranean clover pastures earlier in spring so as to enhance seed production in paddocks or low subterranean clover populations. The value of closing earlier to increased subterranean clover abundance is considered further in Chapter 5.

3.4.3 Liveweight gain per head

Higher liveweight gain per head during early-mid spring 2006 was generally obtained from pastures (Cf/Cc and Rg/wc) with higher clover content (16-18% of total dry matter) and pre grazing herbage mass (1950-2000 kg DM/ha). Despite generally low clover content (<20%) of pastures in spring, it appeared that increases in clover content (Figure 3.8) had positive impacts on sheep liveweight gain per head and per hectare (Figures 3.4 and 3.5). Of note was that the higher clover content and pre grazing herbage mass tended to occur together in the same treatment (Figure 3.10). The importance of legume content for sheep liveweight gain per head was also highlighted in spring 2007 when average clover content was 37% in Cf/sub pastures (Figure 3.8). The Cf/sub pastures gave higher sheep liveweight gain per head (173 g/hd/d) and more grazing days (827) than other pastures which led to greater animal production per hectare during spring 2007. The influence of clover content and pre grazing herbage mass on liveweight gain per head with hoggets was consistent with the findings of Hyslop *et al.* (2000) and Litherland and Lambert (2000) who reported improved liveweight gains when animals were offered pastures with higher clover content and herbage mass.

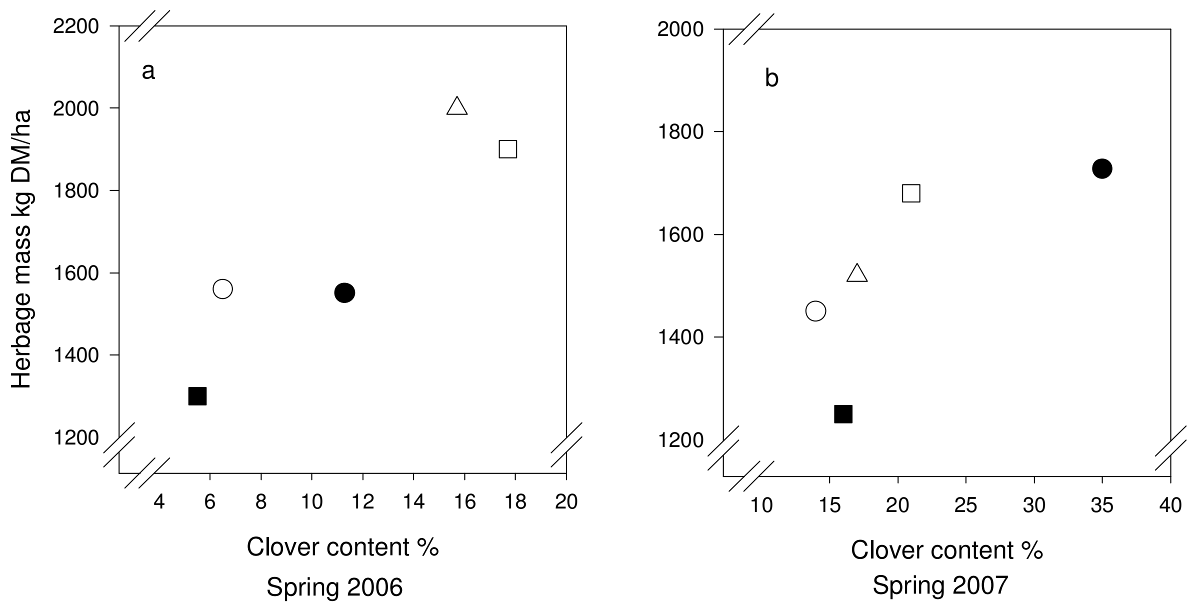

Figure 3.10 Mean pre grazing herbage mass of Cf/bal (■), Cf/sub (●), Cf/Cc(□), Cf/wc (○), Rg/wc (Δ) pasture treatments relative to clover content of pastures on offer in spring (a) 2006 and (b) 2007.

Sheep liveweight gain per head showed a similar trend to the ME content of pastures (Figure 3.11), demonstrating the importance of ME as a predictor of liveweight gain (Waghorn & Clark, 2004; Litherland & Lambert, 2000). The early spring period resulted in the highest animal liveweight gain per head with a continuous decline towards November-December at varying rates in each pasture. This was due to decreasing feeding value and generally lower herbage growth in grass/clover pastures. Overall, the ME and CP content of pastures were the highest in September and October and began to decline in all grass/clover pastures towards summer due to moisture stress, increasing maturity of the leaves (switch from vegetative to reproductive growth) and natural senescence of annual clovers (Lambert & Litherland, 2000).

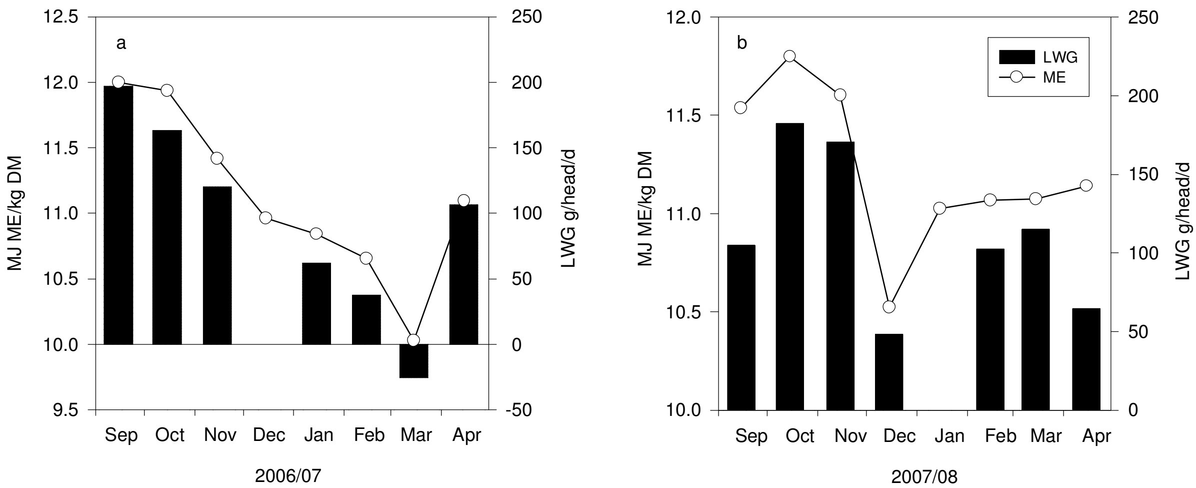

Figure 3.11 Average sheep liveweight gain per head (g/head/d) relative to mean ME content of pastures in (a) 2006/07 and (b) 2007/08. Data are averaged across liveweight gain per head and mean ME content of pastures.

The lowest ME, CP and highest NDF concentration of pastures were obtained when the dead material content of herbage on offer was the maximum (27.4% in March 2006 and 17.2% December 2007; Figure 3.9). This also coincided with the periods when sheep liveweight gain per head was the lowest in both years (Figure 3.11). Litherland and Lambert (2007) explained the amount of dead material in the pasture is the main determinant of pasture quality and the ME content of dead material is low (4-8 MJ ME/kg DM, Litherland & Lambert, 2007). The impact of the dead material content on the nutritive value was still obvious in summer 2006/07 when white clover content increased up to 50% in some grass clover based pastures owing to atypically high rainfall (Figure 3.1). The results from this study are also consistent with the findings of Sheath *et al.* (2001) who reported decreases in animal performance when dead material content of pasture is high since this pasture component has low feeding value and reduces voluntary intake. It is also noteworthy that the ryegrass pastures appeared to have greater ME content than cocksfoot pastures presumably due to lower dead material content

(2%) in both spring seasons. In contrast, the higher weed content of up to 50% in ryegrass pastures compared with cocksfoot pastures (~9%) did not seem to affect sheep liveweight gain per head or nutritive value of pastures during spring when plants were still vegetative (Litherland & Lambert, 2007).

Of note is that the ME and CP content of pastures did not respond to changes in clover content as expected particularly in spring 2007 (Figures 3.8 and 3.9). For example, in spite of an average of 40% clover content in Cf/sub pastures, the ME and CP contents were generally similar with other pasture treatments with <20% clover content. However, increased animal production per hectare from Cf/sub pastures indicates that the high clover content of Cf/sub pastures might have increased total clover and pasture production (Mills *et al*., 2008a), which in turn resulted in higher total carrying capacity (or grazing days) during spring. High clover content might have also promoted the intake of the high quality legume and allowed more selection opportunities (Cosgrove & Edwards, 2007).

3.4.4 Grazing management

Although the "put and take" stocking method was applied, higher than average rainfall during late spring 2006 and early summer 2007 caused more pasture growth than expected. Thus the higher pre and post grazing herbage mass in summer 2006/07 than 2007/08 implies that stocking rate was not high enough for optimum pasture and animal production (Figures 3.6 and 3.7). The low grazing intensity in summer 2006/07 is indicated by the increased dead material content which resulted in lower nutritive value of herbage on offer in the grass/clover pastures (Litherland & Lambert, 2007). Another example is that the high Cf/Cc pasture pre grazing herbage mass which was up to 1000 kg DM/ha greater than other pastures during the autumn period (Figure 3.6). This indicates that stocking rate was too low and cocksfoot was probably shading regrowth of the sown Caucasian and the volunteer white clover.

The study was carried out with hoggets in spring and mean liveweight gain per head varied from 129 to 177 g/hd/d over two spring periods (Figure 3.3). Compared to pre-weaning lamb liveweight gains of approximately 300 g/hd/d, reported by Muir *et al*. (2003) and Ates *et al*. (2006), the lower liveweight gains per head reported in this study may have been mainly due to ewe hoggets which are less sensitive than lambs in terms of liveweight gains, being used as grazing animals in spring (Rattray *et al*., 1987; Nicol, 1989). The experiment was also done with rotational grazing rather than continuous grazing which is common on many farms during lactation and best management practices for each pasture treatment. It is likely that herbage mass, pasture composition and animal performance will be sensitive to stocking rate and the class of animals (Bransby, 1989). Therefore, in the next chapter the most productive grass clover combination, Cf/sub pasture, was tested under continuous grazing at two stocking rates using lactating ewes and their twin lambs.

These results show the importance of high quality legume spring feed for animal production in dryland farms. This was highlighted particularly with the Cf/sub pasture treatments which also provided good maintenance feed during summer. It is possible that similar benefits may occur with other grass-subterranean clover combinations such as tall fescue or perennial ryegrass (Ates *et al*., 2006; Muir *et al*., 2000). Although the most common pasture combination in New Zealand of ryegrass and white clover does not perform well in dryland (Brock & Hay, 2001), subterranean clover may be a better companion to perennial ryegrass which was not considered in this experiment. Therefore, the productivity and persistence of ryegrass-subterranean clover pastures under continuous grazing at two stocking rates is explored and compared with cocksfoot subterranean clover pastures in Chapter 6.

3.5 Conclusions

The following main conclusions can be drawn from this chapter.

- Lucerne supported the highest animal production from mid spring to autumn. Animal production from lucerne was 42-85% higher than all grass based pastures in both summer periods.
- Cf/sub pasture provided equal (381 kg LW/ha in 2006) or higher (476 kg LW/ha in 2007) animal production than other grass pastures in spring. The results from this experiment highlight the complementarity of lucerne with subterranean clover for dryland pastures.
- Sheep liveweight gain per head was closely related to the ME content of herbage on offer. Pasture quality deteriorated in summer and therefore animal production was reduced.
- A combination of species in pasture mixtures may be needed to cope with seasonal and year to year variation and provide the most efficient feed supply required for dryland farms.

Chapter 4

Liveweight gain of sheep from cocksfoot-subterranean clover dryland based pastures managed at high and low stocking rate in spring

4.1 Introduction

An important aim in grazing management of pastures is to optimize animal and herbage production. Stocking rate is one of the most important decisions as it can affect both animal and pasture performance (Smetham, 1990). The general relationship of animal production to stocking rate is that individual animal liveweight gain per head increases at lower stocking rates (Bransby, 1989), reflecting more herbage mass on offer to livestock and improved diet quality, in particular the relative amounts of dead, green leaf and legume eaten (Cosgrove & Edwards, 2007). Diet quality may also be enhanced relative to the herbage on offer due to greater opportunities for selective grazing (Burns *et al.*, 1989). In contrast, animal production per hectare increases to a peak point then declines as stocking rate increases. This is because decreasing liveweight gain per head as a response to decreasing pasture allowance and intake is not compensated for by the increased number of animals after the peak point (Jones & Sandland, 1974).

While the effects of stocking rate on per head and per hectare production are well defined for ryegrass-white clover pastures (Smetham, 1975; Harris, 1981; Scarisbrick, 1971), less information is available for dryland pastures based on annual legumes. In particular, the effect of fixed stocking rate as pasture quality and mass decline towards summer due to the onset of dry conditions and plant senescence has not been defined. In dryland pastures containing annual legumes such as subterranean clover, stocking rate in spring is likely to be a crucial decision that affects both the liveweight gain of lambs and the longer term persistence of the annual pasture species. In spring, there is high feed demand from lactating ewes and their lambs as farmers attempt to finish lambs before the onset of summer dry. The late winter, early spring growth pattern of subterranean clover (Chapter 3; Smetham, 2003a; Moot *et al.*, 2003) is well suited to support this high feed demand. However, subterranean clover is dependant on adequate seed production for persistence and productivity, and grazing that is too intense may reduce this and seedling numbers in subsequent year (Ates *et al.*, 2006). It is hypothesized that lower stocking rates may lead to greater lamb growth rates, with reduced impact on subterranean clover seed production than higher stocking rates. Hence, a lower stocking rate may be a management strategy to promote clover content in paddocks of low subterranean clover content.

To help providing management guidelines for spring grazing management of subterranean clover based pastures, this study compared liveweight gain at a stocking rate of 13.9 ewes/ha, typical of dryland farms in Canterbury in spring (10-14 ewes/ha) with a lower stocking rate of 8.3 ewes/ha. The determination of these stocking rates was done in the light of a previous study on dry, stony soils at Ashley Dene, Canterbury (Ates *et al.*, 2006). In this study, LW gain and pasture composition was examined at 10 and 20 ewes with twin lambs/ha in spring. In a dry spring, LW gain of lambs in both stocking rates exceeded 300 g/head/day. However in both treatments there was a detrimental effect on subterranean clover reproduction with little seedling established in autumn. Thus a lower stocking rate (8.3 ewes/ha) was chosen to ensure low grazing pressure. This study was conducted in a cocksfoot-subterranean clover based dryland pasture over two spring seasons. The specific objectives were to:

1- Quantify the effect of stocking rate on liveweight gain per head and per hectare.
2- Determine the effect of stocking rate on pasture nutritive value in spring.

Chapter 5 will deal with the results of the effect of grazing intensity and duration of grazing in spring on subterranean clover seed production and subsequent performance.

4.2 Materials and methods

4.2.1 Site description

The experiment was conducted from September 2006 to November 2008 in a 2.9 ha paddock C9A(S) at Ashley Dene, the Lincoln University dryland research farm, Canterbury, New Zealand (43° 38 'S, 172° 19 'E, 11 m a.s.l.). The paddock is slightly undulating with small (~50 cm) variations in topography.

4.2.2 Soil characteristics

The soil is a Lismore stony silt loam (Pallic Orthic Brown Soil; Udic Haplustept loamy skeletal) (Hewitt, 1998) with an average of 60 mm available water holding capacity in the top 1.0 m (Webb *et al.*, 2000). The parent materials of these soils are predominantly loess or sediments derived from quartzo-feldpathic rocks (greywacke) (Hewitt, 1998). The soil has a shallow layer of 0.18 m topsoil at the surface, containing more than 7% by weight of stones on a compact sandy gravel content of very stony fine sandy loam subsoil (Cox, 1978).

4.2.3 Soil fertility

A total of 20 soil cores was taken at random across the site to 75 mm depth on 30 July 2006, 4 August 2007 and 23 August 2008. A sub sample of the bulked soil was analysed by Ministry of Agriculture and Fisheries Quick Test (MAF QT) procedures. Data from each year are presented in Table 4.1. Based on soil test results, a total of 200 kg/ha sulphur super 20 (20.8% S, 18% Ca and 8.1% P) was applied to the paddock on 18 August 2006 before the grazing experiment started. Over the two year study, only SO_4^-S levels of 2-4 µg/g were lower than the optimum range, while K levels were higher than the optimum levels (McLaren & Cameron, 1996).

Table 4.1 Soil test results from paddock C9(A)S at Ashley Dene, Lincoln University Research Farm, from 2006 to 2008.

Year	pH	Olsen P µg/ml	SO_4^-S (µg/g)	Ca^{++}	K^+	Mg^{++}	Na^+
				-------------(meq/100 g)-------------			
2006	6.4	18	4	10	14	17	6
2007	6.4	30	4	9	24	19	5
2008	6.1	25	2	10	21	20	5
Optimum levels*	6-6.5	12-20	8-16	10-15	5-8	20-30	5-10

* McLaren and Cameron (1996) for pasture growth.

4.2.4 Meteorological conditions

Meteorological data were collected from Ashley Dene climate station, located 1 km from the experiment site.

4.2.4.1 Rainfall and temperature

Ashley Dene has a mean annual rainfall of 625 mm. Rainfall and air temperatures at Ashley Dene during the experimental period (August 2006 to November 2008) are given in Figure 4.1. It is noteworthy that rainfall through October to December in 2006 and through July to September 2008 was above average, while October and November 2008 was below average. Temperature was also lower than average from December 2006 to February 2007.

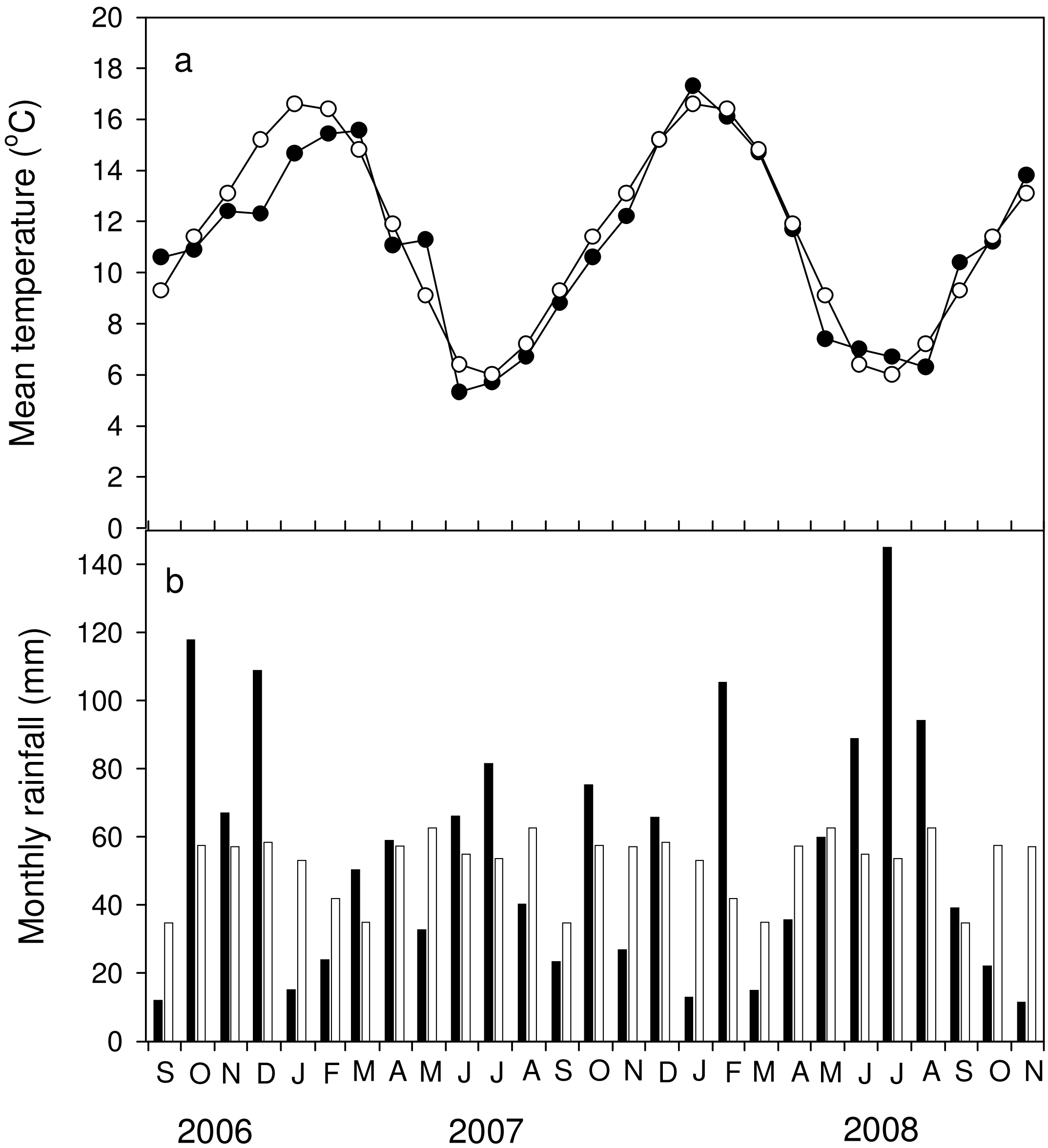

Figure 4.1 Mean monthly air temperature (a) (●) and monthly rainfall (b) (■) at Ashley Dene from 1 September 2006 to 30 November 2008. Long term averages (2001-2008) are shown for temperature (○) and rainfall (□).

4.2.5 Pasture establishment

The paddock was sprayed with glyphosate, cultivated and split into four blocks in September 2002. Blocks were not of equal size due to the trapezoid shape of the paddock and ranged from 0.55 to 0.91 ha. Prior to the experiment, the paddock had been in lucerne for 7 years. Each block was divided into five subplots (16 x 87 m) which were randomly allocated to five seed mixtures on 7 October 2002. The five treatments comprised perennial ryegrass sown at 0, 5, 10 or 15 kg/ha with 2 kg/ha of cocksfoot and 2 kg/ha of white clover, and perennial ryegrass sown at 10 kg/ha ryegrass and 2 kg/ha white clover but with no cocksfoot (Table 4.2). The establishment and persistence of white clover was poor with white clover cover of <0.1% in March 2005. All plots were then direct drilled across the original 16 m x 87 m main plots with 10 kg/ha of subterranean clover (5 kg/ha 'Leura' and 5 kg/ha 'Campeda') and balansa clover (3 kg/ha 'Bolta') on 18 March 2005. Four strips, each 10 m wide were not drilled to act as controls lacking annual clovers. This gave 2 x 10 m wide strips with no overdrilled subterranean clover in each main plot to provide an indication of the value of subterranean clover compared with the negligible white clover and the resident annual cluster clover (Appendix 16).

Table 4.2 Seed sowing rates (kg/ha) and cultivars sown in paddock C9(A)S, Lincoln University dryland research farm in Canterbury.

Establishment	Plant species	Cultivars	Sowing rates (kg/ha)				
			a	b	c	d	e
Original mixture (7 October 2002)	Cocksfoot	'Vision'	2	2	2	2	0
	Ryegrass	'Aries HD AR1'	0	5	10	15	10
	White clover	' Grasslands Demand'	2	2	2	2	2
Overdrilled annual clovers (18 March 2005)	Sub clover	'Campeda'	5	5	5	5	5
	Sub clover	'Leura'	5	5	5	5	5
	Balansa clover	'Bolta'	3	3	3	3	3

Botanical composition was scored by visual estimates (% cover) in three (2 quadrats on annual clover drilled area and 1 quadrat on no annual clover drilled area) randomly placed 1 m^2 quadrats on each sowing rate treatment in each main block on 25 September 2006. The percentage cocksfoot cover was similar (P>0.05) in each cocksfoot pastures overdrilled with annual clovers and varied from 38.3 to 45.8%. The ryegrass cover was similar at 5 (3.9%), 10 (6.5%) and 15 kg/ha (6.6%) sowing rates but lower (P<0.001) than pure (10 kg/ha) ryegrass pastures (58.9%). The subterranean clover cover did not differ significantly (P=0.54) across each sowing rates and ranged from 41.8 to 51.8%. There was little (< 1%) white clover cover across the whole five sowing treatments. The percentage bare ground cover of 20.8% in pastures grown without annual clovers was significantly higher (P<0.001) compared with 3.2% in pastures overdrilled with annual clovers.

Table 4.3 Percentage botanical composition of five sowing rate treatments in areas sown with and without annual clovers.

Sowing rate treatments	CF	RG	Sub clover	Balansa clover	White clover	Cluster clover	Annual weeds	Perennial weeds	Bare ground
					%				
a + AC	44.1	0.7	50.8	0.9	0.0	0.2	1.3	0.0	2.1
a - AC	66.2	1.0	0.0	0.0	0.7	2.7	3.3	0.2	26.0
b + AC	44.3	2.1	46.2	1.2	0.0	0.4	1.7	0.0	4.3
b - AC	63.5	5.7	0.0	0.0	0.5	2.8	2.2	0.0	25.3
c + AC	38.4	9.5	45.3	0.8	0.0	0.8	1.4	0.0	3.8
c - AC	57.3	14.3	4.8	0.1	0.0	3.1	2.3	0.2	18.0
d + AC	45.8	3.4	45.3	1.2	0.0	0.3	0.8	0.1	3.1
d - AC	60.5	9.8	0.0	0.0	0.3	3.0	2.2	0.3	23.8
e+ AC	0.0	44.4	48.7	0.9	0.0	0.6	2.9	1.4	1.1
e- AC	0.0	73.8	0.0	0.0	0.2	10.2	3.4	2.2	10.2
P_{SR}	*0.001*	*0.001*	0.54	0.86	0.40	*0.06*	0.15	0.10	0.17
P_{AC}	*0.001*	*0.001*	*0.001*	*0.001*	0.03	*0.001*	*0.02*	0.15	*0.001*
$P_{SR \times AC}$	0.16	*0.001*	0.41	0.67	0.53	0.07	0.70	0.48	0.187
$S.E.M_{SR \times AC}$	3.74	1.79	3.82	0.20	0.19	1.08	0.55	0.39	3.07

* P values are from ANOVA for effects of sowing rate (SR), annual clovers (AC) and interaction (SR x AC). Subscript CF= Cocksfoot, RG= Ryegrass. Sowing rate treatments: a= 2 (wc) 2 (cf), 0 (rg) kg/ha, b= 2 (wc) 2 (cf), 5 (rg) kg/ha, c= 2 (wc) 2 (cf), 10 (rg) kg/ha, d=2 (wc) 2 (cf), 15 (rg) kg/ha, e=2 (wc) 0 (cf), 10 (rg) kg/ha.

4.2.6 Stocking rate treatments for spring grazing experiments

The original four blocks were fenced and grazing treatments were imposed on three of the four original blocks in September 2006 (Appendix 16). The smallest fourth block was used to run spare ewes and lambs of similar stock class which could be used as replacements if required in the main experiment. Each of the three larger blocks was split in half and randomly allocated to the two main plot grazing treatments of high (13.9 (range 13.2-14.8) ewes with twin lambs/ha) or low (8.3 ewes with twin lambs/ha) stocking rate for spring 2006 and spring 2007. Coopworth ewes with 6-12 day old twin lambs were selected on initial liveweights for spring grazing experiments. Unfasted ewes (mean initial liveweight (LW)= 69 kg in 2006 and 63 kg in 2007) and mixed sex lambs (mean initial LW= 8.6 kg in 2006 and 6.8 kg in 2007) were weighed and ear tagged at the beginning of each experiment and randomly allocated to the six main plots.

The grazing experiments ran for 77 days in 2006 from 19 September to 5 December and 88 days in 2007 from 23 August to 19 November. Both low and high stocking rates were repeated on the same plots in each year. Ewes and lambs grazed continuously on the main plots for each spring period. Treatments were not balanced for lamb sex. The sex of lambs was not recorded in 2006. There were 11 male and 21 female lambs in the high stocking rate and 11 male and 9 female in the low stocking treatment in 2007.

4.2.7 Grazing management outside the spring experimental period

After weaning, dry ewes were used to reduce the accummulated herbage mass in all plots to ~900 kg DM/ha. This was done by a total of 400 dry ewes rotationally grazed from mid-January to mid-February in 2007 and from mid-January to end of January in 2008. Pastures were then spelled from grazing to allow annual clovers to re-establish following autumn rains, before being grazed by 18 hoggets/ha from 23 April until 2 June 2007 and with 21 hoggets/ha from 14 March to 29 April 2008. Plots were not grazed to simulate normal spelling of lambing paddocks during winter when ewes would usually be on winter forage crops.

4.2.8 Measurements

4.2.8.1 Liveweight gains

All animals were weighed unfasted during spring on 19 September, 16 October, 10 November and 5 December 2006 and 23 August, 16 October and 19 November 2007. A total of 2 ewes affected by flystrike were replaced with spare animals of similar liveweight that have been grazing on the fourth replicate in both years. Their weight gains were not recorded but their grazing days were noted to provide data for the calculation of liveweight gain per hectare. Liveweight gain per head (g/head/day) was calculated for core animals on plots between weighing dates. Liveweight gain per hectare (kg/ha/day) was calculated for each stocking rate treatment by multiplying liveweight gain per head by the average stocking rate over the period. No data were recorded from the second measurement on 24 September 2007 due to a malfunction in the sheep weighing scales. Animal liveweights were not measured during summer and autumn grazing periods.

4.2.8.2 Herbage mass

Herbage mass (kg DM/ha) was measured weekly during spring grazing experiments using a calibrated rising plate meter. A total of 20 rising plate meter readings was taken across the area in each of the five sowing mixture treatments present in each grazing main plot, giving a total 100 readings per stocking rate main plot in spring 2006. Rising plate meter readings were calibrated by double sampling four, 0.2 m^2 quadrats per stocking rate plot in each pasture type. Each quadrat was cut to 10 mm residual height with electric hand shears from ryegrass and cocksfoot pastures grown with and without annual clovers in each plot at weekly intervals and samples were dried at 70 ^{o}C to a constant weight and weighed. Plate meter readings were calibrated by regression against herbage masses in spring 2006 and the same regression data were used for spring 2007 (Table 4.3).

Table 4.4 Linear equations for cocksfoot and ryegrass pastures by regression between plate meter readings and herbage mass.

Period	Pasture type	Stocking rate	Regression	r^2
September-October	Cocksfoot	High	y=307.53x	0.76
September-October	Cocksfoot	Low	y=330.48x	0.77
September-October	Ryegrass	High	y=331.50x	0.91
September-October	Ryegrass	Low	y=337.5x	0.77
November-December	Cocksfoot	High	y=292.3x	0.80
November-December	Cocksfoot	Low	y=317.27x	0.78
November-December	Ryegrass	High	y=306.53x	0.72
November-December	Ryegrass	Low	y=308.02x	0.80

4.2.8.3 Herbage on offer and nutritive value

A total of 50-75 snip samples, representative of pasture eaten by sheep, were collected by hand randomly across pasture in each stocking rate main plot at weekly intervals. Sub samples were sorted to sown grass (cocksfoot and ryegrass), subterranean clover, balansa clover, white clover, cluster clover, dead material, annual grasses and broadleaf weeds and dried in an oven at 70 ^{o}C to a constant weight. Percentage botanical composition of samples on a dry weight basis was then calculated. A well mixed bulk sample was ground in a mill with a 1 mm stainless steel sieve (Cyclotec Mill, USA) for chemical analyses. Ground samples were analyzed for nitrogen content (N %), digestible organic matter in dry matter (DOMD %) acid detergent fiber (ADF %) and neutral detergent fiber (NDF %) by near infra-red spectroscopy using a NIRS-Foss NIR Systems 5000 Rapid Content Analyser (Adesogan 2000). Crude protein content of herbage on offer was calculated by N%*6.25 and metabolisable energy (ME) (MJ kg/DM) content was calculated by DOMD*0.16 (Nicol, 1989). Analyses were carried out by the Lincoln University Analytical Service.

Herbage macro (N, P, S, Mg, Ca, Na, and K) and micro (Fe, Mn, Zn and Co) nutrient concentrations were also determined for each liveweight gain measurement period of the experiment in both years. All snip samples collected within the same liveweight gain measurement period were combined for each stocking rate main plot after grinding for mineral analyses. Analyses were conducted by R.J. Hill Laboratories Limited by using Nitric Acid/Hydrogen Peroxide digestion followed by ICP-OES for P, K, S, Ca, Mg, Na, Fe, Mn, Zn and Co and Dumas combustion for N.

4.2.9 Statistical analyses

Liveweight gain per head (g/d) and per ha (kg/ha) were analysed by one-way ANOVA with repeated measures for each liveweight gain measurement period. Mean liveweight gain per head averaged across the 3 to 7 ewes in each plot was used as the response variable rather than individual sheep. Herbage mass (kg DM/ha) was analysed by ANOVA of a split plot design where stocking rate was the main plot and the pastures were the sub-plot treatments. The effect of stocking rate on the nutritive value of herbage on offer (CP, ME, DOMD, and NDF) and components of botanical composition (sown grasses, clovers, dead material and weeds contents) of herbage on offer were analysed by one-way ANOVA at each date. No statistical analyses could be performed on the mineral contentration of the herbage on offer as samples from the 3 plots of each stocking rate treatment were bulked for chemical analyses. Where ANOVA was significant, means were separated by Fisher's protected least significant difference (LSD) at $\alpha = 0.05$.

4.3 Results

4.3.1 Liveweight gain per head

Mean lamb liveweight gain per head was 75 g higher ($P<0.05$) at low than high stocking rate in 2006 (Table 4.4). Averaged over the entire spring period, lambs grew at 327 and 252 g/head/d at low and high stocking rates respectively. Lambs grew about 120 g/head/d faster ($P<0.01$) in the first two periods than the third period but the interaction between stocking rate and period was not significant ($P=0.45$). Mean lamb liveweight gain per head in 2007 was 100 g/head/d higher ($P<0.05$) at low than high stocking rate, but was not affected by period ($P=0.57$) or the interaction of stocking rate and period ($P=0.30$).

Table 4.5 Mean liveweight gain per individual lamb and ewe (g/head/d) in spring 2006 and 2007 under low (8.3 ewe/ha) and high (13.9 ewe/ha) stocking rates.

Year	Period	Lamb			Ewe		
		Low	High	Mean	Low	High	Mean
2006	19 Sept-16 Oct	353	308	331_a	172	78	125_a
	16 Oct-10 Nov	367	291	329_a	8	2	5_b
	10 Nov-05 Dec	260	158	209_b	2	-124	-61_c
	Mean	$\mathbf{327_a}$	$\mathbf{252_b}$	**290**	**61**	**-44**	**9**
	P_{SR}*		*0.05*			*0.09*	
	P_P		*0.01*			*0.02*	
	$P_{SR\ x\ P}$		*0.45*			*0.52*	
	$S.E.M_{SR}$		*12.0*			*16.6*	
	$S.E.M_P$		*15.1*			*37.1*	
	$S.E.M_{SR\ x\ P}$		*21.2*			*46.0*	
2007	23 Aug-16 Oct	376	287	332	125_a	45_c	85
	16 Oct-19 Nov	393	282	338	265_b	-24_d	121
	Mean	$\mathbf{385_a}$	$\mathbf{285_b}$	**335**	**195**	**11**	**103**
	P_{SR}*		*0.03*			*0.03*	
	P_P		*0.57*			*0.27*	
	$P_{SR\ x\ P}$		*0.30*			*0.02*	
	$S.E.M_{SR}$		*11.6*			*21.2*	
	$S.E.M_P$		*6.3*			*20.1*	
	$S.E.M_{SR\ x\ P}$		*13.3*			*29.2*	

* P values are from ANOVA for effects of stocking rate (SR), period (P) and interaction (SR x P). Values with different letter subscripts are significantly different ($\alpha=0.05$)

In 2006, there was a significant decline (P<0.05) in ewe liveweight gain per head over the grazing periods at both stocking rates (Table 4.4). However, neither stocking rate (P=0.09) nor the interaction (P=0.52) of stocking rate and period affected ewe liveweight gain per head. In 2007, an interaction (P<0.05) occurred between stocking rate and period for ewe liveweight gain per head. This was higher at low than high stocking rate at both measurement periods but increased 140 g/head/d from the first period to the final period at low stocking rate compared with a decline from a 45 g/head/d gain to 24 g/head/d loss of liveweight at the high stocking rate.

4.3.2 Liveweight gain per hectare

In 2006, a significant interaction (P<0.01) occurred between stocking rate and grazing period for lamb liveweight gain per hectare (Table 4.5). This was 2.5-3.2 kg/ha/d higher at high stocking rate for the first two periods but not different in the third period. In 2007, lamb liveweight gain per hectare over the entire spring period at high stocking rate was 1.5 kg/ha/d higher (P<0.05) than at the low stocking rate (Table 4.5). In 2007, there was no significant effect of period (P=0.75) or the interaction of stocking rate and period (P=0.31) on lamb liveweight gain per hectare.

In 2006, ewe liveweight gain per hectare was unaffected (P=0.18) by stocking rate but declined significantly (P<0.05) from 1.24 kg/ha/d at the first measurement to -0.81 kg/ha/d over the third period (Table 4.5). There was no significant interaction (P=0.39) between stocking rate and period. In 2007, ewe liveweight gain per hectare increased 1.2 kg/ha/d at low stocking rate from the first period to the final period but decreased 0.6 kg/ha/d at high stocking rate. This caused a significant interaction (P<0.05) between stocking rate and period.

Table 4.6 Mean liveweight gain per hectare for lambs and ewes (kg/ha/d) in spring 2006 and 2007 under low (8.3 ewe/ha) and high (13.9 ewe/ha) stocking rates.

Year	Period	Lamb			Ewe		
		Low	High	Mean	Low	High	Mean
2006	19 Sept-16 Oct	5.9_a	9.1_b	7.5	1.43	1.04	1.24_a
	16 Oct-10 Nov	6.1_a	8.6_b	7.4	0.07	-0.02	0.03_{ab}
	10 Nov-05 Dec	4.3_c	4.1_c	4.2	0.02	-1.64	-0.81_b
	Mean	**5.4**	**7.3**	**6.4**	$\mathbf{0.50_a}$	$\mathbf{-0.21_b}$	**0.15**
	P_{SR}*		*0.07*			*0.18*	
	P_P		*<0.01*			*0.02*	
	$P_{SR\ x\ P}$		*0.01*			*0.39*	
	S.E.M $_{SR}$		*0.37*			*0.25*	
	S.E.M $_P$		*0.22*			*0.41*	
	S.E.M $_{SR\ x\ P}$		*0.45*			*0.54*	
2007	23 Aug-16 Oct	6.2	8.0	7.1	1.0_a	0.9_a	1.0
	16 Oct-19 Nov	6.5	7.8	7.2	2.2_b	-0.3_c	1.0
	Mean	$\mathbf{6.4_a}$	$\mathbf{7.9_b}$	**7.2**	**1.6**	**0.3**	**1.0**
	P_{SR}*		*0.04*			*0.03*	
	P_P		*0.75*			*0.92*	
	$P_{SR\ x\ P}$		*0.31*			*0.05*	
	S.E.M $_{SR}$		*0.20*			*0.16*	
	S.E.M $_P$		*0.13*			*0.30*	
	S.E.M $_{SR\ x\ P}$		*0.25*			*0.34*	

* P values are from ANOVA for effects of stocking rate (SR), period (P) and interaction (SR x P). Values with different letter subscript are significantly different (α =0.05).

4.3.3 Herbage mass

In 2006, herbage mass was similar at both stocking rates until the fourth week on 12 October. It was then lower (P<0.05) at high than low stocking rate in both cocksfoot and ryegrass sub plot pastures (Figure 4.2a). Herbage mass ranged from 900 to 2250 kg DM/ha at high stocking rate and from 1600 to 2380 kg DM/ha at low stocking rate in cocksfoot areas of main plots. Herbage mass was initially 200 kg DM/ha higher (P<0.05) in ryegrass than cocksfoot plots but decreased faster in the ryegrass than cocksfoot plots possibly due to selective grazing for ryegrass at both stocking rates. It became consistently lower (P<0.05) until the end of the grazing period. Herbage mass of ryegrass plots varied between 600 and 2000 kg DM/ha at high and between 800 and 1950 kg DM/ha at low stocking rate. An interaction (P<0.05) occurred in the last two weeks of grazing since the difference between high and low stocking rate plots in ryegrass sub plots was smaller than that in cocksfoot sub plots.

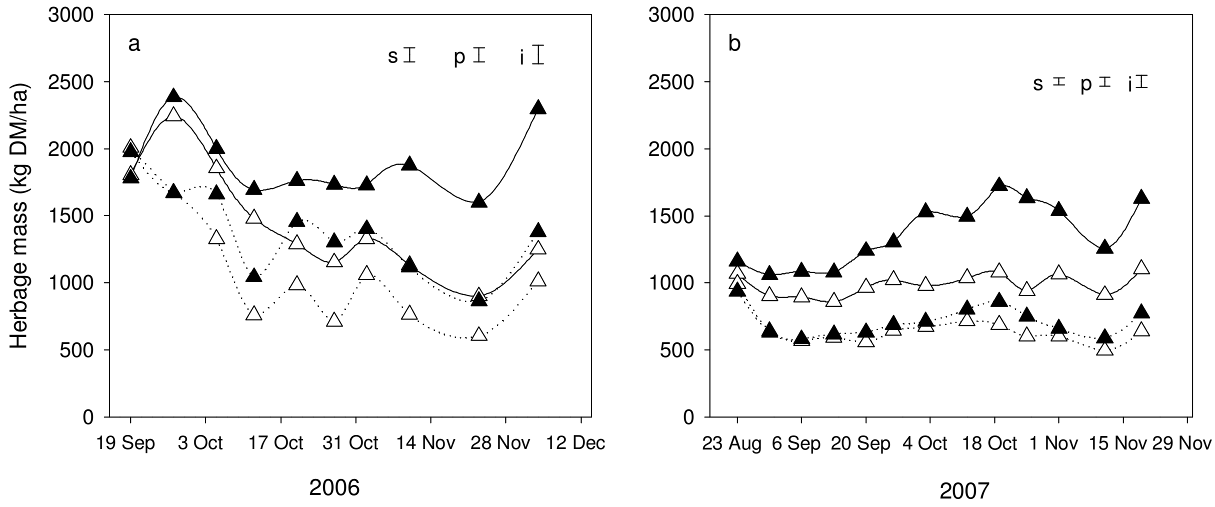

Figure 4.2 Weekly herbage mass (kg/DM/ha) of ryegrass (······) and cocksfoot (—) pastures under low (▲) (8.3 ewes/ha) and high (Δ) (13.9 ewes/ha) stocking rates in 2006 (a) and 2007 (b). Bars represent maximum SEM for s) stocking rate, p) pasture type and i) interaction of stocking rate x pasture type.

There was an earlier start to grazing in 2007 than 2006 and in most cases pastures were maintained at a lower mass (Figure 4.2b). The difference between stocking rates on both ryegrass and cocksfoot sub-plots became significant after the fourth week of grazing when pasture was 150 kg DM/ha lower (P<0.05) in high than low stocking rate. Herbage mass in ryegrass plots declined to 600 kg DM/ha in the first two weeks at both stocking rates and stayed around this level until the end of experiment. Herbage mass fluctuated between 850 and 1080 kg DM/ha in high stocking rate cocksfoot pastures and ranged from 1050 to 1720 kg DM/ha in low stocking rate plots. An interaction between stocking rate and pasture treatments occurred after the fifth week of grazing. Herbage mass in low stocking rate was higher than high stocking rate in cocksfoot pastures, whereas ryegrass pastures had similar herbage mass at both stocking rates. The exception was the final week of the grazing experiment when the difference between low and high stocking rate in cocksfoot pastures became larger ($P<0.05$) than that in ryegrass pastures.

4.3.4 Botanical composition of herbage on offer

Clover comprised more than 40% of ground cover in the herbage on offer at both stocking rates at the beginning of spring grazing in both years (Figure 4.3). In 2006, the clover percentage declined quickly to 5% in the high stocking rate plots after the fourth week of grazing. Clover percentage declined more slowly in low stocking rate plots. In 2007, the initial clover content of >40% in low stocking rate plots was sustained until the last week of grazing in November before it dropped to ~20%. In contrast clover content decreased gradually to 10% in high stocking rate plots. The higher percentage of clover in herbage on offer in low stocking rate plots was ($P<0.05$) different at one harvest date in 2006 and four dates in 2007. The dead material content averaged about 17% in high and 9% in low stocking rate and tended to increase in both years throughout spring (Figure 4.3e, f). The difference between stocking rates was only significant on one date in 2006 and three dates in 2007. The weed (annual grass and broadleaf weeds) percentage of pastures on offer was ≤5% on both stocking rates and it was only significant at one date in 2007 when high stocking rate had a higher ($P<0.05$) weed content than the low stocking rate (Figure 4.3g, h).

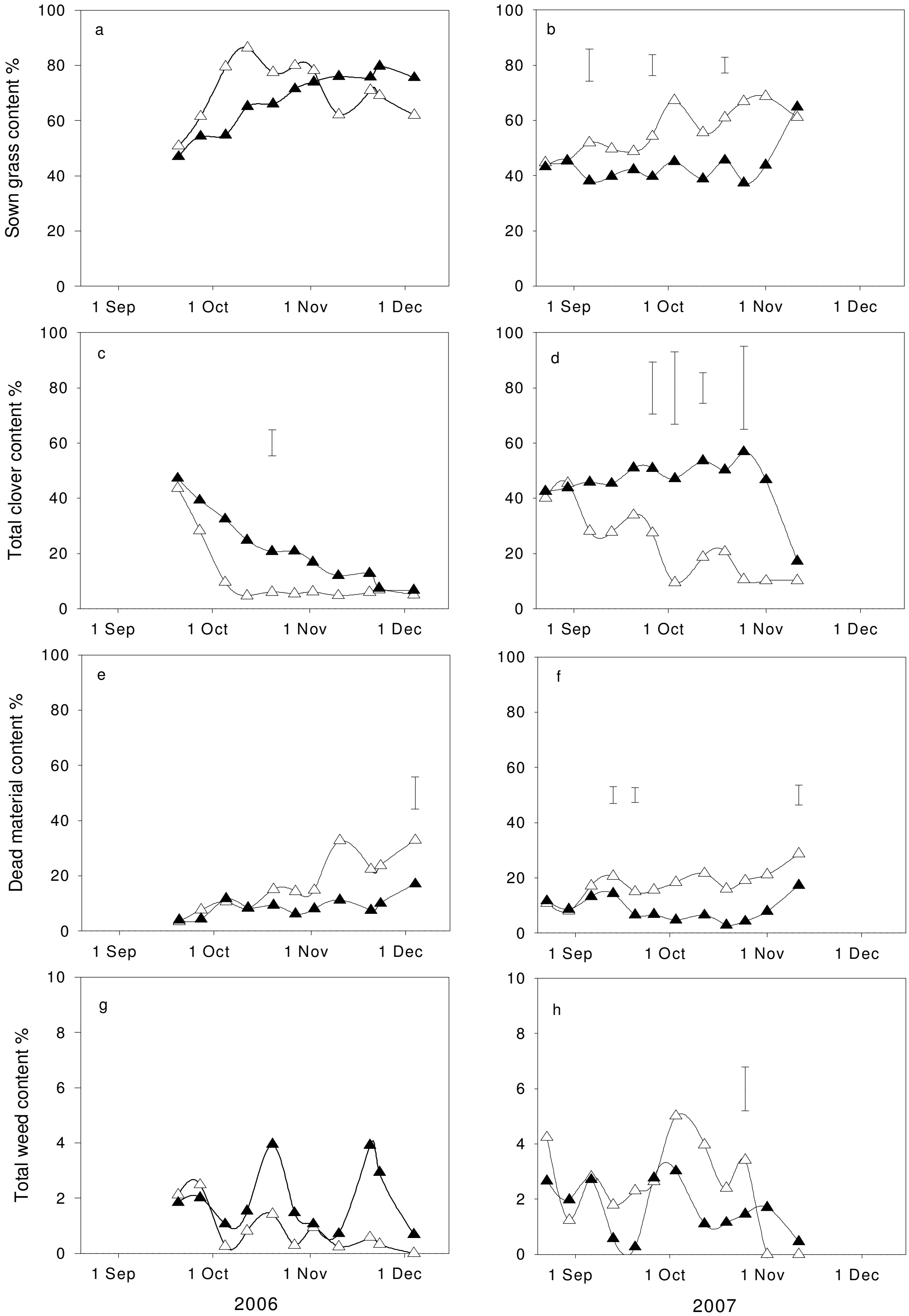

Figure 4.3 Total sown grasses (%) (a, b), total clovers (%) (c, d), dead material (%) (e, f) and total weed content (%) (g, h) of pastures on offer in spring 2006 and spring 2007 under low (▲) (8.3 ewes/ha) and high (Δ) (13.9 ewes/ha) stocking rates. Bars represent the LSD above the date when the ANOVA was significant ($P<0.05$).

4.3.5 Nutritive value of herbage on offer

The metabolisable energy (ME) content of the herbage on offer in 2006 ranged from 10.5 to 12.1 MJ ME/kg DM and had a declining trend over the grazing period (Figure 4.4a). The ME content tended to be higher at low than high stocking rate but the difference was only significant ($P<0.05$) at the final week of grazing. The ME content of the herbage on offer ranged from 10.7 to 11.7 MJ ME/kg DM in 2007 (Figure 4.4b). The trend of higher ME in low than high stocking rate was only significant ($P<0.05$) on 15 October 2007. The crude protein content of the herbage on offer in 2006 was similar in both stocking rates and gradually decreased from 22 to 13% as the grazing season progressed (Figure 4.4c). The CP content was relatively static through spring 2007 and ranged from 21 to 25% before it declined to approximately 20% at the final week of grazing. The difference between stocking rates was only significant ($P<0.05$) on one date in 2007 (Figure 4.4d). NDF content of the herbage on offer appeared to be higher at high than low stocking rate but the difference was only significant ($P<0.05$) at three dates in 2006 and two dates in 2007. There was an increase in NDF content of herbage on offer from 33 to 55% through the grazing period in 2006 and from 36 to 47% in 2007 (Figure 4.4e, f).

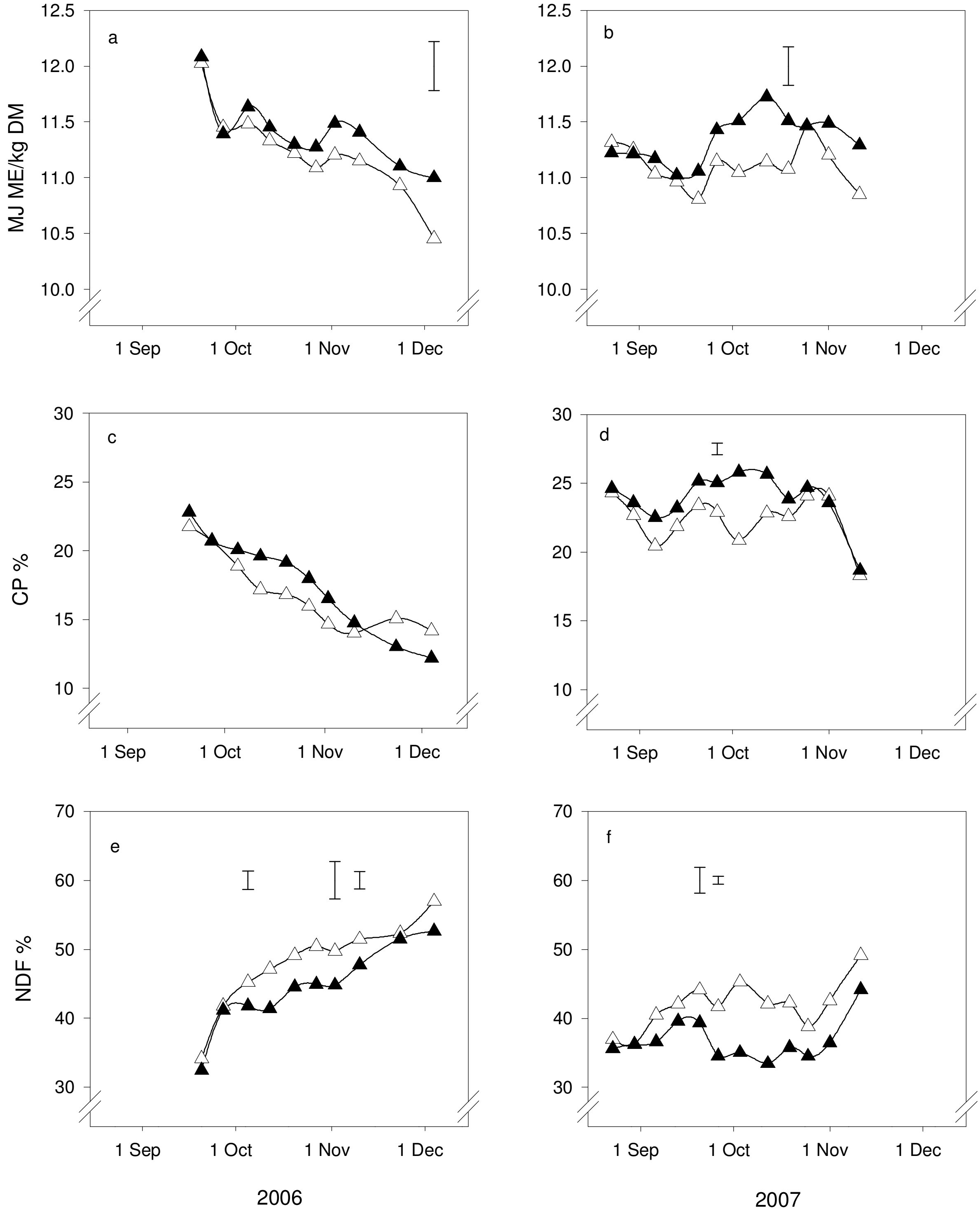

Figure 4.4 Metabolisable energy (MJ ME/kg DM) (a, b), crude protein (%) (c, d) and neutral detergent fiber (%) (e, f) concentration in spring 2006 and spring 2007 under low (▲) (8.3 ewes/ha) and high (Δ) (13.9 ewes/ha) stocking rates. Bars are LSD above the date when the ANOVA was significant (P<0.05).

4.4 Discussion

4.4.1 Liveweight gain per head

This study confirms previous findings of Muir *et al.* (2003), Ates *et al.* (2006) that high growth rates (>300g/d) of twin lambs can be achieved on dryland pastures where subterranean clover is the main legume. The results here for lamb growth rate ranged from 252 to 385 g/head/d and compare favourably with the high twin lamb growth rates of 407 g/head/d reported by Muir *et al.* (2003). In the Muir *et al.* (2003) study, high milk producing East Friesian x Romney ewes and rams were selected to produce high progeny growth rate and the ewes and lambs grazed on a newly established pastures of perennial ryegrass, white and subterranean clovers that were maintained at a herbage mass of 1800-2600 kg DM/ha at Poukawa, Hawkes Bay. However, this study was carried out with a Coopworth flock on lower herbage masses (1000-1500 kg DM/ha). This indicates the potential of subterranean based pasture to produce high lamb liveweight gains in adverse conditions.

Stocking rate had a large effect on liveweight gain per head. Over the entire spring period lambs grew 75 and 100 g/head/d faster at low than high stocking rate in 2006 and 2007, respectively (Table 4.5). Ates *et al.* (2006) reported a similar effect of stocking rate with tall fescue-subterranean clover pastures in a grazing experiment where lamb liveweight gains were 374 and 307 g/head/d at low and high stocking rate, respectively. This was despite the high stocking rate treatment in the current study being lower than the study of Ates *et al.* (2006) (2006) (13.9 vs. 20 ewes/ha) and the wetter than average spring in 2006 in this study, leading to more sustained subterranean clover growth at both stocking rates. The high growth rates in the Ates *et al.*, (2006) study at high stocking rate may reflect a high level of selective grazing of subterranean clover amongst sparse tall fescue as shown by severe grazing of subterranean clover.

The other key result was that higher lamb liveweight gain per hectare came at cost of reductions in ewe liveweight (Table 4.6). Ewe liveweight gain per animal was greater at the low than high stocking rate in all periods in both years. Ewes gained 4.9 and lost 0.9 kg at low and high stocking rate respectively in 2006, while ewes gained 15.5 and 1.6 kg at low and high stocking rate respectively in 2007. It has been reported that ewes commonly mobilize body tissues during the initial 4-6 weeks of lactation but liveweight gains can occur if ewes are offered allowances of ≥5 kg DM/ewe/d at later stages of lactation (Geenty, 1983). Both lamb and ewe liveweight gains were compromised by lower intake at high stocking rate at an extent of 124 and 24 g/head/d liveweight losses for the final period of the grazing experiment with ewes in 2006 and 2007, respectively. These losses in ewe liveweight may cause the necessity for supplemental feeding or high quality pasture to prevent low conception rates of ewes at mating (Rattray *et al.*, 1987). It has been reported that ewes will require a diet ME above 10 MJ ME/kg DM to grow 100 g/d (Litherland *et al.*, 2007). However it may be challenging to achieve this growth rate due to insufficient feed supply and poor pasture quality during summer.

4.4.1.1 Herbage mass

One factor contributing to the greater (75-100 g/head/d) lamb liveweight gain at low stocking rate was probably the 400-500 kg DM/ha higher herbage mass at low stocking rate. Litherland and Lambert (2000) reported that an increase of 260 kg DM/ha in herbage mass during lactation increased twin lamb growth rates by 50 g/d.

The difference between stocking rate treatments in herbage mass increased over spring by up to a maximum 900 kg DM/ha in both years (Figure 4.2). The relationship between pasture allowance and ewe liveweight gain responses became stronger when herbage mass dropped below 1500 kg DM/ha in 2006 and below 1000 kg DM/ha in the high stocking rate plots in 2007. Compared with lambs, ewes appeared to be affected more severely by lower herbage mass, responding with liveweight losses presumably to maintain milk production for twin lambs in both years (Geenty, 1983). Of note is that despite lower herbage mass, lamb liveweight gain per head was greater in 2007 than 2006, reflecting the positive impact of increased clover content in spring 2007 (mean 17% in 2006 vs. 35% in 2007).

4.4.1.2 Botanical composition and nutritive value

A further explanation for the higher lamb liveweight gain per head at low compared with high stocking rate probably reflects the greater proportion of clover (Hyslop *et al.*, 2000) and lower proportion of dead material. In general the ME content of the herbage on offer in the low stocking rate was 0.1-0.6 MJ ME/kg DM higher, although this was not always significant (Figure 4.4). However the intake of plant parts with high digestibility might be higher in low stocking rate owing to greater selection opportunity (Cosgrove & Edwards, 2007). Similar to the response of lamb liveweight gain to increasing herbage mass, Litherland and Lambert (2000) reported, an increase of 8% clover in pasture or 0.7 MJ ME/kg DM resulted in 50 g/head/d increase in twin lamb liveweight gain. The importance of clover on offer for lamb liveweight gain is highlighted further by the lower growth rates at both high and low stocking rates in the third period in spring 2006. The clover content declined to below 10% and growth rates fell to 260 and 158 g/head/d at low and high stocking rate, respectively (Table 4.5 and Figure 4.3).

The relationship between clover content and lamb liveweight gain was also consistent in spring 2007 when greater lamb liveweight gain at both high (17%) and low (12%) stocking rates was obtained with increased proportion of clover on offer (average 17% in 2006 vs. 35% in 2007) (Figure 4.5). When plotted together, overall, the relationship between clover content and lamb liveweight gain was similar to previous findings reported by Hyslop *et al.* (2000). They found that increases in white clover content in spring positively affected liveweight gain of lambs that grazed on perennial ryegrass or tall fescue based pastures.

There were contrasting changes in clover content between 2006 and 2007. The most likely explanation is the differences in start date of grazing, clover content and climate. The effect of grazing pressure might be offset by increased clover content as it occurred in spring 2007 when the decline rate in clover content was lower over grazing periods at both stocking rates (Figure 4.5). Of note is that the clover content in low stocking plots had an increasing rate over spring grazing in 2007 before it dropped to 20% at the final week due to senescence. Lactating ewes and their lambs have the potential to quickly reduce the clover content of subterranean clover pastures in spring, and particularly in dry seasons (Ates *et al.*, 2006). The effect of grazing on the clover component of pastures is generally more severe when clover content is low and at higher stocking rates. Although there may be a higher opportunity for selection at low stocking rate, this was outweighed by higher grazing pressure and intensity, and clover content decreased more rapidly at high stocking rate.

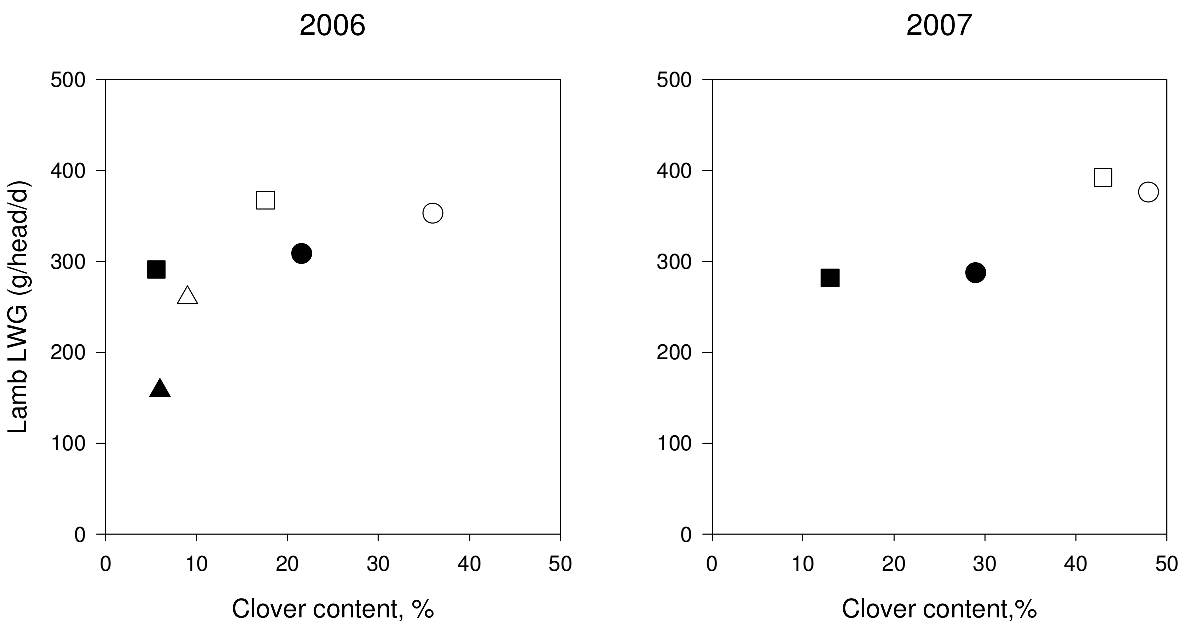

Figure 4.5 Lamb liveweight gain (LWG) (g/head/d) relative to clover content (%) of pastures on offer at high (black) and low (white) stocking rate during period 1 (○), 2 (□) and 3 (Δ) in spring 2006 and period 1 (○) and 2 (□) in spring 2007.

Generally the metabolisable energy and crude protein content of the herbage on offer followed similar trends with clover content and an inverse relationship with dead material content in both years. This finding may suggest that decreasing clover content in pasture coupled with increasing plant maturity and dead material led to a lower nutritive value towards late spring and particularly in 2006 when grazing extended into early December. Similarly, Mulholland *et al*. (1996) reported a rapid decline in the lamb growth rate from a pure subterranean clover pasture, associated with decreasing levels of digestible nutrients in the pasture and in the diet and increasing levels of structural plant components at the post flowering stage of subterranean clover. This is an important point to consider in subterranean clover dominant pastures and provides a strong reason for selling all lambs as soon as possible by mid November or move to other feed supplies such as lucerne.

Pasture quality inevitably declines with aging as cell wall/cell content ratio and the degree of lignification increases in late spring and summer. However the decline in quality with tissue age is lower in clovers (Lambert & Litherland, 2000). The proportion of legumes in the sward is also reported to be the main impact of botanical composition to nutritive value and legumes usually have higher crude protein content relative to grasses. In contrast, legumes have less cell wall components (NDF <40% of DM) with higher cell wall digestibility (Litherland & Lambert 2007). Thus, the most likely explanation for improved nutritive value at low stocking rate, particularly in 2007 was due to the greater clover proportion which provided high CP, ME and DOMD but low NDF. Greater clover proportion at low stocking rate in late spring may have reduced the impact of decline in overall pasture nutritive value because of aging.

Among macro minerals of herbage on offer, Ca and N appeared to be affected the most from grazing intensity and showed a similar decline with clover content of herbage on offer (Appendices 13 and 14). It has been reported by Walsh and Birrell (1987) that grasses are a poor source of Ca for ruminants. Therefore, the explanation for greater Ca and N contents at low than high stocking rate could be due to higher clover content of pastures at low stocking rate. In general, macro and micro nutrient content of herbage on offer was adequate for the requirements of grazing sheep reported by Grace (1983). The increased Fe and Mn concentration in high stocking rate towards summer was probably due to soil contamination (Metson *et al.*, 1979). This was mainly because lower herbage mass caused the collection of a higher proportion of herbage samples closer to the plant base which possibly had higher soil contamination risk.

4.4.2 Liveweight gain per hectare

Lower liveweight gain per head was compensated for by the greater number of animals in high stocking rate treatments with an average of 38% (2006) and 19% (2007) greater liveweight gain per hectare obtained from high stocking compared with low stocking rate (Table 4.6). Total meat production of lambs was greater at high than low stocking rate treatments by 140 kg/ha in 2006 and by 132 kg/ha in 2007. Ates *et al.* (2006) noted the same effect of stocking rate with greater lamb liveweight gains due to higher number of animals at both stocking rates (8.3 vs. 10 at LS and 13.9 vs. 20 ewes/ha at HS). Final lamb liveweights were lower at high than low stocking rate plots in this study with liveweight of 34 kg (low) and 29 kg (high) in 2006 and 41 kg (low) and 32 kg (high) in 2007. These results are consistent with the findings of Reeve and Sharkey (1980) who found a linear increase in number of lambs reared per hectare with increasing stocking rate however with a decline in carcass weights. Similarly, Lloyd Davies and Southey (2001) reported that stocking rate and grazing management affected pasture availability, leading to a lower proportion of lambs achieving 30 kg liveweight per lamb at higher stocking rate. The implications of these lamb growth rates at different times in spring to slaughter policy of lambs are considered in Chapter 7.

This study showed that the clover content declined throughout spring at a greater rate at high than low stocking rate. This raises the possibility that high liveweight gain per hectare at high stocking rate might be maintained at a cost to subterranean clover reproduction (Ates *et al.*, 2006). One purpose of lowering stocking rate may be to reduce grazing pressure on subterranean clover, so allowing increased seed production and seedling populations the following autumn. Lower stocking rates may also allow lambs to be finished for slaughter earlier in October or November than at high stocking rate. This may allow pastures to be spelled earlier in spring to enhance subterranean clover populations where they are low. Thus in the next chapter the effects of stocking rate and closing date on subterranean clover reproduction and subsequent herbage production will be examined.

4.5 Conclusion

The following main conclusions can be drawn from this chapter.

- This study showed that twin lamb liveweight gains of greater than of 300 g/head/d can be obtained from subterranean clover pastures in dryland environments at stocking rates exceeding 8 ewes/ha with twin lambs in spring.
- Stocking rate had a large effect on lamb liveweight gain. Lambs grew 75-100 g/head/d faster at low than high stocking rate but lower liveweight gain per head was compensated by greater number of animals at high stocking rate producing more liveweight per hectare.
- Both clover content and available herbage mass had large impacts on lamb liveweight gain. Lamb liveweight gain declined in response to decreasing clover content throughout spring.
- Lactating ewes and their lambs quickly reduce the clover content of subterranean clover pastures in the later part of spring, especially in drier seasons.

Chapter 5
The influence of spring grazing management on reproduction and herbage production of subterranean clover

5.1 Introduction

The previous two chapters demonstrated the importance of high legume content in spring for animal production in dryland farming sheep systems. Thus, when the clover content of pastures is low, it may be desirable to have methods to increase it. This chapter examines two approaches to increase the subterranean clover content of pastures by increasing the seed production in spring to encourage higher seedling recruitment in the following year.

Several studies have examined the subterranean clover seedling populations required for maximum DM production in dryland pastures (e.g. Smetham & Jack, 1995; Prioul & Silsbury, 1982). Smetham (2003a) recommended 500-1000 seedlings/m^2 to maximize herbage production the following autumn in mixed grass-clover pastures, and that paddocks below this should be identified as targets for strategies to increase seed populations. However, Smetham and Dear (1995) also noted that increased seedling size may compensate for low seedling numbers so that DM production, particularly in spring, may be less affected by seedling population.

One strategy to increase the subterranean clover content of pastures identified as having low legume content is early closing in spring. The rationale is that this prevents sheep from consuming leaves, runners, flowers and seed burrs (Ates *et al.*, 2006) and that the increased seed production that follows replenishes the seed bank for subsequent years. However, early closing date reduces the number of grazing days available during the critical spring liveweight gain period. Thus, identifying at which phenological stage in spring that closing enhances seed production is a priority. Previous studies with monocultures of subterranean clover (Collins, 1978; Young *et al*., 1994) showed the potential benefits of early closing on seed production. They reported that defoliation during flowering and burr formation decreased the seed yield at varying degrees. These studies were conducted with mechanically defoliated, pure subterranean clover swards. Whether similar results are applicable in mixed grazed pastures where competition and selective grazing may operate is unknown.

A further possible strategy to increase clover content is to graze paddocks at lower stocking rates in spring than those traditionally used. The rationale is that lower than normal stocking rates may allow sufficient leaves, runners, flowers and seed burrs to escape defoliation for the seed bank to be replenished (Ates *et al*., 2006). However, it is plausible that subterranean clover may suffer hard grazing even at low stocking rates. Sheep prefer grazing subterranean clover to grasses (Broom & Arnold, 1986) and selective grazing may be enhanced at high herbage masses (at low stocking rates) particularly when pastures are sparse (Burns *et al*., 1989). It is also possible that stocking rate may interact with closing date. Ru and Fortune (1999) noted that hard grazing in spring resulted in an increase in the number of growing points (and secondary branching). This may lead to potentially more sites for flower and burr production, which could increase seed production if combined with an early closing date.

In Chapter 4, the effect of two stocking rates on liveweight gain of sheep grazing subterranean clover cocksfoot pastures was considered. This showed that lambs grew faster at low than high stocking rate but lower liveweight gain per head was compensated for by a greater number of animals at high stocking rate producing more liveweight production per hectare. This chapter considers the effects of those stocking rates and closing dates in spring on subterranean clover pastures. The main aim of this study was to establish sustainable grazing management practices for subterranean clover pastures. The specific objectives were to:

1. Determine the effect of stocking rate and closing date in spring on subterranean clover morphology, seed production in spring and seedling recruitment the following autumn.
2. Determine the effect of stocking rate and closing date in spring on DM production of clover and grass in the following autumn and spring.

5.2 Materials and methods

The experiment was conducted within the stocking rate study described in Chapter 4. Information describing the site, location, soil, pasture establishment and meteorological conditions were presented in Chapter 4.

5.2.1 Experimental design

The experiment has three replicates of a split plot design. Stocking rate (low vs. high) was the main plot factor and closing date (4 levels in 2006 and 3 levels in 2007) was the sub plot factor.

5.2.1.1 Stocking rate treatments

The information about the stocking rate treatments and grazing durations were presented in Chapter 4.2.3.

5.2.1.2 Grazing exclusion treatments

Small 3x3 m sub-plots in each stocking rate treatment were fenced to exclude sheep at different times in spring to create four time of grazing exclusion treatments in 2006 and three in 2007. Grazing exclosure sub-plots in spring 2006 were located on plots originally sown with 10 kg/ha ryegrass + 2 kg/ha cocksfoot + 2 kg/ha white clover. In spring 2007, exclosures were on plots sown with 5 kg/ha ryegrass + 2 kg/ha cocksfoot + 2 kg/ha white clover (Chapter 4.2.2). The change was necessitated due to lack of space to place the 3x3 m sub-plots in the same sowing rate treatment plots in both years. However, these plots had a similar pasture composition according to visual estimations (Chapter 4.2.2). In 2006, the 3x3 m sub-plots were installed to mimic closing on 10 October, 26 October and 15 November. The remaining area of pasture was grazed until weaning on 5 December 2006 and then spelled. In 2007, closing date sub-plot fences were erected on 16 October and 1 November and pastures in all stocking rate main plots were spelled on 19 November 2007.

A description of the phenology of the subterranean clover plants at each closing date is given in Table 5.1. The first visible flowers were sighted on 27 September 2006 and closing dates corresponded to approximately 2, 4, 6 and 8 weeks after subterranean clover had started flowering. In 2007, the first visible flowers were sighted on 25 September and the closing dates coincided with 3, 5 and 8 weeks after early flowering (Table 5.1). The precise observation of flowering times of the 'Campeda' and 'Leura' subterranean clover cultivars were not attempted but the main flush of flowering occurred in mid October in both years. Fences around exclosure plots were pulled down before the summer grazing each year and left open during the remainder of year.

Plate 5.1 A view of the experimental site on paddock C9(A)S at Ashley Dene on 19 October 2007.

Table 5.1 Reproductive pheonology stage description of subterranean clover plants at the time of closing in spring 2006 and 2007.

Year	Closing date	Maturity stage	Stage description
2006	10 October	Early flowering	• 2 weeks after the first visible flower. • 40% plants flowering and 20% plants bearing immature burrs.
	26 October	Burr formation	• 4 weeks after the first visible flower. • 43% plants flowering and 50% plants bearing immature burrs. • Peduncles elongating and bending towards ground. • Some buried immature burrs were evident.
	15 November	Burr fill and maturation	• 6 weeks after the first visible flower. • 17% plants flowering and 76% plants bearing fully formed and immature burrs. • Burrs being formed and filled. Many burried burrs.
	5 December	Burr maturation and plant senescence	• 8 weeks after the first visible flower. • 8% plants flowering and 78% plants bearing fully formed and immature burrs. • Majority of the burrs were fully formed, filled with seeds and buried.
2007	16 October	Early flowering	• 3 weeks after the first visible flower. • 42% plants flowering and 24% plants bearing immature burrs.
	1 November	Burr formation	• 5 weeks after the first visible flower. • 75% plants flowering and 51% plants bearing fully formed and immature burrs. • Peduncles elongated and bended towards ground. Some buried burrs were observed. Few burrs were fully formed and filled with seeds.
	19 November	Burr fill and maturation	• 8 weeks after the first visible flower. • 15% plants flowering and 65% plants bearing fully formed and immature burrs. • Majority of the burrs were fully formed, filled with seeds and buried.

5.2.2 Measurements

5.2.2.1 Dry matter production

DM production from each closing date treatment during the period from autumn 2007 to spring 2008 was measured using quadrat cuts inside 1 m^2 exclosure cages placed in the 3 x 3 m sub plots (Table 5.1). Cages were placed on 8 February 2007 and production was measured on 23 April 2007 (autumn production). Cages were placed on a new site on 2 June 2007 and production was measured on 31 August, 4 October and 6 November in 2007 (winter-spring production) from the same cage site. At each harvest, an area of 0.2 m^2 under the cages was cut to a 20 mm stubble height with electric shears. After cutting, the same caged area was mown to 20 mm height and cages were replaced in the same sites. Similarly, to assess the effect of the closing date treatments in spring 2007, cages were placed on each sub plot on 14 February 2008 and herbage production was measured on 12 March, 24 April and 26 June (autumn production) and on 7 September, 6 October and 7 November in 2008 (winter-spring production) from the same cage sites.

Table 5.2 Exclosure cage cut dates and pasture regrowth durations from the closing date cages at high and low stocking rates at C9(A)S, Ashley Dene from 8 February 2007 to 7 November 2008.

Year	Season	Harvest	Regrowth period		Duration (days)
			Start	Finish	
2007	Autumn	1	8 February	23 April*	74
	Winter	2	2 June	31 August	90
	Spring	3	31 August	4 October	34
	Spring	4	4 October	6 November	33
2008	Autumn	1	14 February	12 March	27
	Autumn	2	12 March	24 April	43
	Autumn	3	24 April	26 June	63
	Winter	4	26 June	7 September	73
	Spring	5	7 September	6 October	29
	Spring	6	6 October	7 November	32

* Herbage production was not measured between 23 April 2007 and 2 June 2007 because 3 x 3 m closing date cages were open to grazing.

5.2.2.2 Botanical composition

The harvested herbage samples were stored in a cooler at 4 °C and were processed within 7 days after collection. Prior to drying, a sub-sample of approximately 400 pieces was sorted into cocksfoot, ryegrass, annual grass weeds, subterranean clover, white clover, cluster clover, dicot weeds and dead material. The quartering technique was used to obtain random subsamples from the total harvest (Cayley & Bird, 1996). Botanical composition samples were oven-dried at 70 ^{o}C to a constant weight and then used to calculate composition on DM basis.

5.2.2.3 Plant morphology and reproductive phenology

To describe plant morphology at each closing date (Table 5.1), two 0.2 m^2 quadrats were placed randomly in each 3 x 3 m closing date sub-plot in both years and all the subterranean clover plants were harvested with a knife to ground level. This sampling occurred on the day fences were erected except sub plots closed on 15 November 2006 were collected on 21 November 2006. Another set of subterranean clover plants were sampled from all closing date sub-plots after the end of the spring grazing experiment on 4 December 2007. Plants were then stratified into size categories after being lined up on the laboratory bench. Young plants which did not have runners were classified as 'small' and the rest were defined as 'big' plants. The number of subterranean clover plants was counted and the number of plants bearing flowers and burrs were noted.

A total of six subterranean clover plants was randomly selected from the 'big' plants for morphological and phenological measurements. For each plant, the runner length and the number of runners, leaves per plant, burrs and inflorescences were recorded. The runner length was measured from the main stem, arising from the taproot to the tip of each runner (primary and secondary runners). All flowers and immature burrs were counted and classified as total inflorescence number. Fully formed burrs and broken off peduncles were counted and classified as total burrs. Although fully formed burr numbers may have been overestimated with this process, as burrs may have been eaten, it was observed that the majority of these peduncles were broken during the plant harvest process. Sub-sampled subterranean clover plant leaves were dissected to measure the leaf area. All leaves were spread onto a plain A4 paper and photocopied to an A4 sized transparent paper. A leaf area meter (LiCor 3100 Area Meter from LiCor Ltd, USA) was then used to measure leaf areas on each transparent paper.

Plate 5.2 An example of randomly selected six 'big' subterranean clover plants from the low stocking pastures closed on 5 December 2006.

Plate 5.3 An example of 'small' subterranean clover plants from the pastures closed on 5 December 2006.

5.2.2.4 Soil seed bank

The initial subterranean clover buried seed population in the top 50 mm of soil was determined by taking 100 random soil cores, each 60 mm in diameter (total area of cores 0.28 m^2) across the paddock on 23 August 2006. Following the summer clean up grazing in each year, six random soil cores were taken in each 3x3 m closing date sub-plot on 16 March 2007 and 11 February 2008. On each occasion, soil cores collected from the same plots were bulked and washed to remove soil through mesh sieves. A total of three Retsch test sieves with sizes of 2 mm, 500 µm and 250 µm were used for separation of seeds from soil material. After the removal of the soil, individual subterranean clover seeds and seeds inside the burrs retained in each sieve were counted.

As a further indication of seed numbers in the soil and of the potential impacts of grazing and closing date treatments on seed populations and seedling establishment, a caged area of 1 m^2 inside each 3x3 m closing date sub-plot was sprayed with 'Roundup 360 SC' (a.i. glyphosate at 1.5 kg a.i./ha) to kill all existing vegetation before the germination of annual clovers in early February 2007 and 2008. All subterranean clover seedlings were counted and pulled out of ground in one randomly placed permanent 0.1 m^2 quadrat inside each cage on 5 April and 30 May 2007 and 5 March, 21 April and 30 August 2008. Seedling numbers were summed to give an indication of potential impacts of treatments on seed numbers per m^2 in the soil.

5.2.2.5 Seedling populations

Subterranean clover seedlings were counted in two randomly placed 0.01 m^2 quadrats in each 3x3 m closing date sub plot on 2 June 2007 and 8 May 2008. In autumn 2007, subterranean clover seeds germinated on 15 March after first significant autumn rain. In autumn 2008, the main seedling emergence occurred on 20 February with the early onset of rain (88 mm) on 15 February. A subsequent seven week dry period (5 March-30 April) occurred after emergence with only 37 mm of rainfall but the majority of seedlings survived from the first rainfall.

5.2.3 Statistical analyses

Total autumn and spring pasture and subterranean clover DM production, seed and seedling numbers, plant numbers in spring (big, small and total), runner numbers per plant, runner length per plant, number of leaves per plant, leaf area per plant, number of inflorescence per plant and percentage flowering and burr bearing plants were analysed by ANOVA with three replicates of a split plot design where stocking rate was the main plot factor and the closing date was the sub plot factor. Where ANOVA was significant, means were separated by Fishers protected LSD at $\alpha=0.05$. Plant number data (big, small and total) in both spring seasons were square root transformed to obtain homogeneous variances. For the number of fully formed burrs per plant in 2006, only the last two closing dates were analysed as ANOVA of three replicates of a split plot design where stocking rate was the main plot and the closing date was the sub-plot treatments. The number of fully formed burrs per plant in 2007 were analysed by ANOVA with three replicates of a completely randomized block design. In 2007, only the stocking rate effect at the last closing date was analyzed since earlier closing dates did not have fully formed burrs. Linear regressions between established seedling numbers and total DM and subterranean clover production in autumn and winter-spring seasons were calculated in 2007 and 2008. Regressions were fitted to data from each plot and slopes were compared by ANOVA of linear regression analyses. All the presented significant results are at $P<0.05$ level or less, unless otherwise stated.

5.3 Results

The effects of stocking rate, closing date and the interaction of stocking rate and closing date on the measured parameters between 2006 and 2008 are presented in Table 5.3.

Table 5.3 Level of significance for the effects of stocking rate (SR), closing date (CD) and the interaction (SRxCD) from ANOVA between 2006 and 2008 on the measured parameters.

Parameters	2006/2007			2007/2008		
	SR	CD	SRxCD	SR	CD	SRxCD
Measurements taken during spring grazing at each closing date						
Plant numbers/m^2						
Total	N.S.	N.S.	N.S.	**	N.S.	N.S.
Big	N.S.	N.S.	N.S.	*	N.S.	N.S.
Small	**	*	N.S.	N.S.	N.S.	N.S.
Vegetative						
Runner number/plant	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Runner length/plant	*	*	N.S.	*	*	**
Leaf number/plant	N.S.	***	N.S.	*	*	**
Leaf area/plant	N.S.	**	N.S.	*	***	***
Reproductive						
Flowering plants (%)	N.S.	**	*	N.S.	***	**
Plant bearing burrs (%)	N.S.	**	N.S.	N.S.	***	NS
Inflorescence number/plant	**	**	*	N.S.	***	**
Fully formed burrs number/plant	N.S.	***	*	***	-	-
Measurements taken following year+						
Regeneration of seedlings/m^2						
Areas treated with herbicide	**	***	N.S.	N.S.	**	N.S.
Mixed pastures	N.S.	**	N.S.	N.S.	***	N.S.
DM production (kg/ha)						
Total autumn	N.S.	*	N.S.	N.S.	N.S.	N.S.
Autumn subterranean clover	N.S.	**	N.S.	N.S.	*	N.S.
Total spring	*	N.S.	N.S.	N.S.	N.S.	N.S.
Spring subterranean clover	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Note: The levels of significance are 0.05 (*), 0.01 (**) and 0.001 (***). N.S. = not significant.
+ measuring the effects of spring grazing previous year.

5.3.1 Plant population and morphology

The total number of plants/m^2 in spring 2006 was unaffected by stocking rate (P=0.45) or closing date (P=0.37) (Figure 5.1a) (Table 5.3). The number of 'big' subterranean clover plants was similar (P=0.84) in both stocking rates and each closing date (P=0.82) during spring grazing (Figure 5.1c). The number of 'small' plants per m^2 at high stocking rate was approximately twice that at low stocking rate (P<0.01) with this effect persisting throughout spring (Figure 5.1e). The mean number of 'small' subterranean clover plants per m^2 in spring increased (P<0.05) from 278/m^2 on 10 October to 1290/m^2 on 26 October and then remained similar until the end of spring grazing at each closing date. This indicates significant recruitment of spring emerged seedlings.

In 2007, there were 50% more (P<0.05) subterranean clover plants at low (1923/m^2) than that at high stocking rate (1230/m^2). However, closing date did not affect (P=0.60) the total number of plants/m^2 (Figure 5.1b). The number of 'big' plants per m^2 in spring was also higher (P<0.05) at high than low stocking rate (Figure 5.1d). The mean number of 'small' subterranean clover plants ranged from 289 to 460/m^2. There tended to be more (P=0.09) at low than high stocking rate but the number of small plants was unaffected by closing date (P=0.37) (Figure 5.1f).

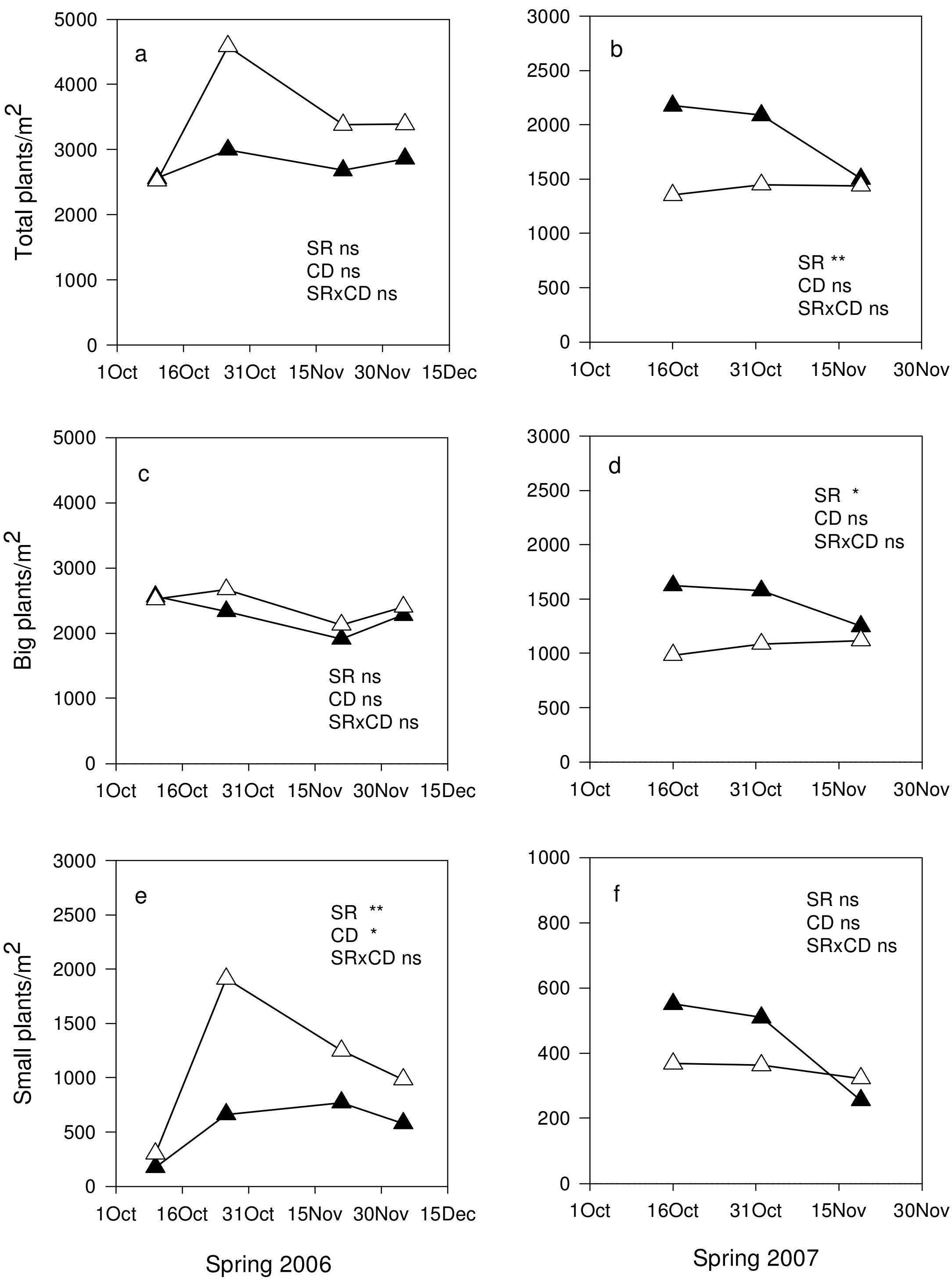

Figure 5.1 Total (a, b), big (c, d) and small (e, f) subterranean clover plant numbers (m^2) from pastures grazed at low (▲) and high (Δ) stocking rates at time of closing on 10 October, 26 October, 21 November and 5 December in 2006 and 16 October, 1 November and 19 November in 2007. Data are untransformed means. Test of significance was done on the square root transfromed plant numbers. The levels of significance are 0.05 (*), 0.01 (**) and n.s. = not significant. The y axis of spring 2006 and spring 2007 graphs are on different scale, reflecting greater plant numbers in 2006.

The number of runners per plant ranged from 3.0 to 3.5 and was unaffected by stocking rate or closing date in 2006 or 2007 (all P>0.05, Figure 5.2a, b) (Table 5.3). The mean runner length per plant in spring 2006 was approximately 8 cm longer (P<0.05) at low than high stocking rate (Figure 5.2c). There was also an effect (P<0.05) of closing date on runner length per plant in spring 2006. Runner length was similar for plots closed on 10 October (15.2 cm) and 26 October (18.3 cm) before declining to 11.7 cm for those closed on 21 November. Runner length then increased to 14.7 cm on 5 December which was a similar length to the first and third closing dates.

The mean runner length per plant in spring 2007 at low stocking rate was approximately double (P<0.01) that of high stocking rate (Figure 5.2d). There was also a significant closing date x stocking rate interaction (P<0.01) on runner length per plant in spring 2007 (Table 5.3). Runner length per plant increased from 14.1 cm on 16 October closing to 17.9 cm on 1 November closing before it decreased to 12.3 cm on 19 November closing at low stocking rate. In contrast, runner length per plant remained similar (~8 cm) for the high stocking rate at each closing date.

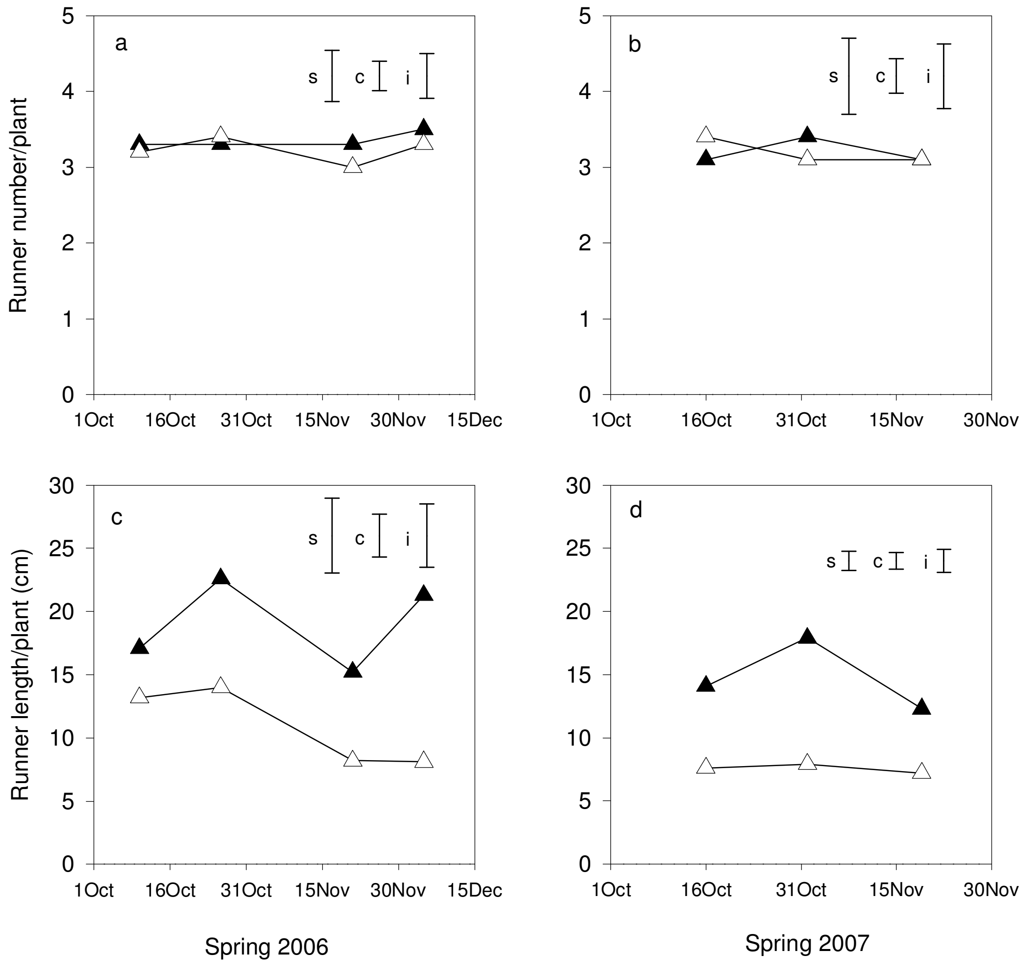

Figure 5.2 Runner number per plant (a, b) and runner length per plant (c, d) of subterranean clover plants from pastures grazed at low (▲) and high (Δ) stocking rates at time of closing on 10 October, 26 October, 21 November and 5 December in 2006 and 16 October, 1 November and 19 November in 2007. Bars represent L.S.D for the effect of stocking rate (s), closing date (c) and stocking rate x closing date interaction (i).

The total number of leaves per plant was lower (P<0.001) at the last closing date on 5 December than the first three closing dates, which all had similar values (Figure 5.3a). Mean leaf area per plant in 2006 was similar from the pastures closed on 10 October and 26 October but then decreased (P<0.01) to 3.66 cm^2 for those closed on 21 November compared with 1.97 cm^2 for the 5 December closing. There was no effect (P=0.11) of stocking rate or the interaction between stocking rate and closing date (P=0.19) on leaf area per plant in spring 2006 (Table 5.3).

An interaction occurred between stocking rate and closing date for leaf number (P<0.01) and leaf area (P<0.001) per plant in spring 2007. The number of leaves per plant was greater at the low stocking rate on 1 November but not on 16 October or 19 November (Figure 5.3b). Leaf area per plant was similar at all closing dates at a high stocking rate but declined between each closing date at a low stocking rate (Figure 5.3d). Leaf area per plant was greater at the first two closing dates only.

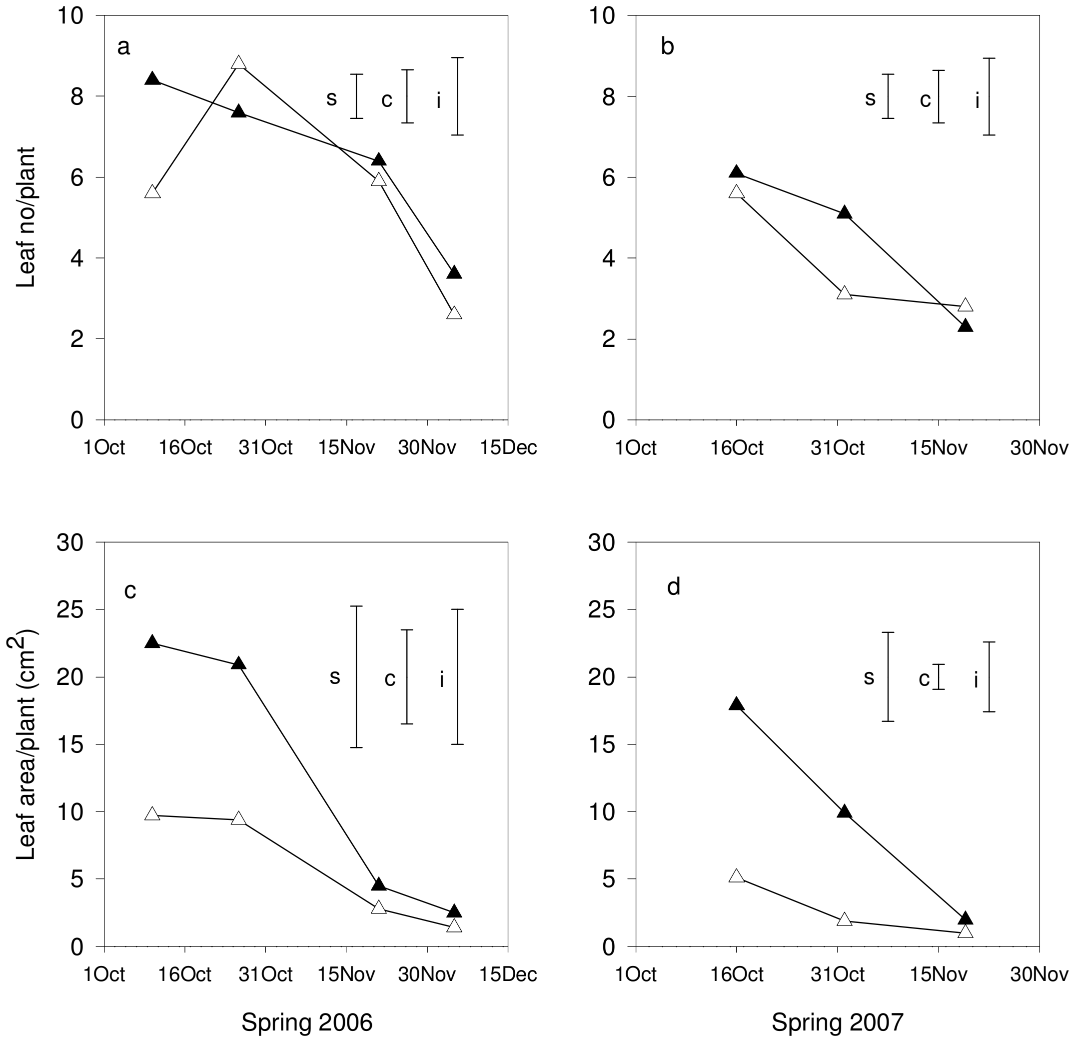

Figure 5.3 Subterranean clover leaf number per plant (a, b) and leaf area per plant (c, d) from pastures grazed at low (▲) and high (Δ) stocking rates at time of closing on 10 October, 26 October, 21 November and 5 December in 2006 and 16 October, 1 November and 19 November in 2007. Bars represent L.S.D for the effect of stocking rate (s), closing date (c) and stocking rate x closing date interaction (i).

There was an interaction ($P<0.05$) between stocking rate and closing date on the proportion of flowering plants in spring 2006 (Figure 5.4a). In most cases, the proportion of flowering plants declined with later closing. However, on 26 October there was a sharp rise in the proportion of flowering plants at low stocking rate, so that on this date only there was a higher proportion at low than high stocking rate. There was an effect ($P<0.01$) of closing date on the proportion of burr bearing plants in spring 2006, but no effect ($P=0.09$) of stocking rate or the interaction ($P=0.36$) (Figure 5.4c). The proportion of burr bearing plants increased from 23% on 10 October to 50% on 26 October and to 76% on 21 November and this was similar to 79% on 5 December.

In 2007, the proportion of flowering plants in both low and high stocking rates was similar on 16 October and 1 November. However, there was a more rapid decrease at the low than high stocking rate on 5 December so that the proportion of flowering plants was greater at high stocking rate (SR x CD interaction $P<0.01$) (Figure 5.4b). The proportion of plants bearing burrs in spring 2007 increased ($P<0.001$) from 24% on 16 October to 52% on 1 November and 66% on 19 November but was unaffected stocking rate ($P=0.11$) or the interaction ($P=0.17$) (Figure 5.4d).

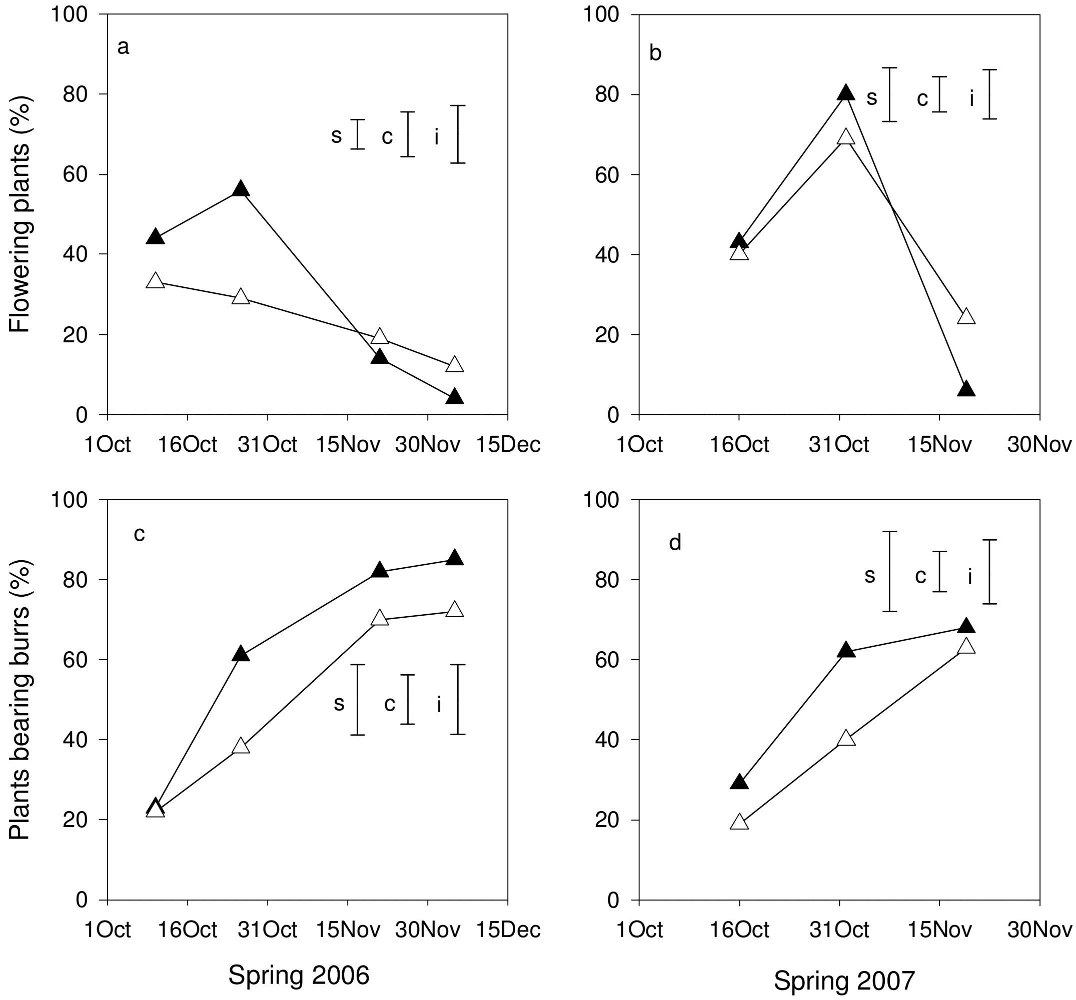

Figure 5.4 Proportion of flowering (a, b) and burr bearing subterranean clover plants (c, d) from pastures grazed at low (▲) and high (Δ) stocking rates and at time of closing on 10 October, 26 October, 21 November and 5 December in 2006 and 16 October, 1 November and 19 November in 2007. Bars represent L.S.D for the effect of stocking rate (s), closing date (c) and stocking rate x closing date interaction (i).

There was an effect (P<0.05) of the interaction between stocking rate and closing date on the number of inflorescences and burrs per plant in spring 2006. The number of inflorescences per plant was greater (P<0.05) at the low than high stocking rate for the 26 October and 21 November closing dates but not at the first and last closing dates (Figure 5.5a). The number of fully formed burrs per plant increased with late closing dates, with more burrs at low than high stocking rate at the last (5 December) closing date (Figure 5.5c).

There was also a significant effect of the interaction between stocking rate and closing date on inflorescence number per plant (P<0.01) in spring 2007. There were more inflorescences per plant at high than low stocking rate on the last (19 November) closing date only (Figure 5.5b). There were more (P<0.001) fully formed burrs per plant at the low than high stocking rate on the last (19 November) closing date only (Figure 5.5d).

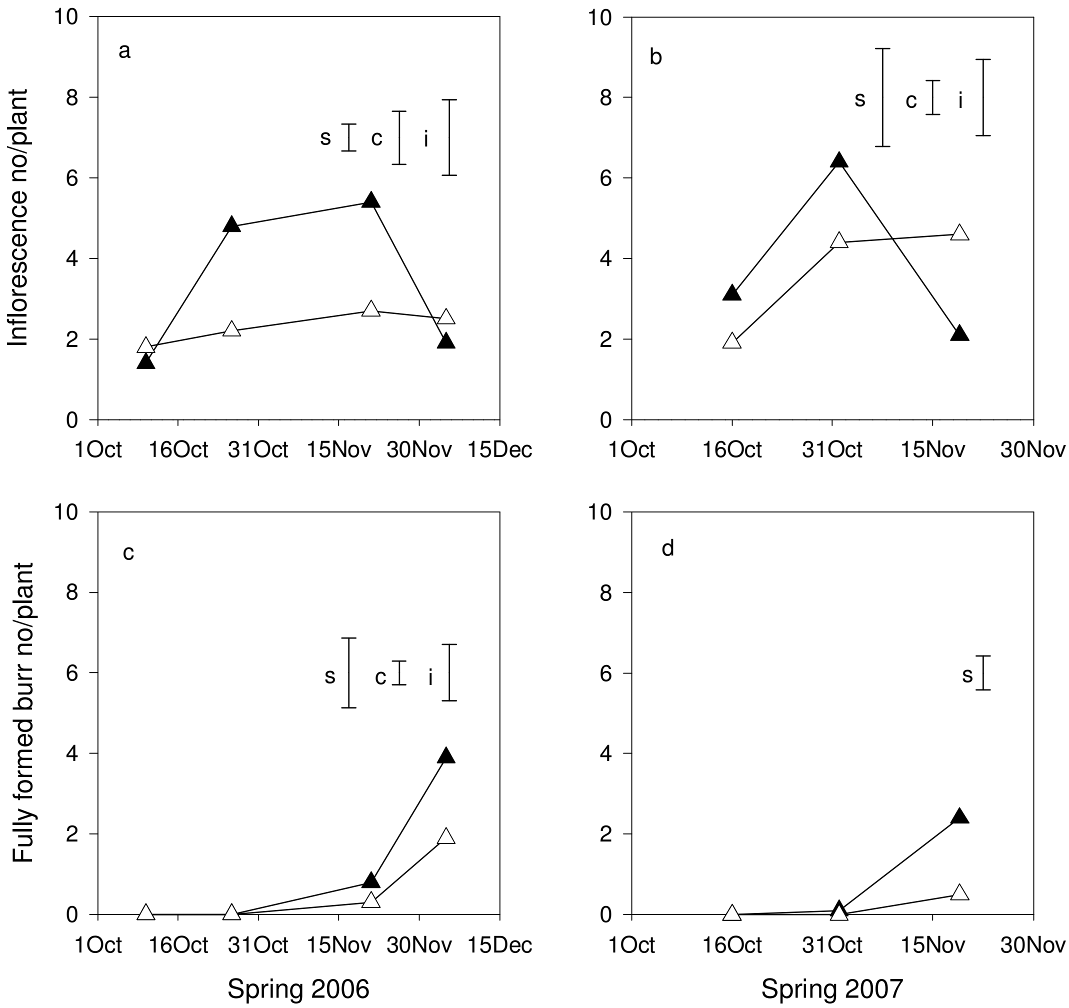

Figure 5.5 Total inflorescence per plant (a, b) and total burr number per plant (c, d) from pastures grazed at low (▲) and high (Δ) stocking rates and at time of closing on 10 October, 26 October, 21 November and 5 December in 2006 and 16 October, 1 November and 19 November in 2007. Bars represent L.S.D for the effect of stocking rate (s), closing date (c) and stocking rate x closing date interaction (i).

5.3.2 Plant morphology and reproductive phenology after the grazing experiment in spring 2007

Compared with the number of plants measured on the final closing date on 19 November 2007 (1472/m^2) (Fig 5.1b), there were 890 fewer plants per m^2 on 4 December 2007 because of plant senescence (Fig 5.6a). There was no effect (P=0.92) of stocking rate, closing date (P=0.97) or the interaction (P=0.19) on the number of total and big plants per m^2 on 4 December. Pastures closed on 19 November had more small plants (P<0.01) than pastures closed on 16 October and 1 November (Figure 5.7c).

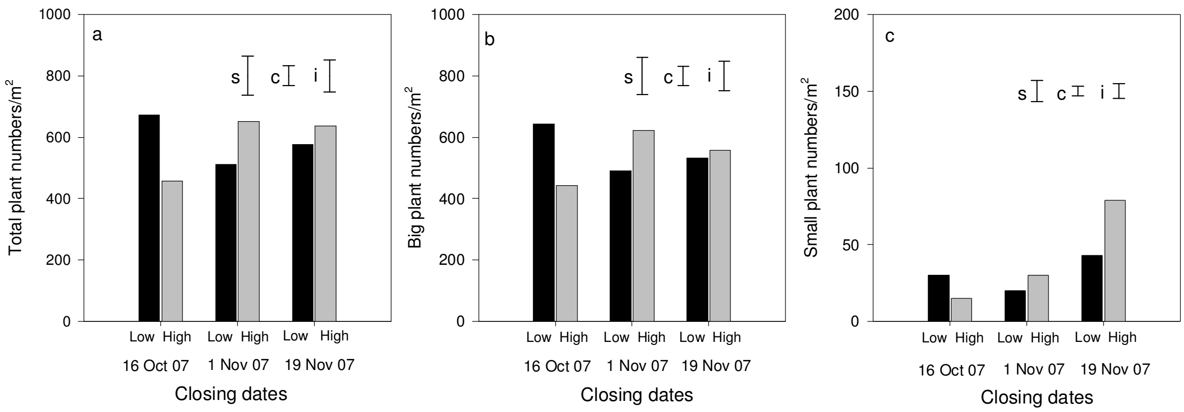

Figure 5.6 Total (a), big (b) and small (c) subterranean clover plant numbers (m^2) on 4 December 2007 from pastures grazed at low and high stocking rates and closed on 16 October, 1 November or 19 November in 2007. Bars represent S.E.M for the effect of stocking rate (s), closing date (c) and stocking rate x closing date interaction (i).

The number of runners per plant was unaffected by stocking rate (P=0.88), closing date (P=0.21) or their interaction (P=0.53) on 4 December 2007 (Figure 5.7a). Runner length per plant was similar (P=0.10) at both low and high stocking rates. Runner length per plant on 4 December was similar on 16 October and 1 November but declined to half these values (P<0.001) with 19 November closing (Figure 5.7b).

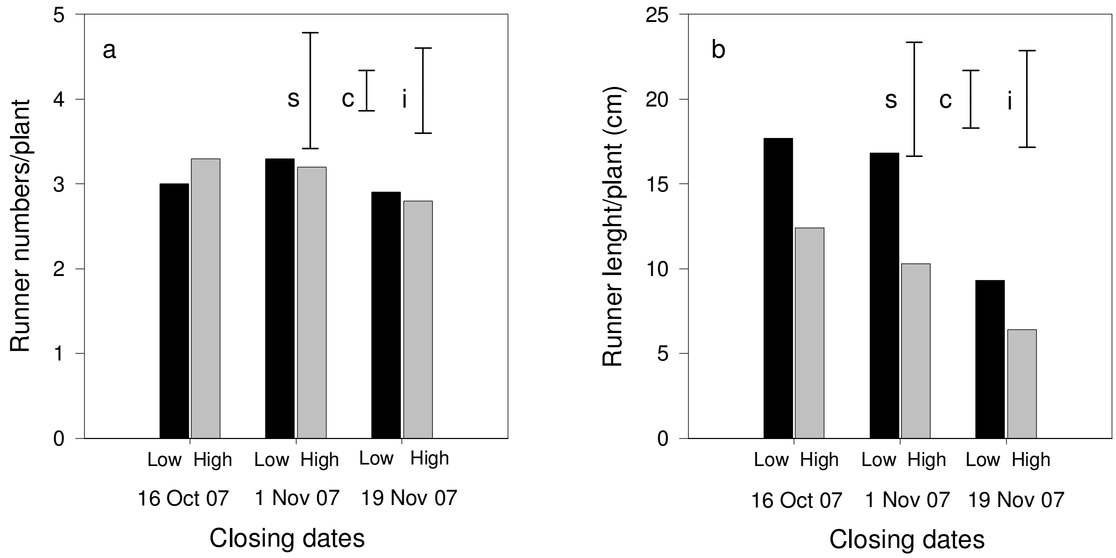

Figure 5.7 Number of runners per plant (a) and runner length per plant (b) of subterranean clover plants on 4 December 2007 from pastures grazed at low and high stocking rates and closed 16 October, 1 November or 19 November in 2007. Bars represent L.S.D for the effect of stocking rate (s), closing date (c) and stocking rate x closing date interaction (i).

An average of 80% of the subterranean clover plants had burrs on 4 December and this was unaffected by stocking rate (P=0.95), closing date (P=0.10) or their interaction (P=0.10) (Figure 5.8a). There were 83% more (P<0.05) inflorescences per plant in high than low stocking rate but the effect of closing date (P=0.17) and the interaction (P=0.28) was not significant (Figure 5.8b). The number of total fully formed burrs per plant was similar on the first two closing dates but both were greater (P<0.01) than those closed on 19 November. There was no effect (P=0.85) of stocking rate or the interaction (P=0.58) on the number of fully formed burrs per plant.

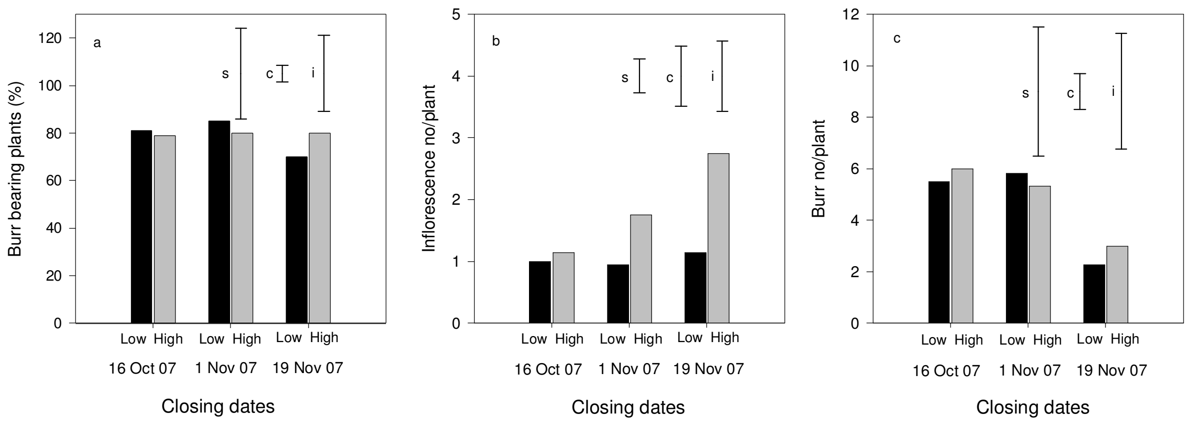

Figure 5.8 The proportion of burr bearing subterranean clover plants (a), total inflorescence per plant (b) and total burr number per plant (c) on 4 December 2007 from pastures grazed at low and high stocking rates and closed on 16 October, 1 November and 19 November in 2007. Bars represent L.S.D for the effect of stocking rate (s), closing date (c) and stocking rate x closing date interaction (i).

5.3.3 Soil seed population

The initial subterranean clover soil seed population across the paddock before the grazing experiment started on 23 August 2006 was 1932 (SD ± 1000) seeds per m^2. In March 2007, following spring 2006 grazing management treatments, the mean soil seed population was 8777 (S.D ± 3029) seeds per m^2. There was a significant effect ($P<0.05$) of closing date on soil seed population but no effect ($P=0.56$) of stocking rate. The soil seed bank population was greater from the first closing date on 10 October 2006 than the other three closing dates, which all had similar populations (Figure 5.9a).

In February 2008, following further grazing treatments in spring 2007, the mean soil seed population was 6637 (S.D ± 1116). As in 2007, there was an effect ($P<0.01$) of closing date on soil seed population but no effect ($P=0.57$) of stocking rate. Soil seed bank populations from pastures closed on 16 October and 1 November were similar and about twice ($P<0.01$) those found for pastures closed on 19 November (Figure 5.9b).

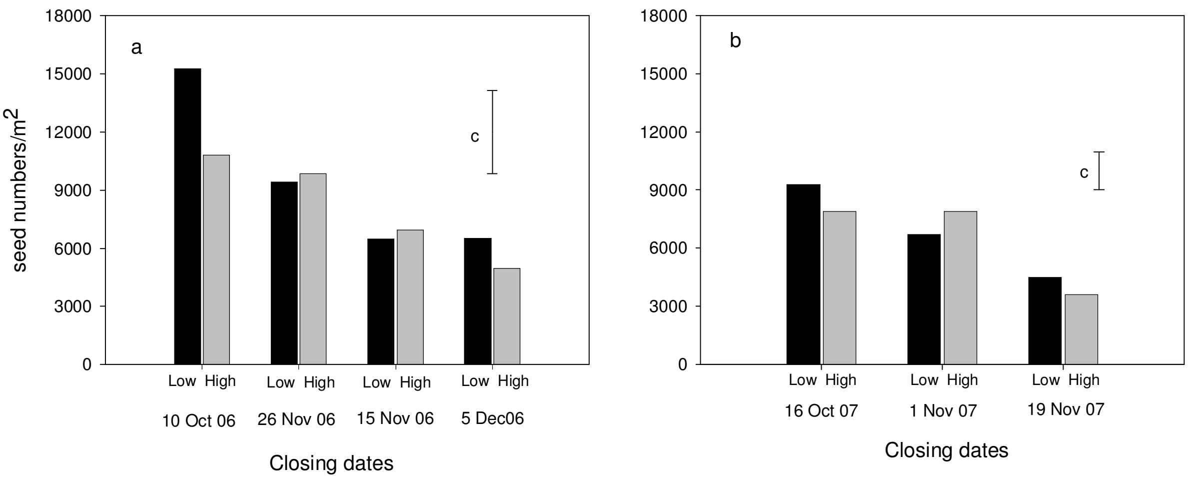

Figure 5.9 The effect of stocking rate (low vs. high) and closing date in spring 2006 on seed population on 16 March 2007 and closing date in spring 2007 on seed population on 11 February 2008. Bars represent LSD for main effect of closing date (c) (P<0.05).

5.3.4 Seedling numbers in areas treated with herbicide

Seedling populations in areas treated with herbicide were used as a further measure of the potential effect of treatments on the soil seed bank. The response of seedling numbers in autumn 2007 to closing date and stocking rate treatments in spring 2006 was similar to that of soil seed numbers. Seedling numbers per m^2 (average 2007 =3614, average 2008 =2649) were about half that estimated for soil seed numbers (Figure 5.10a, b). There were 1262 more seedlings per m^2 ($P<0.01$) at low (4914) than high (3652) stocking rate in 2007. The number of subterranean clover seedling in areas treated with herbicide decreased ($P<0.001$) from 6970/m^2 for the 10 October closing to 5040 for the 26 October closing. Further grazing until 15 November in the previous spring reduced ($P<0.001$) the number of seedlings to 2790/m^2 and this was similar to the 2300 seedlings/m^2 from pastures grazed until 5 December (Figure 5.10a).

There was an effect ($P<0.01$) of closing date on the mean number of seedlings per m^2 in areas treated with herbicide in autumn 2008, but no effect ($P=0.09$) of stocking rate or their interaction (P=0.58). Seedling numbers from the pastures closed on 16 October ($3564/m^2$) and 1 November ($2926/m^2$) were similar but further grazing until 19 November reduced the seedling numbers to $1459/m^2$ in areas treated with herbicide in autumn 2008.

In 2008, mean number of seedlings in areas treated with herbicide was similar (P=0.09) at both low ($2813/m^2$) and high ($2486/m^2$) stocking rates (Figure 5.11b). Earlier closing always resulted in a higher (P<0.01) number of subterranean clover seedlings emerged in areas treated with herbicide. Averaged across stocking rates, the mean number of seedlings in areas treated with herbicide were $3564/m^2$ on 16 October compared with $2926/m^2$ on 1 November and $1459/m^2$ on 19 November.

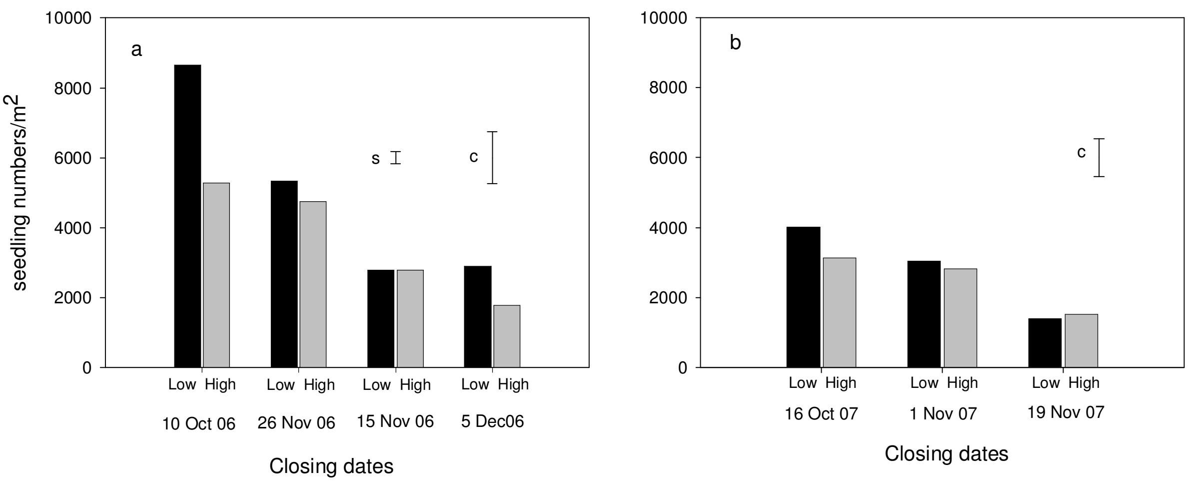

Figure 5.10 The effect of stocking rate (low vs. high) and closing date in spring 2006 and 2007 on seedling numbers in areas treated with herbicide counted during (a) autumn 2007 (b) autumn 2008. Bars represent LSD for main effect of stocking rate (s) and closing date (c) (P<0.05).

5.3.5 Established seedling numbers in mixed pasture

There were 962 and $1400/m^2$ fewer seedlings in the mixed pasture than in the areas treated with herbicide in 2007 and 2008, respectively, indicating how competition decreased established seedling population. In both June 2007 and May 2008, there was an effect (P<0.01) of closing date on the mean number of seedlings per m^2 in mixed pasture, but no effect (P>0.05) of stocking rate or the interaction (Figure 5.11a, b). In 2007, the mean seedling population from the 16 October closing was greater ($3867/m^2$) than the 26 October closing ($2942/m^2$). In turn both were greater than 15 November ($2100/m^2$) and 5 December ($1700/m^2$) closing dates, which had similar seedling populations (Figure 5.11a). In 2008, mean seedling populations from 16 October ($1467/m^2$) and 1 November closing dates ($1317/m^2$) were similar but both were greater than the 19 November closing date ($942/m^2$) (Figure 5.11b).

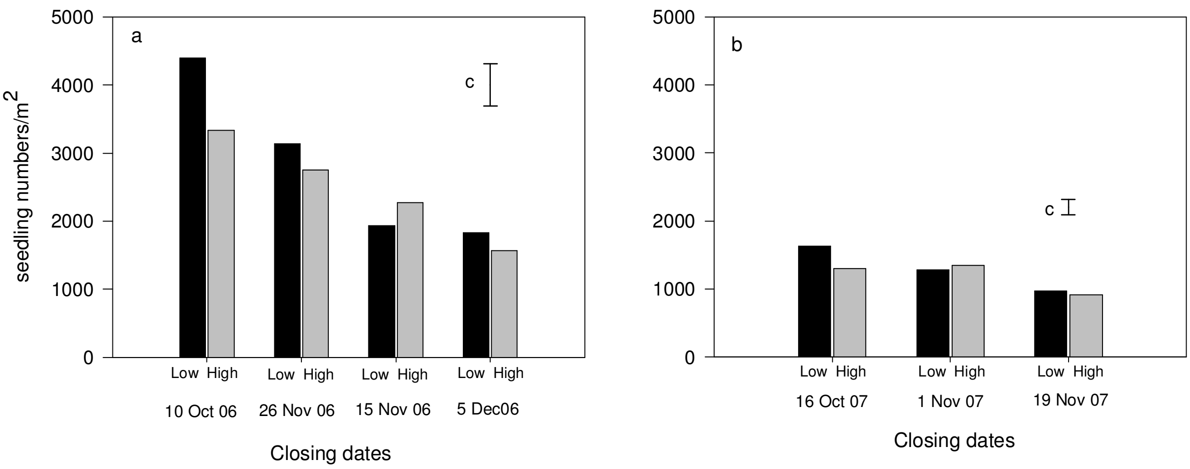

Figure 5.11 The effect of stocking rate (low vs. high) and closing date in spring 2006 (a) on established number of seedlings on 2 June 2007 and in spring 2007(b) on established number of seedlings on 8 May 2008. Bars represent LSD for the effect of closing date (c) (P<0.01).

5.3.6 Autumn dry matter production

There was an effect (P<0.05) of spring closing date on total autumn DM production and subterranean clover DM production in 2007 but no significant effect (P=0.16) of stocking rate or their interaction (P=0.50) (Figure 5.12a). Total autumn DM production was reduced by 170, 415 and 600 kg DM/ha when pastures were closed on 5 December compared with the herbage production from pastures closed on 15 November, 26 October and 10 October, respectively. Total subterranean clover DM production accounted for 38% of the total autumn production and followed a similar pattern, although the last two closing dates had similar production. The highest autumn subterranean clover production (570 kg DM/ha) was obtained from pastures closed on 10 October and this was 190, 370 and 390 kg DM/ha higher than the clover production from pastures closed on 26 October, 15 November and 5 December, respectively. Total autumn DM production in 2008 was unaffected by stocking rate (P=0.12), closing date (P=0.21) or their interaction (P=0.58) Total autumn subterranean clover DM production declined (P<0.05) from one closing date to the next but was unaffected by stocking rate (P=0.17) or the interaction (P=0.50) (Figure 5.12b). The earliest closed pastures (16 October) had the highest (P<0.05) total subterranean clover production of 608 kg DM/ha the following autumn. This was reduced (P<0.05) to 448 kg DM/ha when pastures were closed on 1 November and the latest closing on 19 November resulted in a further decline to 336 kg DM/ha.

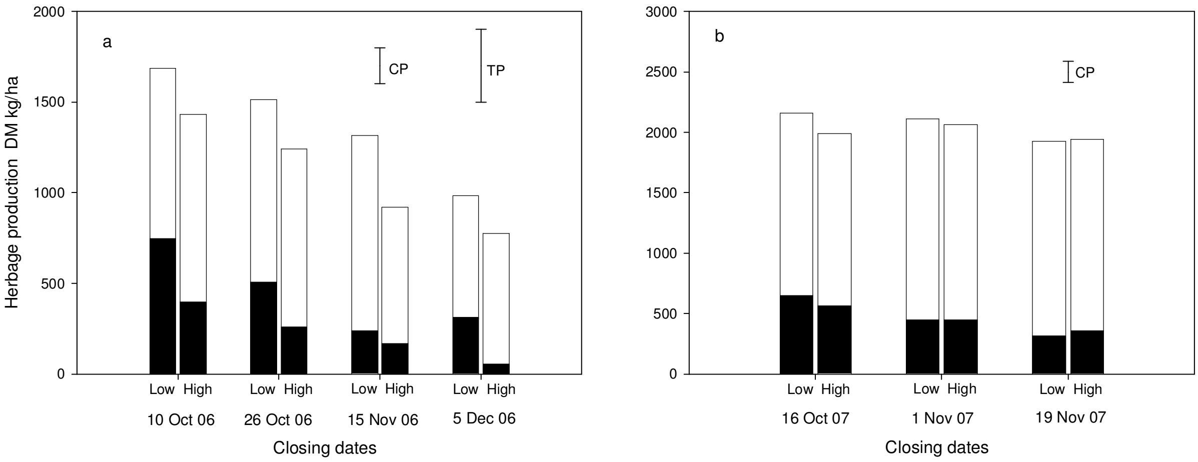

Figure 5.12 The effect of stocking rate (low vs. high) and closing date in spring 2006 and 2007 on total (■+□) and subterranean clover (■) dry matter production in (a) autumn 2007 (2 February to 23 April) and (b) autumn 2008 (14 February to 26 June). Bars represent LSD for main effect of closing date on clover production (CP) and total pasture production (TP) (P<0.05). The y axis of the graphs are on different scale, reflecting greater herbage production in 2007.

5.3.7 Spring dry matter production

Total accumulated winter and spring pasture DM production in spring 2007 was 12% higher (P<0.05) from low (5450 kg DM/ha) compared to high (4860 kg DM/ha) stocking rate

(Figure 5.13a) but was unaffected by closing date (P=0.42) or the interaction (P=0.22). Total subterranean clover production accounted for 48% of the total production but was unaffected by stocking rate (P=0.77) closing date (P=0.60) or their interaction (P=0.80).

Total winter and spring pasture DM production in 2008 was above 4000 kg DM/ha but was also unaffected by stocking rate (P=0.76) closing date (P=0.56) or their interaction (P=0.28) (Figure 5.13b). Total subterranean clover DM production in spring 2008 was unaffected by the previous years stocking rate (P=0.10), closing date (P=0.15) or their interaction (P=0.38).

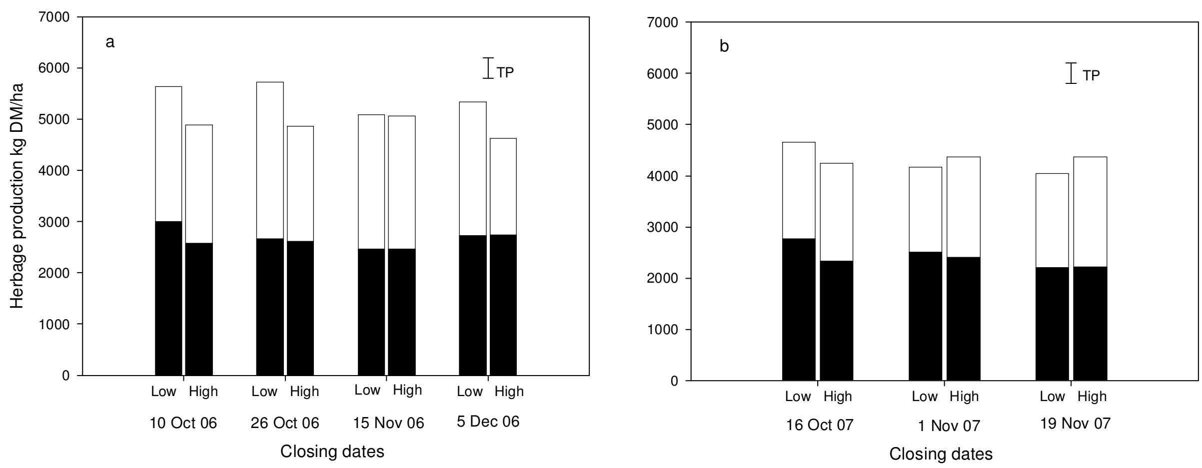

Figure 5.13 The effect of stocking rate (low vs. high) and closing date in spring 2006 on total (■+□) and subterranean clover (■) dry matter production in (a) winter-spring 2007 (2 June to 6 November) and in spring 2007 on total (■+□) and clover (■) dry matter production in (b) winter-spring 2008 (26 June to 7 November). Bars represent LSD for main effect of stocking rate in winter-spring on total pasture production (TP) (P<0.05).

5.4 Discussion

This study examined stocking rate and closing date in spring as methods to increase soil seed and seedling populations in cocksfoot-subterranean clover pastures. The study showed that for the stocking rate and closing dates investigated, earlier closing had the largest impact on seed and seedling populations.

5.4.1 Soil seed and seedling populations relative to recommended values

When interpreting closing date and stocking rate effects, it is important to consider that seed and seedling populations were high relative to recommended values. For example, based on an approximate seed mass of 0.05 mg/seed (Smetham, 2003a), the estimated total seed in the soil in this study ranged from 250 kg/ha (closing on 5 December) to 760 kg/ha (closing on 10 October) in March 2006 and from 180 kg/ha (closing on 19 November) to 460 kg/ha (closing on 16 October) in February 2007. These values are all greater than that calculated by Smetham (2003a) as the minimum seed mass required in the soil for agronomic success of subterranean clover just before germination in autumn. His recommendations were 130, 110 and 80 kg/ha for early, mid, and late flowering cultivars, respectively. Furthermore seedling populations in mixed pastures, ranging from 917 to 4400/m^2, were higher than the 500-1000/m^2 recommended for mixed pastures (Silsbury & Fukai, 1977; Smetham, 2003a).

With high seedling population in this paddock, farmers may choose to graze, all spring at high stocking rate to capture the potential of subterranean clover for liveweight gain. However, it is noteworthy that continuous grazing until the end of two subsequent spring seasons decreased the seed population in the soil from 5728 to 4042/m^2, reflecting the vulnerability of subterranean clover seed populations to continuous grazing, particularly under dry spring conditions (Figure 5.9). This was also highlighted by the fact that continuous grazing until 19 November in spring 2007 (the drier of the two springs) suppressed seedling numbers in the following autumn into the recommended range (e.g. 500-1000/m^2), whereas closing 19 days earlier resulted in 300-400/m^2 more seedlings (Figure 5.11). Furthermore, even at these relatively high seedling populations, closing date in particular had a large impact on the established seedling numbers that may alter clover and total DM production (Figure 5.12). In most cases, higher established seedling numbers resulted in increased autumn clover and total DM production (Section 5.4.6).

5.4.2 Closing date effects on seed and seedling populations

At these relatively high seedling populations, closing date had a greater impact on soil seed and seedling numbers than stocking rate. In the first year, soil seed populations were increased by closing on 10 October (at early flowering stage) (Figure 5.9a), while seedling populations in mixed pasture were increased by closing on 26 October (at burr formation stage) or earlier (Figure 5.11a). In the second spring, seed and seedling populations were increased by closing on 1 November (at burr formation stage) or earlier (Figure 5.9b and Figure 5.11b). This suggests that ceasing grazing at the burr formation stage, before the end of flowering, will increase seed production and enhance seedling establishment in the following year. As an indication of the benefit, there were approximately 3000 more seeds/m^2 (or 150 kg) in the soil from 26 October compared to 15 November closing in 2007 and 3200 more seeds/m^2 (or 160 kg) from 1 November compared to 19 November closing in 2008. These findings were consistent with the results of Young *et al.* (1994) who found that closing pastures from grazing prior to flowering increased the seed yield compared with grazing until burr formation. Similarly, Collins (1978) reported that defoliation prior to the initiation of flowering or midway through flowering resulted in a higher seed yield of subterranean clover plants compared with defoliation until the end of flowering. These results highlight the potential of closing pastures before/at burr formation stage as an important way to improve the abundance of subterranean clover in paddocks of low populations.

Measurements taken on plants at the time of closing in spring indicated that the increased soil seed and seedling populations associated with closing before burr formation stage probably resulted from increased runner length per plant (Figure 5.2c, d), leading to more burrs per plant (Figure 5.5c, d). Although, runner length did not differ when sampled at different times throughout spring, runner length was greater when plants were harvested at the end of spring in 2007 (Figure 5.7a), reflecting growth of runners after the closure of pastures to grazing. It is noted, however, that runner length my also reflect greater internode elongation without affecting number of sites for burr development (Smetham & Dear 2003). Other possible explanations of increased seed and seedling populations with early closing such as greater plant population or runner number per plant are unlikely as these did not alter with closing date in data collected after the end of grazing on 4 December 2007.

The other important factor, which possibly had an impact on seed yield, was plant leaf area during spring as leaf area per plant has been reported to be correlated with seed production (Smetham & Dear, 2003). Leaf area per plant progressively declined at each subsequent closing date (Figure 5.3c, d). Notably, the greatest reduction in leaf area per plant occurred after October in both years and this coincided with the lower availability of herbage mass (Chapter 4.3.3) and initiation of plant senescence.

5.4.3 Stocking rate effects on seed and seedling populations

There was relatively little effect of stocking at lower (8.3 ewes/ha) than normal (13.9 ewes/ha) rates in spring on soil seed and seedling populations (Figures 5.9, 5.10 and 5.11). The only effect that occurred for stocking rate was that there were more seedlings in areas treated with herbicide in 2007 at low than high stocking rate (Figure 5.10). The lack of an effect of stocking rate in this study results is similar to that reported by Ates *et al*. (2006) who found no difference in autumn seedling populations in tall fescue subterranean clover pastures stocked at 10 and 20 ewes/ha in spring. However, the seedling populations in Ates *et al*.

(2006) study in autumn were low (234-286/m^2) in both stocking rates probably due to higher selective grazing of subterranean clover plants on a sparse tall fescue pasture coupled with the drier spring conditions.

The lack of an effect of stocking rate is surprising given that runner length (Figure 5.2c, d), leaf area (Figure 5.3c, d) and fully formed burr numbers (Figure 5.5c, d) were greater at the low than high stocking rate. Smetham and Dear (2003) reported similar effects of grazing on total plant size and noted that runner length per unit area was reduced by hard grazing (at LAI of 0.6) and this negatively affected seed yield. The small effect in this study may reflect that the increase in runner length with low stocking rate was too small to cause large changes in seed production. Alternatively, changes in plant morphology with stocking rate may be important. It was observed, but not measured, that more secondary branching occurred at high stocking rate perhaps providing more sites for burr development and compensation for shorter runners.

Subterranean clover plants under high stocking rate continued to produce flowers in late spring in both years, presumably due to branching as a response to grazing (Ru & Fortune, 1999). In contrast, the percentage of flowering plants under low stocking rate was negligible in the same period since most of the flowers had already developed into burrs (Figure 5.5a, b). At the sampling conducted after grazing had ceased in 2007, there were more flowers per plant at the high stocking rate, particularly at the latest closing date (Figure 5.8b). This may be desirable in a wet year when plants have an opportunity to grow on but it is unlikely to have been beneficial in 2007 as plants were desiccated and close to death (Collins & Aitken, 1970).

5.4.4 Stocking rate x closing date effects on seed and seedling populations

There was no evidence to support the hypothesis that hard grazing in early spring, up to burr formation, then closing would increase seed and seedling populations relative to lax grazing in the same time period prior to closing. The basis for this hypothesis is previous studies noting that defoliation from flower initiation to flowering increased the rate of leaf appearance in subterranean clover (Hagon, 1973). This provided more potential sites for burr development which can be expressed when grazing ceases. Ru and Fortune (1999) also found subterranean clover plants under heavy grazing had a greater number of runners. In this study, stocking rate did not affect runner number per plant, and although some secondary branching was noted, spelling early from hard grazing may not allow sufficient time for runner length to recover. For example, Figure 5.7 b shows runner length per plant was lower at high than low stocking rates for the 16 October (at early stage of flowering) closing date.

5.4.5 Plant numbers in spring

Stocking rate and closing date did not affect the number of plants established at the start of the spring grazing period in either year (Figure 5.1). Of note, was the continuous emergence of subterranean clover seedlings up to a maximum of 2000 seedlings/m^2 in the high stocking rate in 2006 (Figure 5.1e). The difference between years was probably due to favorable climatic conditions for seed softening and germination in the wetter spring of 2006 than 2007 (Section 4.2.4.1). This may reflect more gaps for new seedlings in the high stocking rate pastures. Similar to this finding, Collins and Quinlivan (1980) reported in Western Australia that prolonged moist conditions by either rainfall or irrigation during subterranean clover seed production may cause seed losses through germination and pest attack.

5.4.6 Herbage production

A feature of the results was the contrasting effects of closing date in spring on DM production of the pasture in autumn and spring of the following year. Autumn subterranean clover DM production followed a similar trend to the seedling numbers, with greater DM production at earlier closing dates in both years (Figure 5.12). However, spring clover DM production was unaffected by closing date in both years (Figure 5.13). The difference in effect of closing date data between spring and autumn probably reflects the change in morphology of subterranean clover plants between autumn and spring. In autumn, when subterranean clover plants are a compact rosette, pasture production is likely to be heavily dependant on the population subterranean clover as the main source of leaf area for light interception. In contrast, runner growth in spring compensates for the lower seedling populations by colonizing bare ground with leaves. Further analyses revealed positive linear relationships between seedling numbers and total DM production (Figure 5.14a and 5.15a) in autumn and subterranean clover DM production in autumn of both years (Figure 5.14b and 5.15b) In most cases, the relationship in spring was weak, except total subterranean clover DM production in spring 2008 relative to autumn seedling number/m^2 in autumn 2007 (r^2=81.4) (Figure 5.15d). This explanation is supported by previous work with pure subterranean clover swards. Prioul and Silsbury (1982) reported that higher subterranean clover (e.g.4760 plant/m^2) populations in pure swards had the highest growth rate soon after emergence in autumn but the relative importance of plant population declined as the season progressed. Low population subterranean clover communities showed an increasing crop growth rate during the season so that final yields were similar from pure swards of 428 and 4760 plants/m^2.

A further reason for comparable herbage production of different subterranean clover plant populations in spring might be due to different responses to temperature. Silsbury and Hancock (1990) reported that subterranean clover growth rate at 20 ^{o}C was approximately double that at 10 ^{o}C at low population (2000/m^2) whereas at high population (12000/m^2) the rate at 20 ^{o}C was similar to that at 10 ^{o}C, suggesting that growth rates of swards with higher seedling populations (>5000/m^2) are less sensitive to a low temperature of 10 ^{o}C. They also noted that the growth responses of subterranean clover plants to temperature are markedly altered by the amount of dry matter present. Similarly Cocks (1973) noted that the growth response of subterranean clover plants to temperature depended on the leaf area index (LAI) and low temperatures (12°C day/7^{o}C night) affect growth rates of subterranean clover more when LAI values are below 3. He also noted that high temperature (27°C day/22^{o}C night) increased the growth rate at low LAI (0.2) and promoted the growth of larger plants at above LAI 3. These findings suggest that during autumn, when temperature was relatively low, the high population of subterranean clover pastures developed a higher LAI than low population and consequently had faster growth rates. However, in spring when the LAI of the low population pastures is already relatively high, the effect of temperature is limited except for larger plants at low plant populations which might have promoted higher LAI to compensate for the lower number of plants. It is plausible that at lower plant population (e.g. 300-500 m^2), spring clover DM production may also be reduced as there is less chance for runner growth compensating for low populations and longer runners may also be more vulnerable to selective grazing (Ates *et al*., 2006).

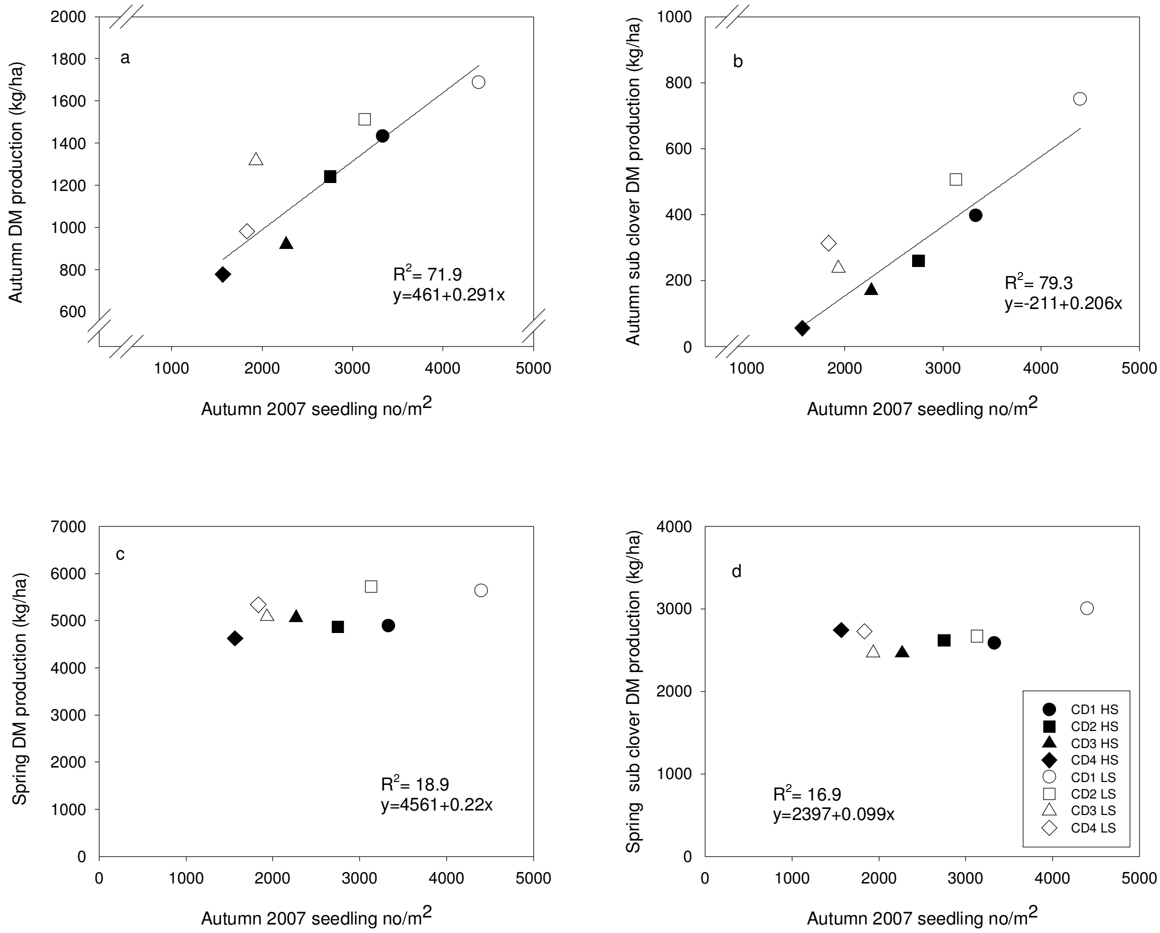

Figure 5.14 Total DM (a) and subterranean clover production (b) kg/ha in autumn 2007 and winter-spring 2007 (c, d) relative to seedling population/m^2 at high (black) and low (white) stocking rate closed on 10 October (○), 26 October (□), 15 November (Δ) and 5 December (◊) in spring 2006.

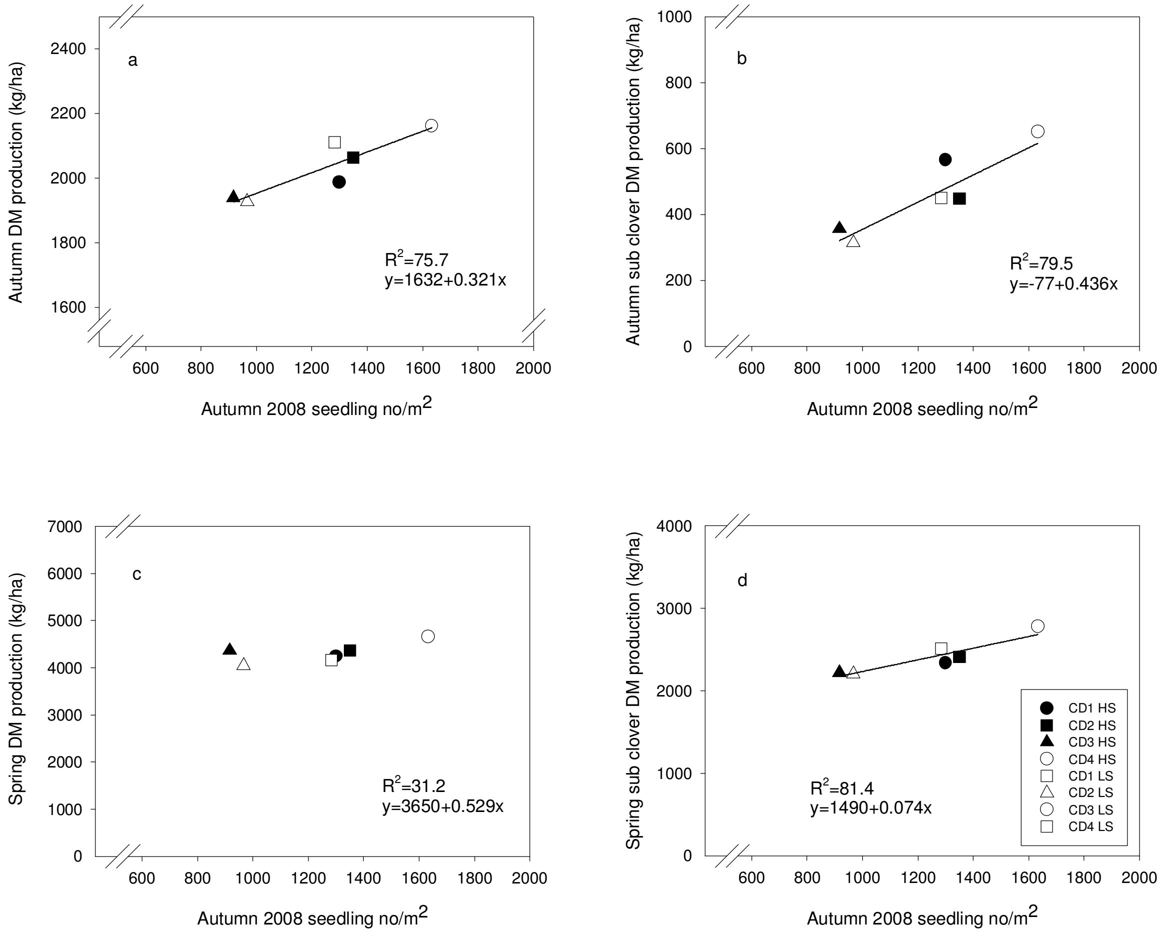

Figure 5.15 Total DM (a) and subterranean clover production (b) kg/ha in autumn 2008 and winter-spring 2008 (c, d) relative to seedling population/m^2 at high (black) and low (white) stocking rate closed on 16 October (○), 1 November (□) and 19 November in spring 2007.

5.5 Conclusions

The following conclusions can be drawn from the findings of this chapter.

- Continuous grazing until the end of plant senescence reduced subterranean clover seed production at both stocking rates by approximately 50% compared with closing at early flowering in mid October in both years.

- Autumn seedling numbers followed a similar trend to the soil seed numbers in both years. Closing at early flowering in mid October gave a mean established seedling number of 3867/m^2 and 1467/m^2 in the following year compared with 1700/m^2 and 942/m^2 in pastures continuous grazed until the end of spring in 2006 and 2007, respectively.

- Stocking rate at 8.3 ewes/ha versus 13.9 ewes/ha in spring had a small effect in both years on soil seed and established seedling numbers.

- There were strong relationships between established seedling numbers/m^2 and total DM and subterranean clover DM production in autumn. The relationship between seedling numbers and spring DM production was generally weak. This was most probably due to runner growth compensating for lower seedling populations.

Chapter 6

Herbage production of cocksfoot and ryegrass pastures with and without annual clovers grazed at high and low stocking rates during spring

6.1 Introduction

Grazing intensity and management decisions influence pasture production and persistence (Waller *et al*., 2001). Selective and preferential grazing by animals can also change botanical composition to varying extents under different stocking rates (Lloyd Davies & Southey, 2001; Reed, 1974; Chapter 4). The impacts of these factors may vary in different pasture mixtures (L'Huillier *et al*., 1986) and are closely related to the changing environmental conditions in different seasons (Smetham, 1990). However, management decisions in dryland farming in New Zealand are challenging due to erratic rainfall and seasonal changes in temperature (Salinger, 2003; Smetham, 1990). In such an unpredictable dryland environment, increasing species diversity and sowing drought resistant pasture plants may improve the resilience and productivity of pastures (Skinner *et al*., 2004).

In previous chapters, the main focus has been on animal performance and persistence of subterranean clover under different grazing managements in dryland pastures. In this chapter the aim was to determine the effect of grazing intensity, grass species and annual clover species on total pasture production and botanical composition over two years. The specific objectives were to:

1- To measure the annual and seasonal herbage production from pastures grazed at high and low stocking rates during spring.

2- To develop relationships between pasture production and the main environmental variables of temperature and moisture.

6.2 Materials and methods

The details of experimental design, site description, location, meteorological conditions and grazing management were presented in Chapter 4.

6.2.1 Experimental design

Briefly, a grazing trial with 2 stocking rates (8.3 ewes/ha at low and 13.9 ewes/ha at high) over two subsequent spring seasons was carried out on a previous seed mixture experiment (Chapter 4). The experiment was a randomized split-split plot design with three replicates. Stocking rate was the main plot, grass species was the sub-plot and annual clover was the sub-sub plot treatment (Table 6.1).

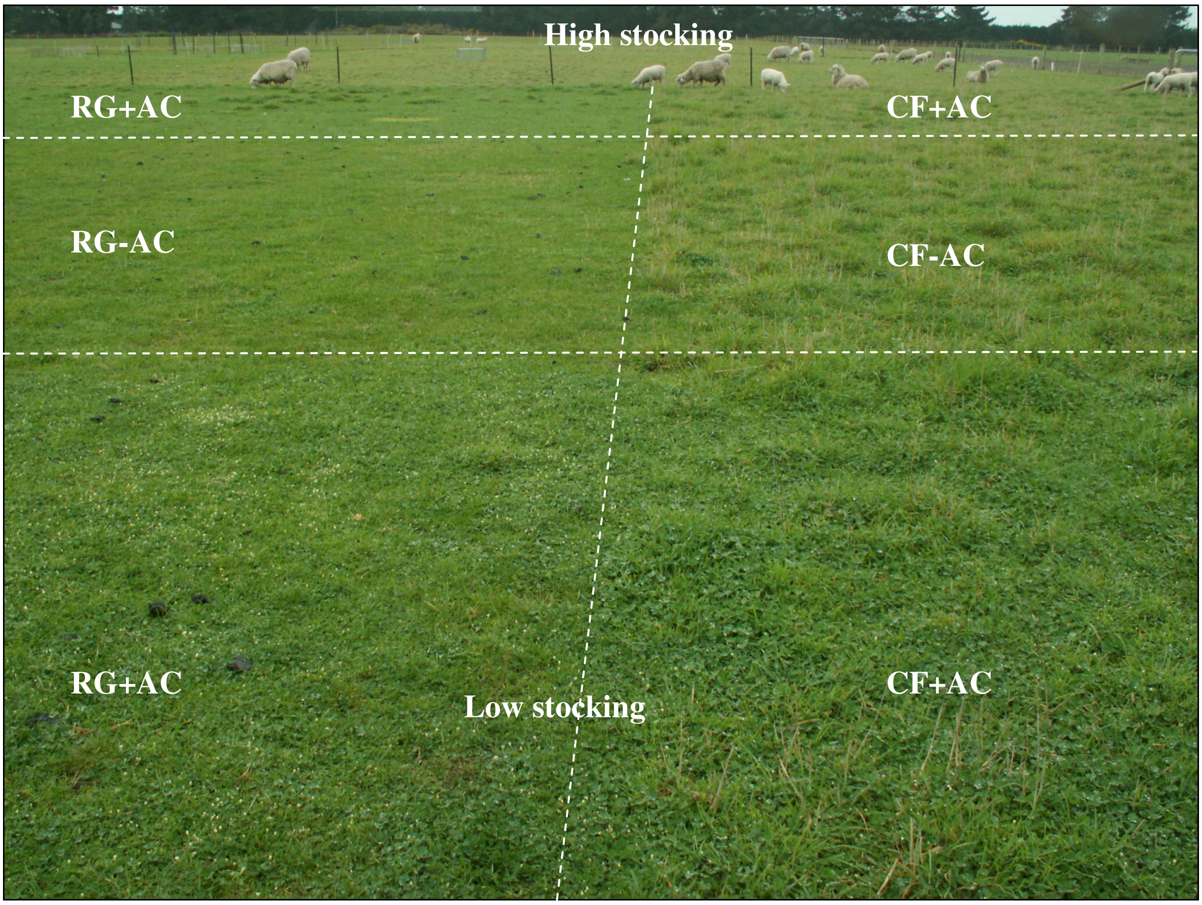

Plate 6.1 A view of the experimental site on paddock C9(A)S at Ashley Dene on 9/10/2007.

Table 6.1 Treatment details of the experiment located in paddock C9(A)S at Ashley Dene, Lincoln University Research Farm.

Stocking rate	Grass species	Annual clover	Nomenclature
High (H)	Cocksfoot (CF)	Plus (+AC)	HCF+AC
High (H)	Cocksfoot (CF)	Minus (-AC)	HCF-AC
High (H)	Ryegrass (RG)	Plus (+AC)	HRG+AC
High (H)	Ryegrass (RG)	Minus (-AC)	HRG-AC
Low (L)	Cocksfoot (CF)	Plus (+AC)	LCF+AC
Low (L)	Cocksfoot (CF)	Minus (-AC)	LCF-AC
Low (L)	Ryegrass (RG)	Plus (+AC)	LRG+AC
Low (L)	Ryegrass (RG)	Minus (-AC)	LRG-AC

6.2.2 Measurements

6.2.2.1 Dry matter production

Pasture growth was measured using exclosure cage cuts (1 m^2) at approximately 30 day (range 28-35 day) intervals during active growth and at approximately 60 day (range 43-97 day) intervals during dry summer and low winter growth periods (Table 6.2). Exclosure cages were placed over an area mown to 20 mm residual height in the three replicates of each pasture treatment and dry matter production was measured from 19 September 2006 to 7 September 2008. Exclosure cages were located on plots originally sown with 2 kg/ha cocksfoot and 2 kg/ha white clover for cocksfoot pastures and on plots sown with 10 kg/ha perennial ryegrass and 2 kg/ha white clover for perennial ryegrass pastures. Measurements from perennial ryegrass pastures without annual clovers started on 3 September 2007. An area of 0.2 m^2 under the cages was cut to a 20 mm stubble height with electric shears. After cutting, cages were relocated to new pre-mown sites in the same pasture treatment in each plot.

Table 6.2 Exclosure cage cut dates and pasture regrowth durations at C9(A)S, Ashley Dene from 2006 to 2008.

Year	Season	Harvest	Regrowth period		Duration (days)	Mid-point date
			Start	Finish		
2006/07	Spring	1	19/09/2006	17/10/2006	28	3/10/2006
	Spring	2	17/10/2006	20/11/2006	34	3/11/2006
	Summer	3	20/11/2006	25/12/2006	35	7/12/2006
	Summer	4	25/12/2006	8/02/2007	45	16/01/2007
	Summer	5	8/02/2007	12/04/2007	63	11/03/2007
	Autumn	6	12/04/2007	29/05/2007	47	5/05/2007
	Winter	7	29/05/2007	3/09/2007	97	16/07/2007
2007/08	Spring	1	3/09/2007	4/10/2007	31	18/09/2007
	Spring	2	4/10/2007	6/11/2007	33	20/10/2007
	Summer	3	6/11/2007	9/01/2008	64	8/12/2007
	Summer	4	9/01/2008	12/03/2008	63	9/02/2008
	Autumn	5	12/03/2008	24/04/2008	43	2/04/2008
	Autumn	6	24/04/2008	26/06/2008	63	25/05/2008
	Winter	7	26/06/2008	7/09/2008	73	1/08/2008

6.2.2.2 Botanical composition

The harvested herbage samples were stored in a cooler at 4 ^{o}C and processed within 7 days after collection. Prior to drying a subsample of approximately 400 pieces was sorted into cocksfoot, ryegrass, subterranean clover, balansa clover, white clover, cluster clover, annual weeds, dicot weeds and dead material. A mixing and quartering technique was used to obtain random subsamples from the 0.2 m^2 harvest (Cayley & Bird, 1996). Botanical composition samples were oven-dried at 70 ^{o}C to a constant weight and then used to calculate composition on a DM basis.

6.2.2.3 Soil moisture

Soil moisture was measured with Time Domain Reflectometry (TDR) (Trace systems model 6050X1, soil moisture equipment, Santa Barbara, California, USA). The two TDR stainless steel rods were placed to a 20 cm depth at one location in the experimental field and data were collected at fortnightly intervals (range 13-38 day) during the experiment period.

Soil moisture level over the 2 year period ranged between a low of 9.8% on 21 January 2008 and a high of 37.4% on 21 July 2008 (Figure 6.1). Seasonal distribution of soil moisture level was erratic and variations occurred in both years. For example the spring/early summer soil moisture level was above 18% (half of the maximum) until January 2007 whereas in the following spring it dropped below this level in early November 2007. The autumn recharge of soil moisture occured from 26 March in 2007 and 15 February in 2008 but this was then followed by another dry period with only 55 mm of rainfall until 14 May.

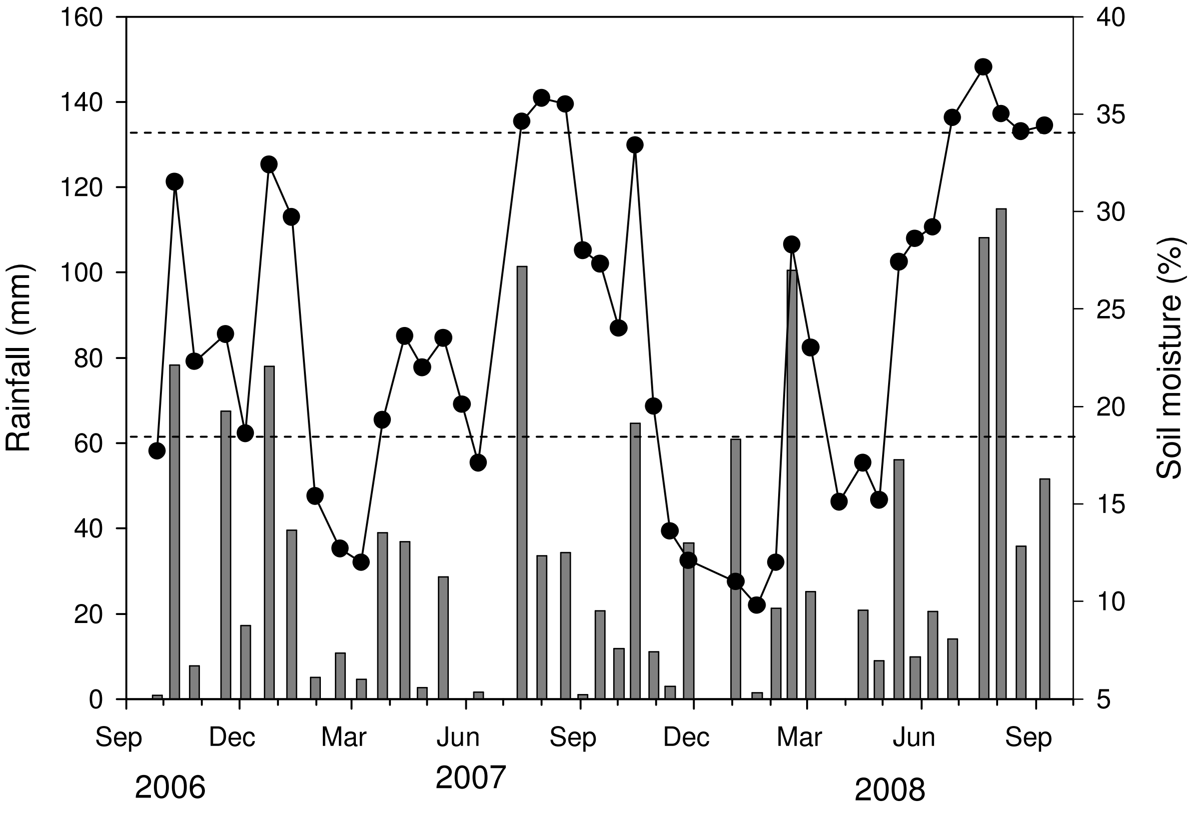

Figure 6.1 Soil moisture (top 20 cm)(–●–) and rainfall (□) at Ashley Dene from 15 September 2006 to 10 September 2008. Dashed lines represent the field capacity and 50% of the field capacity.

6.2.3 Calculations

6.2.3.1 Mean daily growth rates

Mean daily growth rates (kg DM/ha/d) were calculated at each harvest by dividing total DM production (kg DM/ha) by the duration of regrowth since the previous harvest.

6.2.3.2 Thermal time accumulation

Thermal time (Tt) was calculated daily using the method of Jones and Kiniry (1986). A broken stick threshold with a base air temperature of 3 ^{o}C (T_b) (Mills *et al.*, 2006) was used to calculate daily thermal time (Tt) (also known as heat units or growing degree days (^{o}Cd)). Accumulated thermal time ($\sum$Tt) was derived by summing daily thermal time (Tt) for the pasture production period in each year. Thermal time (Tt) was accumulated with linear increments from the base temperature (T_b) of 3 ^{o}C to an optimum temperature (T_{opt}) of 25 ^{o}C above which values of Tt decline linearly to zero at a maximum (T_{max}) of 40 ^{o}C (Mills *et al.*, 2006).

6.2.4 Statistical analyses

Total DM production and mean annual botanical composition were analysed by ANOVA with three replicates as a split plot design in 2006/07 where stocking rate was main plot and grass types were sub-plot. Total DM production and mean botanical composition were analysed as a split-split plot design where stocking rate was the main plot, grass species was the sub-plot and annual clover was the sub-sub plot treatments in 2007/08. Pasture growth rates and botanical composition were analysed for each regrowth cycle using the split plot design in 2006/07 and split-split plot design in 2007/08. Growth rates of subterranean clover were analysed by ANOVA with three replicates as a split plot design where stocking rate was the main plot and grass types were sub-plots. Temperature adjusted growth rates were derived by regression, through the origin, of accumulated DM against accumulated thermal time during spring seasons (when water was non-limiting, e.g. >50% of the field capacity; Figure 6.1) with year as a repeated measure (Mills *et al.*, 2006). Means were separated by Fishers protected L.S.D ($P<0.05$) when ANOVA was significant. A linear regression between accumulated DM production and accumulated thermal time was calculated during spring months in both years. Regressions were fitted to data from each plot and slopes were compared by one-way ANOVA.

6.3 Results

6.3.1 Dry matter production

The mean total accumulated DM production was similar (P=0.63) for both high (9.6 t DM/ha/y) and low (10.0 t DM/ha/y) stocking rate pastures in 2006/07 (Figure 6.2). The average total accumulated DM production ranged from 7.6 to 8.1 t DM/ha/y in 2007/08 and the effect of stocking rate was also not significant (P=0.19).

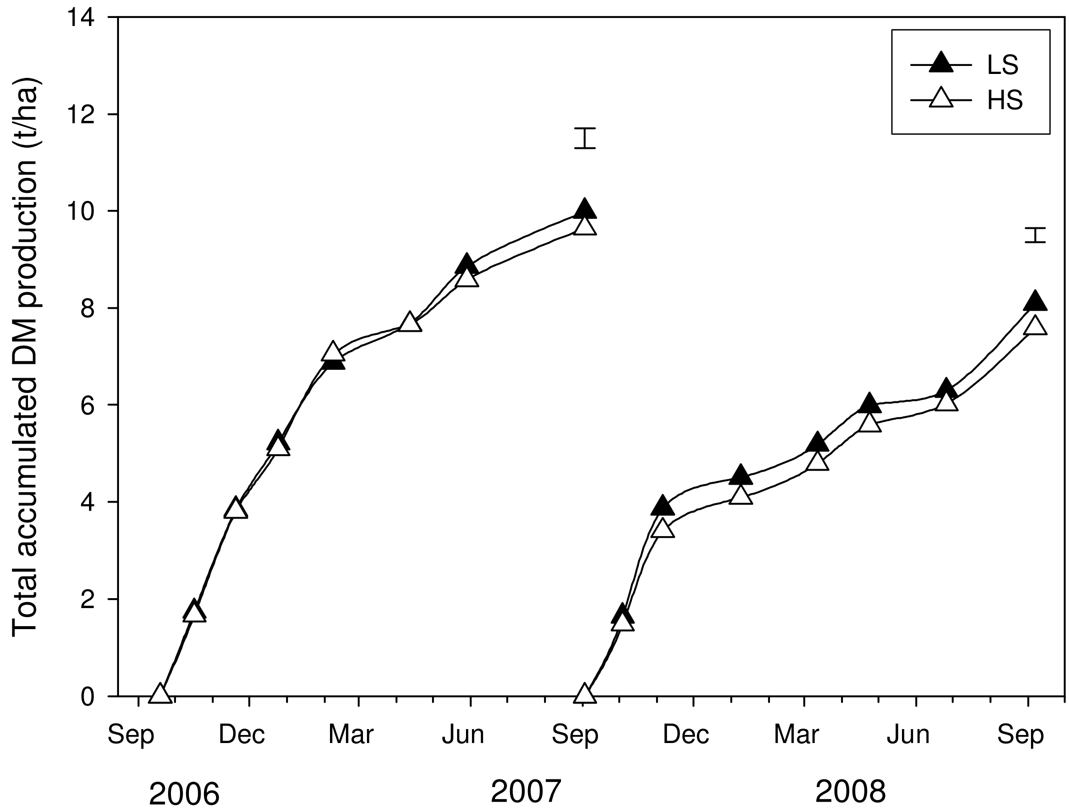

Figure 6.2 The average total accumulated dry matter (DM) production (t/ha) under high (HS) and low stocking (LS) rate treatments at C9(A)S Ashley Dene from 2006 to 2008. Bars represent the S.E.M.

Ryegrass pastures grown with annual clovers provided approximately 12 t/ha/y total DM production in 2006/07 (Figure 6.3). This was similar to total DM production from cocksfoot pastures grown with annual clovers that produced 10.7 t DM/ha/y. However, ryegrass and cocksfoot pastures grown with annual clovers produced greater (P<0.001) DM yield than cocksfoot pastures without annual clovers by about 87% and 61%, respectively. In 2007/08 total DM production in pastures overdrilled with annual clovers was similar in both grasses and ranged from 8.6 to 9.6 t DM/ha/y. This was 34-45% higher (P<0.001) than yields from ryegrass and cocksfoot pastures grown without annual clovers.

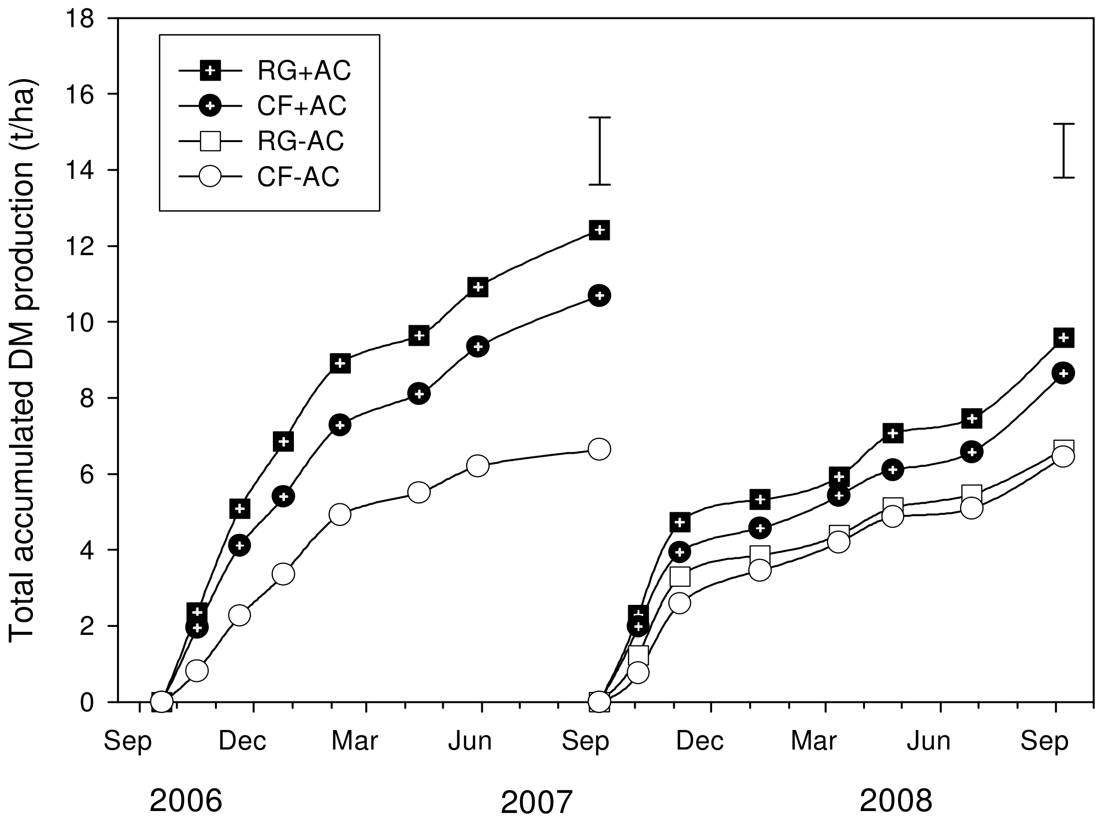

Figure 6.3 Total accumulated dry matter (DM) production of ryegrass (RG) and cocksfoot (CF) pastures with (+AC) and without annual clovers (-AC) at C9(A)S Ashley Dene from 2006 to 2008. Bars represent the LSD. Measurements from ryegrass pastures without annual clovers started on 3 September 2007.

6.3.2 Mean daily growth rates

Stocking rate did not affect (P=0.11) mean daily growth rates of pastures for any regrowth periods in 2006/07 except in October 2007 when pastures at low stocking (67.5 kg DM/ha/d) grew approximately 15% faster (P<0.01) than those under high stocking (58.2 kg DM ha/d) rates (Appendix 9). Mean daily growth rate (kg DM ha/d) was consistently higher (P<0.05) for ryegrass than cocksfoot pastures when both were overdrilled with annual clovers, followed by cocksfoot pastures grown without annual clovers until late spring in 2006/07. However, pasture growth rates did not differ (P=0.19) in summer and early autumn when moisture stress (Figure 6.1) restricted all growth. There were distinctive seasonal shifts in pasture growth rates over the two year period. In spring 2006, growth rates of ryegrass and cocksfoot pastures grown with annual clovers decreased from 84 and 70 kg DM/ha/d in October to approximately 50 and 40 kg DM/ha/d respectively until December 2006. Growth rates of cocksfoot pastures without annual clovers fluctuated between 30 and 42 kg DM ha/d during the same period. These rates remained similar until February 2007, before they dropped to about 10 kg DM ha/d for each pasture in April 2007. This was followed by an increase to around 25 kg DM ha/d for pastures overdrilled with annual clovers, compared with only 5 kg DM ha/d for cocksfoot pastures without annual clovers. Pastures with annual clovers grew 10 kg DM ha/d faster (P<0.05) than those without annual clovers during winter.

In early spring 2007/08, pastures grown with annual clovers grew 37 kg DM/ha/d faster (P<0.01) than pastures without annual clovers and 30% faster (P<0.01) for ryegrass than cocksfoot based pastures. There was a dramatic increase up to about 60 kg DM/ha/d in growth rates for pastures without annual clovers in late spring. This coincided with an increase of adventive cluster clover production, predominantly in pastures sown without annual clovers. In October 2007, pastures in the low stocking rate treatment grew ~10 kg DM/ha faster (P<0.01) than pastures under a high stocking rate. Pasture growth rates ranged from 8 to 14 kg DM/ha/d during summer and 15-25 kg DM/ha/d during autumn. Cocksfoot pastures had higher (P<0.05) growth rates during summer, whereas ryegrass pastures grew faster (P<0.05) during autumn. An average rate of 30 kg DM/ha/d over winter was measured for cocksfoot and ryegrass pastures overdrilled with annual clovers and this was approximately 75% faster (P<0.05) than pastures without annual clovers.

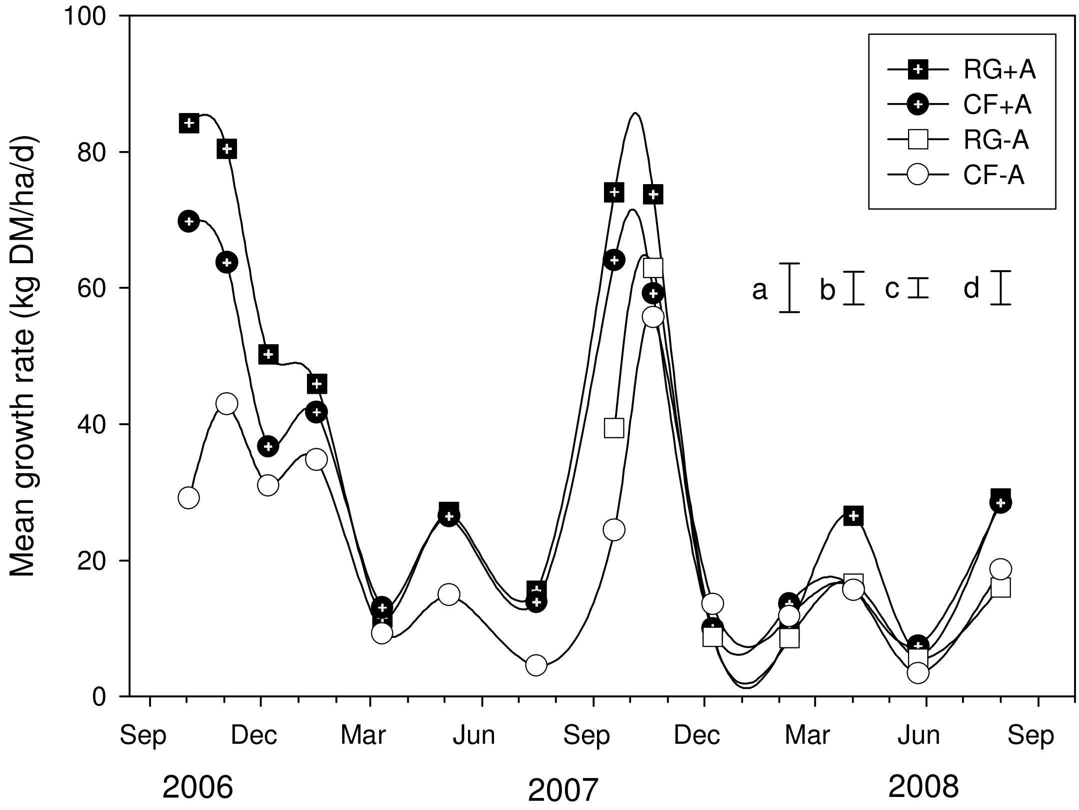

Figure 6.4 Mean daily growth rates of ryegrass (RG) and cocksfoot (CF) pastures grown with (+AC) and without annual clovers (-AC) at C9(A)S Ashley Dene from 2006 to 2008. Error bars represent maximum SEM for a) pasture type, b) grass species c) annual clover and d) interaction of SR*G*A.

6.3.2.1 Mean daily growth rates of grass component of the pastures

In 2006/07, sown grasses in ryegrass and cocksfoot pastures grown with annual clovers tended to grow faster compared with those in cocksfoot pastures without annual clovers (Figure 6.5). However, the difference between pasture treatments was only significant ($P<0.05$) during winter when the grass growth rates of both species were below 5 kg DM/ha/d. Growth rates of grass species were similar during spring 2006 and ranged from 17 to 33 kg DM/ha/d. These mean daily growth rates of grasses remained similar until mid February. Autumn growth rates fluctuated between 7 and 16 kg DM/ha/d.

In early spring 2007, the mean daily growth rates of sown grasses in pastures grown with annual clovers were 5 kg DM/ha/d faster ($P<0.05$) than those in pastures without annual clovers. Growth rates increased in both grass species during mid spring from October to November, particularly for grasses in which no annual clover had been overdrilled. Grasses in pastures without annual clovers grew 14 kg DM/ha/d faster (P<0.05) than those in pastures with annual clover in November. Mean daily grass growth rates of cocksfoot in both clover treatments were comparable during summer and averaged between 5 and 11 kg DM/ha/d. These rates were higher (P<0.001) than for the ryegrass that grew ≤3 kg DM/ha/d regardless of clover treatment during the same period. However, In May 2008, the grasses grew at similar rates that ranged from 5 to 9 DM/ha/d in both pastures regardless of clover treatment before the rate decreased to below 5 kg DM/ha/d for both grass species. Cocksfoot grew at a mean daily growth rate of 11 kg DM/ha/d during winter and this was 6 kg DM/ha/d faster (P<0.05) than ryegrass.

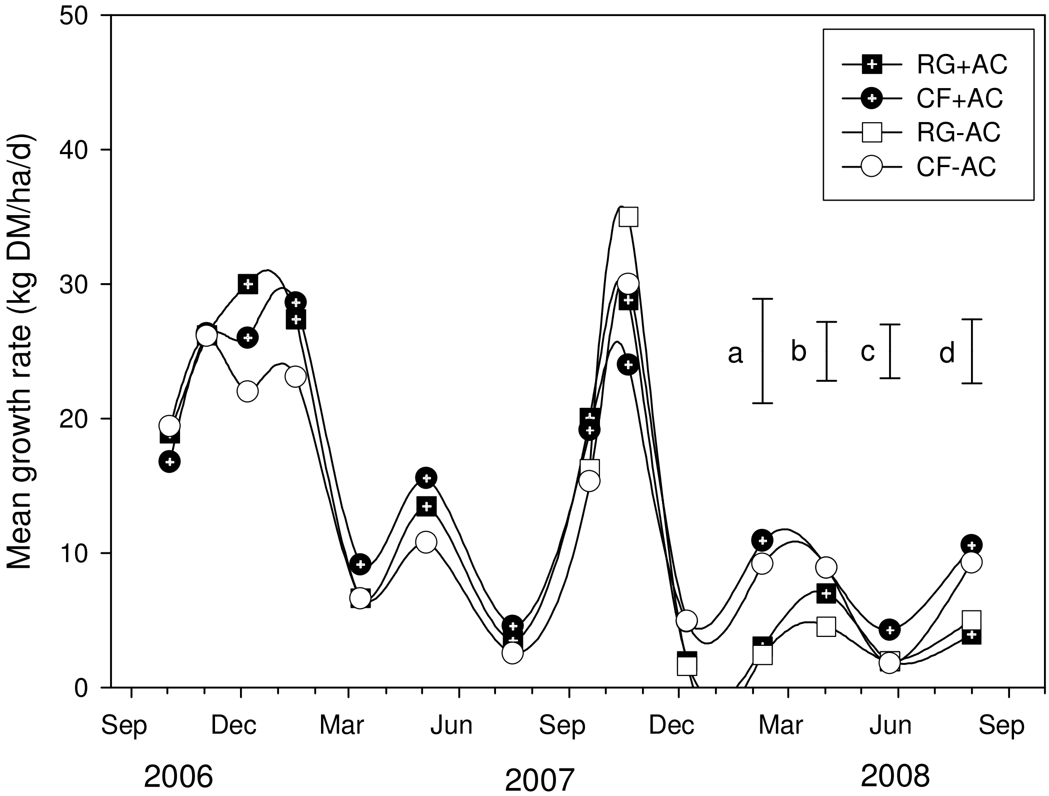

Figure 6.5 Mean daily growth rates for ryegrass and cocksfoot grasses in ryegrass (RG) and cocksfoot (CF) pastures with (+AC) and without annual clovers (-AC) at C9(A)S Ashley Dene, from 2006 to 2008. Error bars represent maximum SEM for a) pasture type, b) grass species c) annual clover and d) interaction of SR*G*A

6.3.2.2 Mean daily growth rates of subterranean clover component of the pastures

Stocking rate did not affect (P=0.16) mean daily growth rates of clover in either pasture at any regrowth period in either year (Figure 6.6). Mean daily growth rates of subterranean clover in spring were similar regardless of the companion grass species at an average of 39-45 kg DM/ha/d in 2006 and 2007, respectively. There was <10 kg DM/ha/d of clover growth during summer, autumn and winter in both years with an erratic pattern of production.

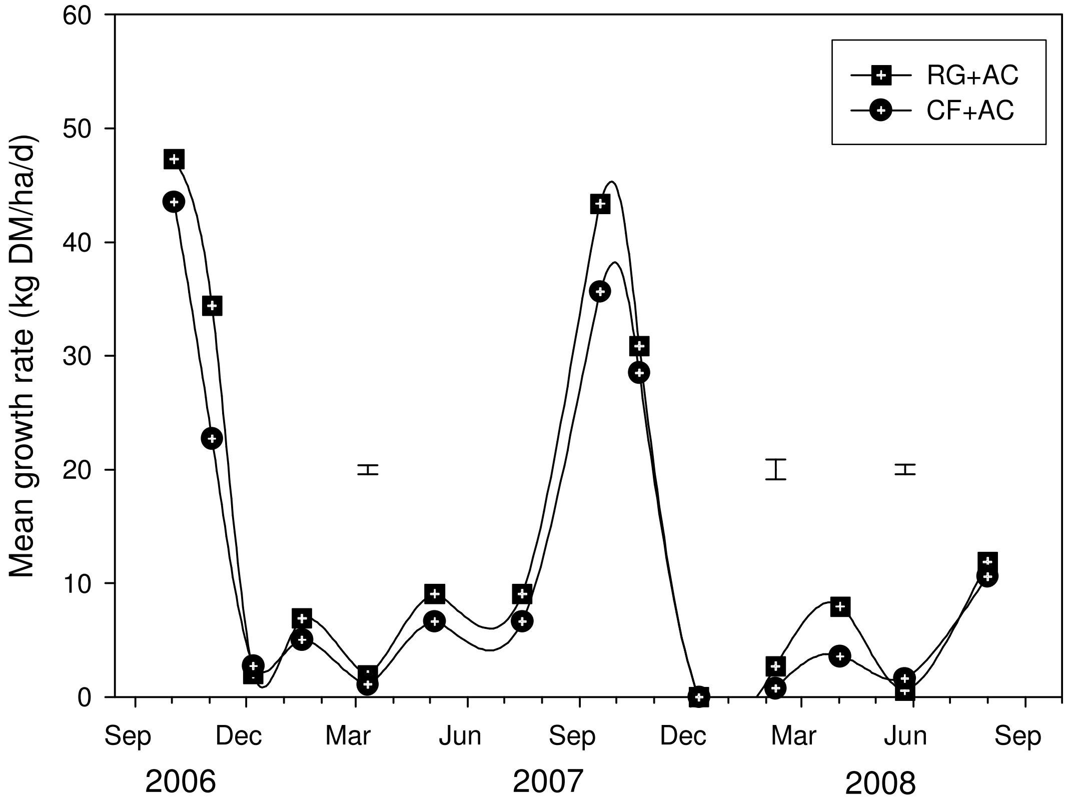

Figure 6.6 Mean daily growth rates of subterranean clover grown with cocksfoot (CF) or ryegrass (RG) at C9(A)S Ashley Dene from 2006 to 2008. Bars represent LSD above the periods when difference was significant (P<0.05).

6.3.3 Botanical composition

Stocking rate had little affect on botanical composition except cluster clover content which was greater (P<0.05) at high than low stocking rate in 2006/07 (Table 6.3). An interaction occurred between stocking rate and pasture treatment for sown grasses and dead material content in 2006/07. Total sown grass content was generally higher (P<0.05) in low stocking rate pastures, except cocksfoot overdrilled with annual clovers which had 56.5% total sown grass content in low, compared with 51.9% in the high, stocking rate treatments (P<0.05). The dead material content was lower (P<0.05) with cocksfoot grown with annual clovers at a high (12.1%) than a low (7.2%) stocking rate. The dead material content did not differ with stocking rate in other pastures. Stocking rate only affected sown grass and balansa clover contents of pastures in 2007/08. Sown grass content was higher (P<0.05) in high than low stocking rate, except cocksfoot pastures grown with annual clovers. This gave an indication of an interaction (P=0.06) between stocking rate and grass treatments. Balansa clover content was also higher (P<0.05) in high (1.5%) than low (0.7%) stocking rate main plot treatments in 2007/08. Total weed content was higher (P<0.05) in ryegrass pastures compared with cocksfoot pastures in both years.

The average sown grass content decreased from 44% in 2006/07 to 31% 2007/08 in ryegrass pastures grown with or without annual clovers (Figure 6.7a) and there was a dramatic increase in broadleaf weeds (predominantly storksbill, dandelion and chickweed) and invasive annual grasses (barley grass and vulpia) after spring 2007 (Figure 6.7d). Total weed (broadleaf and annual grass) content reached an average of 45% in these ryegrass pastures by the end of winter 2008 compared with <5% for cocksfoot (Figure 6.7d). Subterranean clover content accounted for 97% of total sown clover content, whereas total balansa and white clover contents were less than 3% in both cocksfoot and ryegrass pastures. Subterranean clover content was the highest during the spring period with up to a maximum of 50% in both grass pastures (Figure 6.7b). The cluster clover content in spring 2007 averaged 24% in ryegrass pastures grown without annual clovers but had a declining trend in association with increasing broadleaf weed content (Figures 6.7c, d). Mean 2006-2008 dead material content of pastures ranged from 0 to 15%. The exception was January 2008 when the dead material content of pastures ranged between 22% (CF+AC) and 72% (RG-AC) in (Figure 6.7e).

Table 6.3 Mean annual botanical composition of cocksfoot (CF) and ryegrass (RG) pastures with (+AC) and without (-AC) annual clovers under high (H) and low (L) stocking rate treatments from 2006 to 2008 at C9(A)S Ashley Dene.

Year	Treatment	Sown grasses	Sub clover	Balansa clover	White clover	Cluster clover	Dead material	Weeds
					%			
2006-2007	HCF- AC	63.8_a	-	-	2.9	13.0_a	14.5_a	5.3_a
	LCF- AC	74.5_a	-	-	0.1	8.0_b	12.7_a	4.1_a
	HCF+ AC	56.5_b	26.8_a	1.5	0.2	2.9_c	7.8_b	4.2_a
	LCF+ AC	51.9_b	29.8_a	0.8	0.1	2.5_c	12.1_a	2.8_a
	HRG+ AC	40.1_c	32.4_b	1.7	0.4	5.9_b	7.2_b	12.4_b
	LRG+ AC	47.6_c	32.0_b	1.6	0.5	3.1_c	7.5_b	7.7_b
	P_{SR}	0.14	0.75	0.45	0.18	*0.01*	0.30	0.08
	P_{PT}	*0.001*	*0.03*	0.27	0.31	*0.001*	*0.001*	*0.02*
	$P_{SR \times PT}$	*0.02*	0.26	0.43	0.22	0.11	*0.02*	0.37
	$S.E.M_{SR \times PT}$	2.20	2.59	0.39	0.76	0.79	0.85	1.28
2007-2008	HCF- AC	73.0_a	-	-	0.4	5.1_a	15.2_a	5.2
	LCF- AC	70.8_a	-	-	0.5	5.8_{ab}	16.3_a	5.3
	HRG- AC	38.8_b	-	-	0.9	8.4_b	15.7_a	35.6
	LRG- AC	32.0_b	-	-	0.6	8.7_b	16.6_a	41.6
	HCF+ AC	57.2_c	27.7	1.7_a	0.0	1.4_c	8.2_b	3.8
	LCF+ AC	57.6_c	25.9	0.6_b	0.2	1.2_c	11.2_b	4.4
	HRG+ AC	33.3_{bd}	27.6	1.3_a	0.5	1.0_c	10.8_b	25.4
	LRG+ AC	21.3_d	30.8	0.7_b	0.4	1.4_c	10.0_b	35.4
	P_{SR}	*0.03*	0.81	*0.04*	0.80	0.78	0.36	0.29
	P_G	*0.001*	0.46	0.63	0.07	0.15	0.59	*0.001*
	P_A	*0.001*	-	-	0.11	*0.001*	*0.001*	0.08
	$P_{SR \times G}$	0.06	0.44	0.54	0.45	0.94	0.39	0.13
	$P_{SR \times A}$	0.76	-	-	0.69	0.84	0.95	0.74
	$P_{G \times A}$	0.14	-	-	0.87	0.12	0.89	0.23
	$P_{SR \times G \times AC}$	0.35	-	-	0.93	0.81	0.41	0.66
	$S.EM_{SR \times G \times AC}$	2.91	2.91	0.37	0.25	1.40	1.54	11.64

Subscript SR= stocking rate, PT= pasture type and G= grass species. Values with different letter subscript are significantly different (α =0.05)

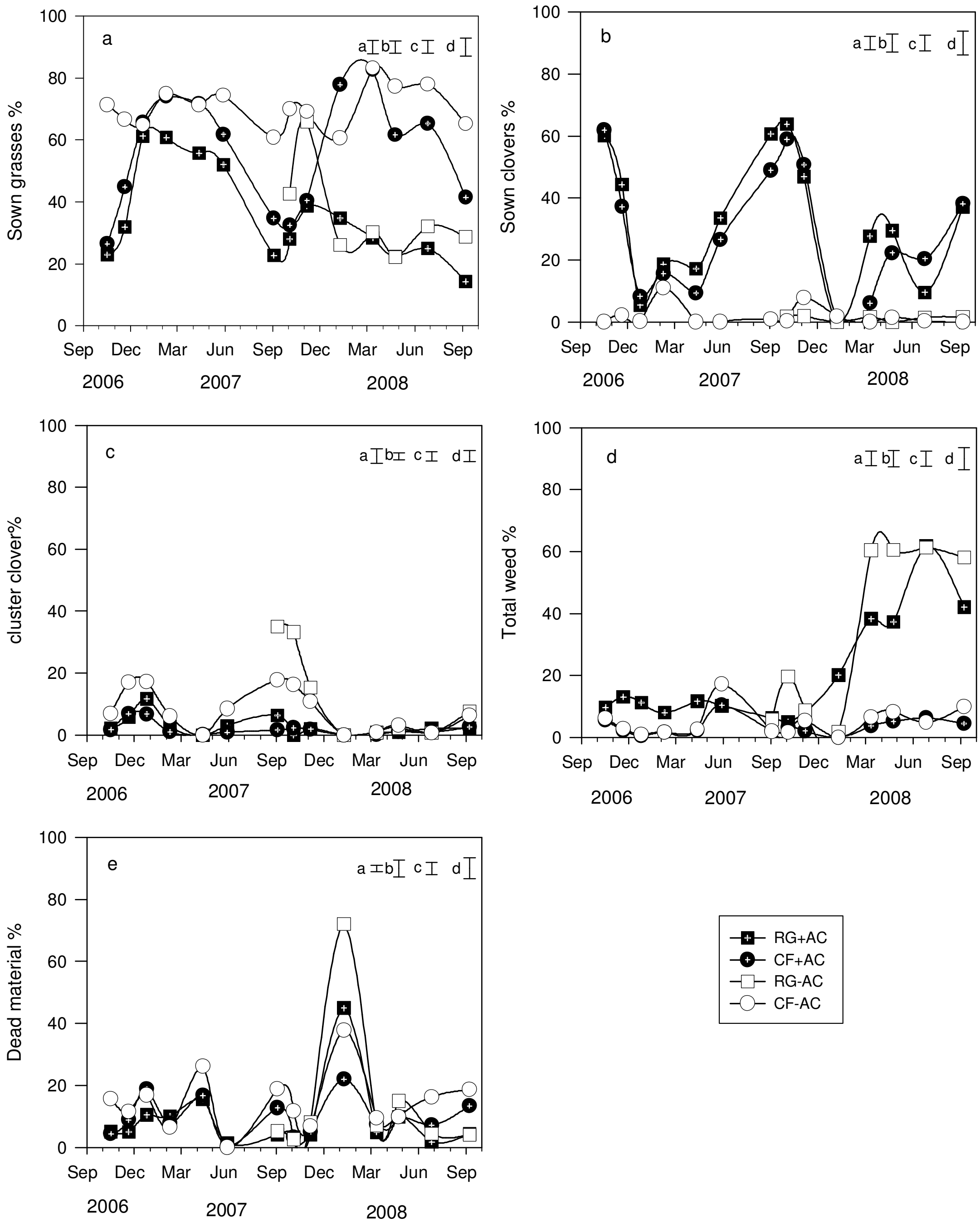

Figure 6.7 Botanical composition of pastures; mean values for high and low stocking rate (a) total sown grasses (%), (b) total sown clovers (%), (c) cluster clover (%),(d) total weed (%) and (e) dead material content (%) of cocksfoot (CF) and ryegrass (RG) pastures grown with (+AC) and without annual clovers (-AC) from 2006 to 2008. Error bars represent maximum SEM for a) pasture type, b)grass species c) annual clover (sown) and d) interaction of SR*G*A.

6.3.4 Dry matter production against accumulated thermal time

In 2006/07, temperature adjusted 2006 spring growth rates of ryegrass pastures overdrilled with annual clovers increased at 8.4 kg DM/°Cd, while the growth rate of cocksfoot pastures grown with annual clovers was 6.8 kg DM/°Cd above the base temperature of 3 °C (Figure 6.8). Cocksfoot pastures without annual clovers had the lowest ($P<0.001$) growth rate of 3.7 kg DM/°Cd for the same period. Temperature adjusted growth rates decreased by approximately 50% for grass pastures overdrilled with annual clovers and 27% or to 1 kg DM/°Cd for cocksfoot without annual clovers in early and mid summer. When the soil moisture was most limiting in late summer, temperature adjusted growth rates were below 1 kg DM/°Cd for each pasture before increasing to about 3 kg DM/°Cd for pastures with annual clovers and to 1.2 kg DM/°Cd for cocksfoot without annual clovers during the late autumn and winter period.

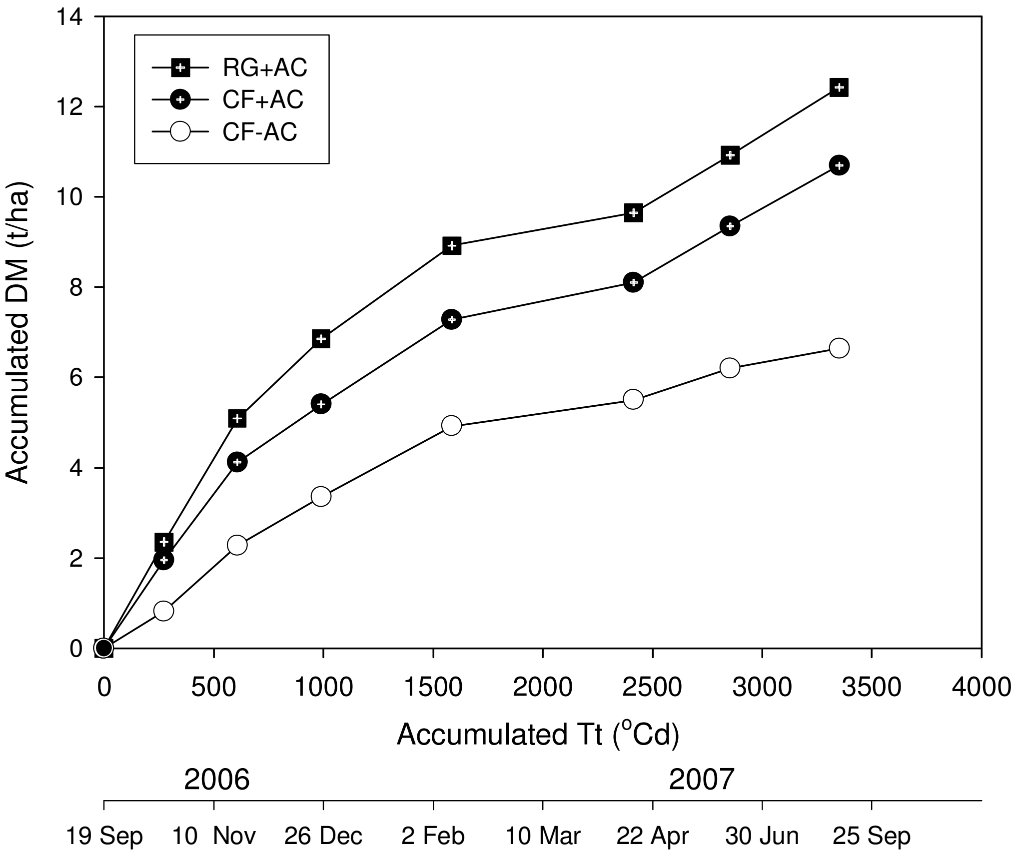

Figure 6.8 Dry matter (DM) accumulation (t/ha) from ryegrass (RG) pastures overdrilled with annual clovers (+AC) and cocksfoot (CF) pastures overdrilled with (+AC) and without (-AC) annual clovers against accumulated thermal time (Tt °Cd) above a base air temperature of 3 °C in 2006/07.

In spring 2007, temperature adjusted growth rate of ryegrass pastures overdrilled with annual clovers increased at 8.7 kg DM/^{o}Cd, while the growth rate of cocksfoot pastures overdrilled with annual clovers was 7.2 kg DM/^{o}Cd (Figure 6.9). Ryegrass pastures without annual clovers had growth rates of 6.1 kg DM/^{o}Cd. Cocksfoot pastures without annual clovers had the lowest ($P<0.001$) growth rate of 4.8 kg DM/^{o}Cd for the same period. Growth rates were only about 1 kg DM/^{o}Cd for each pasture from mid November until late autumn. The growth rates were 3.3 kg DM/^{o}Cd for grass pasture treatments overdrilled with annual clovers during the late autumn and winter period. Temperature adjusted growth rates were 2.2 kg DM/^{o}Cd for ryegrass without annual clovers and 1.8 kg DM/^{o}Cd for cocksfoot without annual clover during the late autumn and winter period.

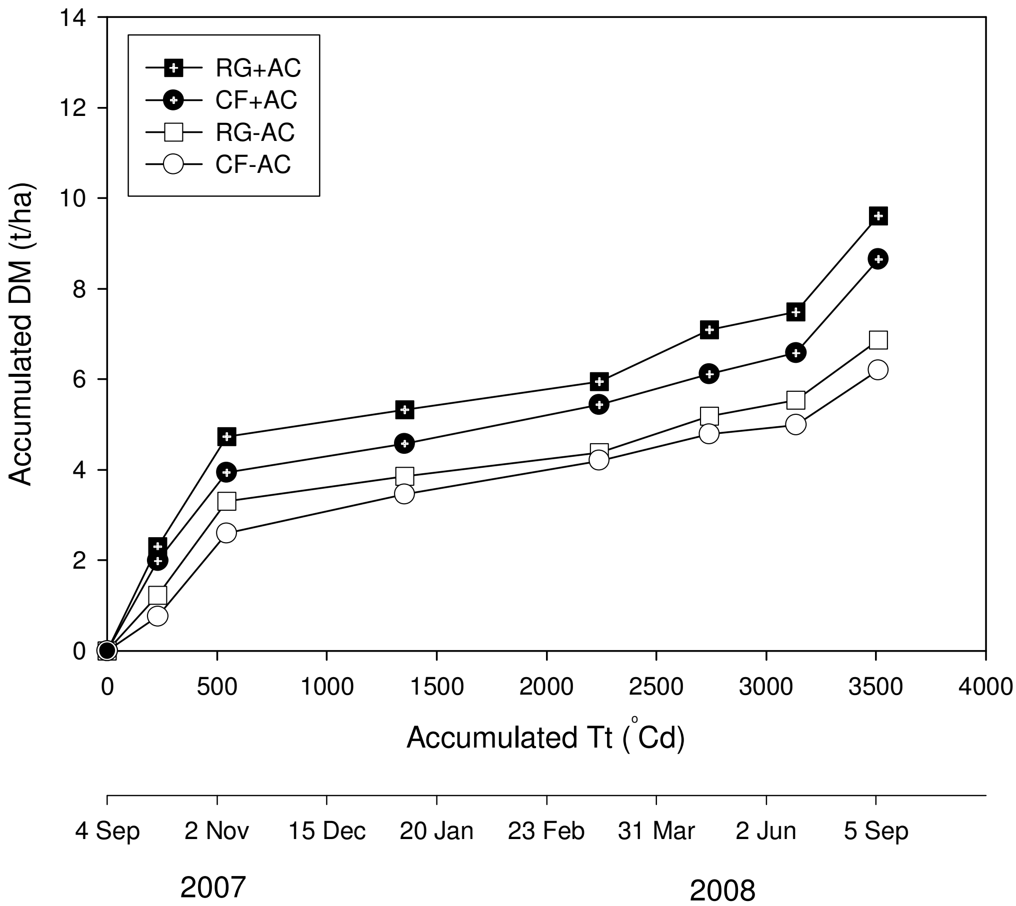

Figure 6.9 Dry matter (DM) accumulation (t/ha) from ryegrass (RG) and cocksfoot (CF) pastures overdrilled with (+AC) and without (-AC) annual clovers against accumulated thermal time (Tt ^{o}Cd) above a base temperature of 3 ^{o}C in 2007/08.

6.4 Discussion

Mean annual pasture production averaged across pasture treatments (weighted means across ryegrass and cocksfoot pastures grown with and without annual clovers under low and high stocking rates) ranged from 7.9 to 9.8 t DM/ha/y in this study which is typical for a sheep grazed dryland pasture in Canterbury (Brown *et al*., 2006 and Mills *et al*., 2008b).

6.4.1 Stocking rate

Pastures grazed at the low stocking rate during spring appeared to have a higher total annual DM yield and subterranean clover production than pastures grazed at the high stocking rate in both years, although the effect of stocking rates was rarely significant in this study (Figure 6.2). Several authors have reported the influence of grazing management and intensity on total herbage and subterranean clover production in dryland or irrigated pastures (Reed *et al*., 1972; Reed, 1974; Cayley *et al*., 1999; Waller *et al*., 2001 and Lloyd Davies & Southey, 2001). The general consensus of these studies is that higher stocking rates are detrimental to herbage production and persistence particularly under dry conditions. The higher stocking rate in this study showed a tendency of lower subterranean clover growth rates with 8-11% less total subterranean clover production compared with the low stocking rate, supporting the small trend for lower seedling numbers reported in Chapter 5. Average stocking rate in dryland pastures growing on shallow stony soils in Canterbury is 10-14 ewes/ha (Lucas, pers. communication) in spring. Similar herbage production from both stocking rate treatments may be due to lower magnitude of difference between stocking rates (8.3 vs. 13.9 ewes/ha) in this study and furthermore the different stocking rates were only applied during the spring lactation period.

The effects of stocking rate during the spring period on botanical composition were also relatively small. Pasture production was similar for both treatments until the commencement of annual clover germination in autumn. Pasture production under low and high stocking rate then started to deviate, giving higher production from the low stocking through increased clover and grass production. This may reflect the effect of grazing management in spring on subsequent production of annual clover and indirectly companion grass production by altering the amount of N fixed. However, heavy summer 'clean up' grazing to remove low quality herbage had detrimental effects on ryegrass, accelerating the increase in broadleaf weeds such as storksbill (*Erodium cicutarium*), and annual grass weeds in the second year of the experiment (Figure 6.7). Such a trend of annual grass weed invasion in ryegrass/white clover pastures in dryland was also reported by Mills *et al*. (2008b). On the other hand, sustained high productivity of subterranean clover in ryegrass pastures confirms the ability of subterranean clover to avoid the harsh summer period and take advantage of the declining ryegrass population. Previous studies have stressed the positive role of subterranean clover in cocksfoot based pastures. This study supports the use of subterranean clover in perennial ryegrass based dryland pastures.

Stocking rate altered cluster clover content, sown grass and dead material content and interacted with pasture grass species in 2006/07 (Table 6.3). The lower competitive ability of small seedlings of cluster clover is one of the major factors that determines their ecological success or failure in a mixed sward (Boswell *et al*., 2003). Increased grazing intensity in the high stocking rate treatment appeared to reduce the competition for light from taller plant species towards cluster clover and possibly provided more gaps for it to establish in autumn. Similarly, balansa clover content was higher in the high than low stocking rate pastures the following year. This indicates that the competitive ability of clovers with small seeds may be enhanced under higher stocking rates by indirectly suppressing the competitive companion grasses perennial clovers and large seeded annual clovers such as subterranean clover.

Stocking rate also influenced the dead material content of pastures and interacted with pasture type in 2006/07 (Table 6.3). The dead material content of ryegrass and cocksfoot pastures grown with annual clovers was similar in both stocking rates, while cocksfoot overdrilled with annual clovers had lower dead material content in high than low stocking rate in 2006/07. This was probably due to preferential grazing of pastures containing subterranean clover by grazing animals. Grazing ewes and lambs prefer low endophyte ryegrass over cocksfoot and clover over grass (Edwards *et al*., 1993). The lower preference of grazing animals towards cocksfoot without annual clovers may not have changed even at high stocking rate. However, ryegrass pastures grown with annual clovers at low stocking rate were grazed harder than the cocksfoot plots and this may have led to lower dead material content in these pastures. Of note, the effect of stocking rate on dead material was more obvious when pastures were maintained at higher herbage mass (1500 kg DM/ha) in 2006/07 compared with 1000 kg DM/ha in 2007/08 (Section 4.3.3).

6.4.2 Seasonal DM production

There were seasonal variations in total pasture production over the two year experimental period (Figure 6.3). Averaged across pasture treatments herbage production was approximately 2.0 t DM/ha/y lower in 2006/07 than 2007/08. This difference between years was mainly due to the differences in the amount and the timing of rainfall (Section 4.2.4.1). Despite lower spring and winter herbage production in 2006/07, elevated summer and autumn herbage production resulted in greater total annual production in that season. The amount of rainfall (mm) from December until February was 127 mm in 2006/07 compared with 79 mm in 2007/08. The extra 50 mm led to relatively high pasture growth rates during summer in the first year. The onset of autumn rainfalls in February 2008 triggered the germination of annual clovers about one month earlier than in March 2007. However the subsequent long dry period after early germination offset the greater potential autumn production of annual clovers. Hence subterranean clover production was 15% less in autumn 2008 than 2007. A warmer winter (Figure 4.1) in 2008 promoted higher pasture growth rate and production compared with winter 2007.

Thermal time was also used to compare the amount and variation of herbage production for pasture treatments (Figures 6.8 and 6.9). In spring, before the onset of dry conditions, pasture production increased at a 30-45% faster rate for ryegrass and cocksfoot pastures overdrilled with annual clovers than pasture treatments without annual clovers. Temperature adjusted dry matter production from pastures grown with annual clovers in spring was 1-1.5 kg DM/ ^{o}Cd lower than cocksfoot-subterranean clover pastures reported by Mills *et al.* (2008b). This was probably due to less favorable soil conditions (shallow & stony) in this study. Of note, is the fact that spring growth rates in 2006/07 increased for about 1500 ^{o}Cd or until February. In contrast, in 2007/08 the spring DM accumulation was only observed for 500 ^{o}Cd or until early November 2008. These differences reflect the contrasting soil moisture status during each spring.

The soil moisture in the top 20 cm remained above 18% until mid January in 2007, whilst it dropped below this level earlier in mid November in 2007 (Figure 6.1). The difference in herbage production among pasture treatments was largest during the warmer period when moisture was available as in 2006/07. In contrast, the earlier onset of drought conditions limited the production rate during summer to only 1 kg DM/^{o}Cd in 2008. The other important point here was that at the times in autumn the soil moisture was not a limiting factor, however, the production against thermal time was 50% lower compared with spring. Similarly, despite the difference in soil moisture levels, pasture production was similar in autumn 2007 and 2008. The soil moisture level in the top 20 cm was above 18% between April and June 2007 while it was below 18% during the same period the following year. However the pasture production was only 0.1-0.2 kg DM/^{o}Cd lower during autumn 2008 compared with 2007. The difference in water use efficiency was similar to findings of Moot *et al.* (2008) who reported poor utilization of available water by ryegrass/white clover pastures during summer and autumn. In this study, the spring period gave the greatest and most reliable temperature adjusted pasture production in both years. The important message for dryland farmers is that they should maximize growth rates during this period particularly with the use of annual clovers.

6.4.3 Grass species

Herbage production varied greatly among grass treatments and in different seasons which affected total production (Figure 6.3). Total annual dry matter production of ryegrass pastures appeared to be similar or higher than that of cocksfoot pastures. The superior production of ryegrass pastures occurred particularly during spring and autumn, when soil moisture was not limiting pasture growth, while cocksfoot gave greater herbage production during summer in both years. Cocksfoot is considered an important alternative for ryegrass in the dry Canterbury environment. However, it was reported that its production was similar to ryegrass in a cool and moist environment when N is not a limiting factor (Stevens *et al*., 1992). Although total herbage production appeared to be greater in ryegrass pastures overdrilled with annual clovers, DM production of both cocksfoot and total sown grass components of pasture treatments were higher in cocksfoot than ryegrass in both years. Greater total DM production in ryegrass pasture treatments was due to higher clover, annual grass and broadleaf weed content in addition to ryegrass content compared with cocksfoot pastures. The high DM production from ryegrass pastures even after heavy weed invasion and under drier conditions was probably due to the high production of storksbill in dry conditions observed in this study.

6.4.4 Annual clovers

The total herbage production of cocksfoot or ryegrass based pastures was primarily determined by the presence and the proportions of companion annual clovers. Annual clovers boosted the herbage production where available. The difference in dry matter production rate among pasture treatments was more apparent during active growth of annual clovers in spring, when moisture and temperature were not limiting production (Figure 6.4 and 6.6). Herbage production from pastures grown without annual clovers was 20-50% less than that from grass treatments overdrilled with annual clovers (Figure 6.3). This probably results from additional N input through the subterranean clover which has the ability to fix 23-34 kg N/t shoot biomass (Dear *et al*., 1999). Nitrogen was reported as the most limiting factor that determines potential production of cocksfoot monocultures (Mills *et al*., 2006). The results from this study support the pasture production responses to environmental factors as described by Mills *et al*. (2006).

Pasture treatments which were not overdrilled with annual clovers had 65-90% higher adventive (cluster) clover content during spring compared with grass treatments overdrilled with annual clovers (Table 6.3). The proportion of cluster clover ranged between 13 and 24% for cocksfoot and ryegrass pastures without annual clovers respectively during spring. There was a dramatic increase up to a maximum of 38 kg DM/ha/d in herbage production rates for pasture treatments without annual clovers in late spring compared with pasture treatments grown with annual clovers (Figure 6.5). This coincided with the increase of cluster clover production in pastures without annual clovers.

The relative magnitude of annual clover contribution was decreased by the inclusion of areas without annual clover to the total pasture production in this study. The main reasons for the reduced total pasture production can be explained by the fact that 33% of the pasture was not sown with annual clovers. The total herbage production from these areas ranged between 6.2 and 6.8 t DM/ha/y compared with 8.6 and 12.4 t DM/ha/y from pastures grown with annual clovers (Figure 6.3).

6.5 Conclusions

The following main conclusions can be drawn from this chapter.

- Mean DM production ranged from 7.9 to 9.8 t DM/ha/y in this study and stocking rate (8.3 vs. 13.9) during spring did not affect annual pasture production.
- Pastures overdrilled with annual clovers yielded 23-45% more herbage production than pastures grown without annual clovers.
- Pastures overdrilled with annual clovers grew at 8.0 kg DM/ ^{o}Cd during spring, while the growth rate of pastures without annual clovers was 6.6 kg DM/ ^{o}Cd.
- Although ryegrass pastures had similar total annual herbage production to cocksfoot pastures, total weed content of ryegrass pastures reached an average of 45% by the end of winter 2008. However, this may have been exacerbated by selective grazing of ryegrass area which was about one quarter the area of cocksfoot.
- Pasture production and growth rates showed great annual and seasonal variations mainly due to temperature and moisture. Growth rates in 2006/07 increased for about 1500 ^{o}Cd or until February 2007, whilst for 2007/08 the spring dry matter accumulation was only observed for 500 ^{o}Cd or until early November 2007 due to drier conditions.

Chapter 7
General discussion

7.1 Overview

Dryland farms in New Zealand are characterized by low and variable rainfall. Potential evapotranspiration often exceeds rainfall by 120-150 mm by February in Canterbury (Salinger, 2003) and this reduces the pasture growth. Early lambing and high lamb growth rates to finish many of the lambs before the drought halts pasture growth is the primary focus of the management decisions in this environment (Askin, 1990). High lamb growth rates are of vital importance to attain this objective. This study considered a range of strategies such as pasture types, including lucerne and grazing management to increase lamb growth rates particularly in spring.

This was realized by building an understanding of the effect of grazing management on both animal performance and the productivity and persistence of subterranean clover in two dryland grazing experiments. The impact of stocking rate and closing date on morphology and reproductive phenology of subterranean clover was described to give practical indications to farmers so that they could make informed decisions regarding subterranean clover management during spring.

Measurements from the experiments over two seasons (2006-2008) provided information on sheep liveweight gain, subterranean clover seed production, seedling re-establishment and herbage production. The first grazing experiment provided the comparison of ewe hogget and lamb liveweight gains from cocksfoot-subterranean clover pastures with cocksfoot based pastures in combination with annual and perennial clovers and a lucerne monoculture and ryegrass-white clover pastures during spring, summer and autumn seasons on a site with 100-120 mm water holding capacity (Chapter 3). This is representative of pasture resources available on dryland farms. In the other grazing experiment, ewe and twin lamb liveweight gains were measured as a sensitive response to grazing intensity in association with herbage mass and nutritive value over two spring seasons in a cocksfoot subterranean clover based pasture (Chapter 4). Seed production and seedling recruitment in two autumn re-establishment periods after spring grazing experiments were monitored as indications of potential persistence of subterranean clover (Chapter 5). Autumn and spring clover and total production were measured to quantify the effect of grazing on production on a site with an average 60 mm water holding capacity (Chapter 6).

7.1.1 Key role of lucerne

Higher sheep liveweight gain per head compared to all grass based pastures in this study confirmed the importance of lucerne in New Zealand dryland farming (Brown *et al*., 2006; Mills *et al*., 2008b). The superiority of lucerne in supporting higher liveweight gain per head was most obvious during summer when lambs grew approximately 60% faster than the average for all five grass based pastures. Even though lucerne is an excellent dryland legume with its superior forage and animal production, there are limitations in use of lucerne in dryland farming. Lucerne has also low winter growth and the onset of rotational grazing of lucerne is not recommended before mid September (Moot *et al.,* 2003). Lucerne may require high management inputs and the area that lucerne covers on a dryland farm is limited to 30-40% (White, 1982). Thus, the use of lucerne during lambing in early spring is restricted. This situation presents the necessity in dryland farming to have alternative grass/legume mixtures which can provide high lamb liveweight gain and complement lucerne.

7.1.2 Complementarity of subterranean clover pastures

The results from Chapter 3 showed that cocksfoot-subterranean clover compared with four other grass/clover based pastures gave similar or more animal production per hectare over a two year grazing period. The higher animal liveweight gain per head from cocksfoot-subterranean clover pastures was most apparent in spring 2007 when clover content increased to 37% compared with only 10% in spring 2006. This indicates that subterranean clover is important for dryland farming particularly in early spring since it provides high pasture growth rates (70-80 kg DM/ha/d) and promotes high lamb liveweight gain per head (>300 g/head/d). Thus, the result from this study suggested that subterranean clover based pastures can be complementary to lucerne in dryland environments where grass clover pastures can be grazed about one month earlier than lucerne.

7.1.3 Other clover species and seasonal variation

The other clover species such as balansa, white and Caucasian used in this study did not demonstrate an advantage over subterranean clover in early spring. Balansa clover content remained low in both the 'Maxclover' (<10%) and Ashley Dene experiments (<3%). Although balansa clover yield was double that of subterranean clover in the (2003-2004) first natural reseeding of annual clovers (Mills *et al.*, 2008a), the lower subsequent balansa clover content was mainly due to a decreasing seed bank (5-7 year old) since first flowering and seed set. In addition, the high quality site (soil conditions) also enabled cocksfoot to become more competitive and gave little opportunity for balansa clover to find bare ground to establish in after summer grazing (Monks *et al.*, 2008).

Caucasian clover was hypothesized to compete successfully with dryland grasses due to its deep taproot and is reported to be more competitive than white clover when sown within perennial ryegrass dryland pastures (Black & Lucas, 2000). However, the potential benefit from deeper rooted rhizomatous Caucasian clover was low because initial establishment was slow and compromised after autumn sowing which was required for annual clovers (Brown *et al.*, 2006). The lack of early spring growth may also limit the usefulness of Caucasian clover in early lactation on dryland farms (Black *et al.*, 2003).

Sheep production per hectare from both grass based pastures and the lucerne monoculture showed annual and seasonal variations. This was mostly due to environmental factors such as total rainfall and its distribution and temperature all of which had a significant impact on botanical composition and dry matter production (Mills *et al*., 2008a). It appeared that the wetter period than average from late spring to mid summer favoured perennial ryegrass-white clover pastures and increased volunteer white clover content particularly in cocksfoot-balansa and cocksfoot-white clover pastures in 2006/07. Although benefit from white clover even on a good soil was small, a range of pasture species may be needed to cope with seasonal climate variability particularly in hill country where lucerne is not a part of the dryland farming system. Of note, subterranean clover was affected by seasonal variations the most since the difference in mean clover content between two spring seasons was >20%. Lower annual clover (subterranean and balansa) content (~10%) in spring 2006 was attributed to the dry 2006 autumn which resulted in poor clover establishment (Mills *et al*., 2008a).

The other constraint for spring production was that overall metabolisable energy concentration and crude protein content of pastures declined in all pastures towards summer due to increasing maturity of the leaves (switch from vegetative to reproductive growth) and dead matter accumulation. The increased clover content up to 48% particularly in white clover based grass pastures did not appear to alter the decreasing nutritive value in summer 2007. This emphasizes the importance of pasture growth and high nutritive value in early spring to promote lamb growth rates no matter which pasture species are used. This may also be a good indication of the potential value of lucerne in exploiting late spring-summer rains more efficiently with retained high DM production and nutritive value (Brown & Moot, 2004). Where lucerne can not be grown (e.g. hill country), perennial legumes such as white clover and Caucasian clover may be more beneficial in exploiting late spring rainfall.

7.1.4 Companion grass for subterranean clover

The study conducted here on liveweight gain per head utilised mainly cocksfoot subterranean clover pastures and this was superior to most other dryland pasture types. However no animal production data were specifically collected from perennial ryegrass-subterranean clover pastures. The DM production data from this study showed that ryegrass can be more productive in spring compared with cocksfoot grown with subterranean clover or with ryegrass-white clover mixtures (Chapter 6). The higher DM production of perennial ryegrass-subterranean clover pastures compared with cocksfoot subterranean clover pastures occurred particularly during spring and autumn when soil moisture was not limiting pasture growth. Ryegrass pastures grown with subterranean clover in this study gave 2 kg DM/^{o}Cd more pasture production during spring compared with the production from perennial ryegrass-white clover pastures in the Mills *et al*. (2008a) study. This indicated that the potential of ryegrass in adverse climatic conditions may be improved relatively more than cocksfoot by inclusion of subterranean clover.

Of note, however, was the increasing weed content of ryegrass pastures which suggests that the persistence of perennial ryegrass in this environment may be problematic even when grown with subterranean clover. The perennial ryegrass used in this study contained the AR1 endophyte which produces only the alkaloid, peramine. This only protects the plant against Argentine stem weevil (ASW) (*Listronotus bonariensis*) (Popay & Wyatt, 1995). The more recently developed endophyte AR37 which produces the alkaloid, janthitrem may have greater persistence due to resistance against ASW, root aphid (*Aploneura lentisci*) and pasture mealy bug (*Balanococcus poae*) in this dry Canterbury environment (Pennell *et al*., 2005). Further work is needed to test compatibility of perennial ryegrass that contains AR37 endophyte with subterranean clover.

7.2 Grazing management of subterranean clover

7.2.1 Effect of grazing management on persistence of subterranean clover

This study concentrated on grazing management of subterranean clover in dryland pastures that had established subterranean clover populations. This phase of pasture is distinct from newly established subterranean clover pastures which need careful management in the first two years after sowing. Farmer experience (Costello & Costello, 2003; Grigg *et al.*, 2008) and research findings (Smetham, 2003a) suggest that developing adequate seedling populations in autumn requires lax grazing management during the first spring flowering and autumn seedling establishment phase and/or extravagantly high sowing rates (25 kg/ha). Previous studies (Collins, 1978; Young *et al.*, 1994; Smetham & Dear, 2003) reported that ultimate success or failure of subterranean clover depends on its persistence and productivity which is largely influenced by spring grazing management. Thus the effects of stocking rate and closing date in spring on persistence of subterranean clover were quantified in this study (Chapter 5).

Both seed yield and established subterranean clover seedling numbers in autumn were affected by spring grazing management. In particular, earlier closing of pastures from grazing prior to completion of burr formation favoured subterranean clover seed production and resulted in more established seedlings the following autumn. This was mainly due to closing preventing the selective grazing of subterranean clover in spring by ewes and lambs which can be detrimental to seed production as sheep consume leaves, runners, flowers and seed burrs (Ates *et al.*, 2006). The results of the study also confirmed previous findings of Young *et al.* (1994) and Steiner and Grabe (1986) who reported similar effects of duration of spring grazing in relation to reproductive development of subterranean clover.

This study also confirmed that early closing particularly at flowering or prior to burr formation in spring, increased the seed populations in the soil. In contrast, continuous grazing in subsequent springs depleted the seed reserves of soil even at low stocking rates. This was probably due to selective grazing and/or dry late spring-early summer period. In this study, the impact of closing date on persistence of subterranean clover was more important than stocking rate as a method to restore seed bank may be more efficient.

The seedling populations which established in autumn responded in a similar manner to the closing date and stocking rate treatments as the number of seeds did. Thus, differential grazing management such as closing pastures early or grazing at lower stocking rate facilitated the replenishment of subterranean clover populations. The established seedling numbers were greater than the suggested minimum 500-1000/m^2 seedlings for mixed pastures in both years (Smetham, 2003a). This was presumably because wet late spring conditions in 2006 counterbalanced the adverse effects of defoliation by providing an opportunity for subterranean clover plants to produce new tissues such as leaves and secondary branches, which in turn improved seed production.

The results from this study suggest that in paddocks where subterranean clover populations are low and therefore unproductive spelling pastures earlier than normal lamb weaning dates can be used to increase soil seed banks. In a 4 or 5 paddock rotational grazing system, this can be achieved by closing the paddock identified as having a low subterranean clover population earlier than the others. Animals that have not reached a killable weight can be finished on lucerne or other high quality feed. The other potential complementarity feature of lucerne is that if farmers can grow it, they are able to reduce grazing intensity on subterranean clover pastures from mid October as lucerne growth rates approach maximum in November and December. This study however shows little value in doing this as indicated by the small effects of reducing stocking rate from 13.9 to 8.3 ewes/ha. Reductions may have to be lower to achieve some of the benefits shown by closing pastures from grazing.

7.2.2 Implications for animal production

The aim of earlier closing pastures from grazing was to increase subterranean clover populations. However, this may have implications for lamb finishing and sales in dryland farming. This is evaluated in Table 7.1 where the proportion of lambs reaching 31 kg liveweight was calculated at each closing date. The figure of 31 kg was chosen as this would represent 13 kg carcass weight, the figure at which carcasses would be accepted at the meat processor without large penalties due to a light weight. Although early closing enabled subterranean clover to produce more seed and replenish the soil seed bank, the proportion of lambs higher than 31 kg liveweight (~13 kg carcass weight) at each closing time was lower (Table 7.1). For example, in this study none of the animals reached the targeted killable liveweights until 15 November in 2006, while the following year with the help of higher subterranean clover content, the killable proportion reached 85% for the low stocking rate by 1 November. On a typical farm, these 'finished' twin lambs at low stocking rate could be drafted from the farm while the rest of the ewes and lambs could have gone on to the lucerne on 1 November 2007, prior to weaning in early December. This reflects that the benefit from closing pastures earlier to increase subterranean clover seed production conflicted with the liveweights of lambs ready for drafting.

Table 7.1 The proportion (%) of twin lambs that reached 31 kg LW and the mean liveweights (kg/head) of lambs at low (8.3 ewes/ha) and high (13.9 ewes/ha) stocking rates and at four closing dates in 2006 and three closing dates in 2007.

Year	Closing date	Low stocking rate		High stocking rate	
		Proportion (%)	LW (kg/head)	Proportion (%)	LW (kg/head)
2006	10 October	0	17.5	0	17.3
	26 October	0	23.4	0	22.0
	15 November	40	29.9	6	27.0
	5 December	70	35.1	38	30.2
2007	16 October	0	27.1	0	22.3
	1 November	85	33.0	6	26.5
	19 November	100	40.6	72	32.3

The other management decision studied was stocking rate which also had a large impact on sheep liveweight gain per head. Lambs grew 23-26% faster in low than high stocking rates and this led to heavier final lamb liveweights by 5-9 kg in the low stocking rate treatments. In contrast, lower growth rates (75-100 g/head/d lower) of twin lambs at high stocking rate resulted in a lower proportion of prime lambs at 12-14 weeks of age at high than low stocking rate. The proportion of lambs which weighed ≥37 kg at weaning was 45% in low stocking rate, whereas none of the lambs reached this level in high stocking rate in 2006. These figures went up to 90% in low and 13% in high stocking rate in 2007, confirming the need to make management decisions in the context of climate variability. High growth rates obtained from the twin lambs at low stocking rate may be more efficient (saleable meat/MJME eaten) in converting pasture into saleable meat due to a lower ratio of maintenance to total feed requirements (Rattray *et al.*, 1987). A further implication of higher stocking rate was that the ewes lost body weight during spring. These losses in ewe liveweights in turn may cause the necessity for supplemental feeding or high quality pasture to prevent low conception rates of ewes at mating (Rattray *et al.*, 1987).

7.2.3 Relevance to hill country

The results of these grazing studies have some relevance to dry hill country, where similar grazing strategies may be applied. In such systems, lucerne may often not be part of the farming system. In hill country farms, ewes and their lambs can be moved to other paddocks with high subterranean clover seed population which can tolerate an increased stocking rate in mid spring. It was also suggested by Ates *et al.* (2006) that herbage mass on south faces, where white clover may contribute more than annual clovers, can be accumulated in early spring so some pastures on sunny faces may be spelled during subterranean clover late flowering-burr production. This implies that later developing cold south faces should not be set stocked for lambing.

7.2.4 Interactions between clovers

Although there are no formal studies of interactions between clovers in New Zealand literature, it is inevitable that adventive (volunteer) white clover will appear in most New Zealand grazed pastures when conditions allow (summer rain, high fertility, deeper soils, frequent grazing). Therefore most New Zealand pastures where clover species other than white clover are sown will tend to have varying amounts of white clover. It is probably easier to manage a pasture for its dominant sown legume but a knowledgeable farmer may be able to produce more total legume by judicious management of a multi-legume/grass pasture (e.g. subterranean clover (10 kg/ha), balansa clover (3 kg/ha) white clover (1 kg/ha) and cocksfoot (4kg/ha). This would particularly apply to a hill country paddock with variable topography presenting a range of soil depth, aspects, slopes and altitude all of which influence soil moisture potential. The different legumes would then dominate on sites where they are best adapted. In the same way, the different legume species would exploit different soil moisture availability in variable stony soils like the Ashley Dene Research Farm. Clearly pastures with more than one legume will be advantageous but on most dryland farms there will be a range of soils, and annual clovers will be expected to be chosen on drier sites and perennial legumes (including lucerne) for deeper soils.

7.3 Recommendation for future work

The results from this thesis highlighted the fact that there might be places for further research on subterranean clover pastures in dryland farming which add to the current understanding of subterranean clover grazing management.

- The spring grazing management on subterranean clover in this study was done by continuous grazing. The adaptation of subterranean clover to rotational grazing may be different. Therefore, a grazing experiment comparing continuous and rotational grazing may bring further insight into the management of subterranean clover.
- The response of subterranean clover plants may differ depending on the growth habit of subterranean clover cultivar and companion grass. Animal preference and selection ability may change under different pasture structures. Thus, subterranean clover cultivars with variation in growth habits (erect, prostrate) may be tested with clumpy (e.g. cocksfoot and tall fescue) and non-clumpy grass species (perennial ryegrass).
- The production and the persistence of mixtures of subterranean clover cultivars with different maturities should be evaluated under various grazing management conditions with perennial ryegrass AR37.

7.4 Conclusions

The research presented in this thesis has provided insight into the effects of grazing management on subterranean clover production and persistence and animal production from dryland pastures in the South Island, New Zealand. The main conclusions from each chapter can be summarized as below:

- A cocksfoot-subterranean clover pasture mixture can provide high (380-475 kg LW/ha) sheep production in dryland pastures and will be complementary to lucerne. However, a combination of species in pasture mixtures may be needed to cope with seasonal and year to year variation and provide the most efficient feed supply required for dryland farms.
- High twin lamb liveweight gain of 300 g/head/d can be obtained in mixed dryland pastures where subterranean clover is the main legume component.
- Application of low stocking rate (8.4 ewes/ha) in cocksfoot subterranean clover pastures resulted in 75-100 g/head/d faster lamb growth rates compared with a high stocking rate (13.9 ewes/ha) but liveweight production per hectare was compromised by the lower number of animals at the low stocking rate.
- Subterranean clover soil seed bank population can be increased by closing pastures earlier prior to or at the burr formation stage in spring in the paddocks identified as having low subterranean clover content.
- Established seedling numbers followed a similar trend with the soil seed bank population in both years. Early closing in October gave a mean established seedling number of 3867/m^2 and 1467/m^2 compared with 1700/m^2 and 942/m^2 in continuous grazing in 2006 and 2007, respectively.

List of publications

Ates S., Brown H.E., Lucas R.J., Smith M.C and Edwards G.R. (2006) Effect of ewe stocking rate in spring on subterranean clover persistence and lamb liveweight gain. Proceedings of the New Zealand Grassland Association 68: 95-99.

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Appendices

Appendix 1 Average stocking rate per plot and per hectare at five grass-clover pasture treatments and lucerne during spring 2006

Stocking rate	Treatments	September	October	November	Mean
Average SR/ha	Cf/bal	180.0	165.7	60.0	165.5
	Cf/Cc	160.0	160.0	160.0	160.0
	Cf/sub	180.0	188.3	128.0	165.0
	Cf/wc	160.0	177.8	180.0	174.4
	Lucerne	140.0	190.0	156.7	168.6
	Rg/wc	160.0	180.0	182.9	175.2

Appendix 2 Average stocking rate per plot and per hectare at five grass-clover pasture treatments and lucerne during spring 2007

Stocking rate	Treatments	August	September	October	November	Mean
Average SR/ha	Cf/bal	180.0	156.0	124.4	228.0	171.9
	Cf/Cc	160.0	160.0	160.0	240.0	189.1
	Cf/sub	180.0	225.0	180.0	231.1	211.3
	Cf/wc	160.0	160.0	130.0	231.1	174.3
	Lucerne	-	146.7	160.0	234.3	192.0
	Rg/wc	160.0	142.2	120.0	232.0	171.9

Appendix 3 The number of 'clean up' grazing days of pastures and lucerne between 2006-2008 in block H19, Lincoln University.

Treatment	2006/07	2007/08
Cf/bal	1392	373
Cf/sub	854	419
Cf/Cc	993	510
Cf/wc	860	420
Rg/wc	1025	397
Lucerne	279	166

Appendix 4 Mean monthly metabolisable energy MJ ME/kg DM of herbage on offer from five pasture treatments at Lincoln University in 2006/07 and 2007/08.

Year	Date	Cf/bal	Cf/sub	Cf/Cc	Cf/wc	Rg/wc	Significance	LSD
2006/07	September	11.9	12.0	11.9	11.8	12.3	<0.01	0.22
	October	11.7	11.9	12.0	11.9	12.2	0.21	NS
	November	11.5	11.3	11.3	11.3	11.7	0.29	NS
	December	10.5	10.8	11.2	11.2	11.1	N/A	-
	January	10.5	11.1	11.1	11.1	10.4	N/A	-
	February	10.7	10.1	10.8	10.7	10.9	N/A	-
	March	9.5	9.7	10.0	10.9	10.1	N/A	-
	April	11.2	11.4	10.8	spelled	11.1	N/A	-
	May	11.6	11.3	11.7	11.9	11.6	N/A	-
2007/08	September	11.4	11.5	11.6	11.4	11.8	0.13	NS
	October	11.8	11.6	11.9	11.7	12.0	0.06	NS
	November	11.5	11.6	11.6	11.6	11.6	0.75	NS
	December	10.6	10.3	10.8	10.6	10.2	0.14	NS
	January	11.2	11.0	11.0	11.0	10.9	N/A	-
	February	11.2	11.2	11.1	10.9	10.9	N/A	-
	March	11.0	10.9	11.4	11.2	10.9	N/A	-
	April	11.0	11.3	11.4	11.1	11.0	N/A	-

Appendix 5 Mean monthly crude protein (%) of herbage on offer from five pasture treatments at Lincoln University in 2006/07 and 2007/08.

Year	Date	Cf/bal	Cf/sub	Cf/Cc	Cf/wc	Rg/wc	Significance	LSD
2006/07	September	25.1	25.7	23.4	24.0	22.9	0.15	NS
	October	23.7	23.9	23.2	22.7	20.7	0.61	NS
	November	25.7	24.2	20.5	22.4	20.3	0.14	NS
	December	11.8	17.3	18.0	21.6	19.9	-	-
	January	12.1	16.0	18.9	18.1	14.3	-	-
	February	15.6	15.8	16.1	15.5	15.5	-	-
	March	15.9	14.2	14.6	15.8	13.9	-	-
	April	23.0	24.4	25.3	spelled	23.1	-	-
	May	19.7	19.4	21.4	21.5	24.4	-	-
2007/08	September	25.8	26.0	25.2	25.2	25.3	0.75	NS
	October	28.2	31.0	25.9	28.3	28.9	>0.01	0.90
	November	20.9	25.0	22.6	21.7	21.2	0.08	NS
	December	19.5	19.9	22.2	21.6	18.9	0.22	NS
	January	21.7	19.5	20.4	17.4	17.4	-	-
	February	22.0	25.3	21.9	22.7	20.6	-	-
	March	23.2	25.9	23.2	23.4	23.0	-	-
	April	23.0	23.8	24.1	21.9	21.3	-	-

Appendix 6 Mean monthly digestible organic matter in dry matter (%) of herbage on offer from five pasture treatments at Lincoln University in 2006/07 and 2007/08.

Year	Date	Cf/bal	Cf/sub	Cf/Cc	Cf/wc	Rg/wc	Significance	LSD
2006/07	September	76.1	77.3	76.9	76.2	80.4	>0.05	1.14
	October	75.1	76.2	77.7	76.6	79.2	0.21	NS
	November	73.7	71.7	72.4	71.9	75.9	0.30	NS
	December	65.1	67.9	71.2	71.2	70.8	-	-
	January	65.6	69.8	70.4	70.7	65.5	-	-
	February	67.4	63.3	67.7	66.8	69.2	-	-
	March	58.7	59.9	62.3	68.9	62.8	-	-
	April	71.7	73.2	69.2	spelled	71.2	-	-
	May	73.9	71.8	74.8	76.1	75.0	-	-
2007/08	September	73.3	74.1	74.6	73.0	76.5	>0.05	1.88
	October	76.3	74.3	76.8	75.8	77.9	>0.05	1.99
	November	73.7	74.4	74.5	75.0	75.4	0.51	NS
	December	67.0	64.8	68.5	66.9	64.6	0.15	NS
	January	72.0	70.2	70.4	69.6	69.4	-	-
	February	70.9	71.3	70.2	68.8	69.1	-	-
	March	69.7	69.0	73.4	71.1	69.2	-	-
	April	69.9	71.8	73.2	70.1	70.4	-	-

Appendix 7 Mean monthly neutral detergent fiber (%) of herbage on offer from five pasture treatments at Lincoln University in 2006/07 and 2007/08.

Year	Date	Cf/bal	Cf/sub	Cf/Cc	Cf/wc	Rg/wc	Significance	LSD
2006/07	September	40.7	38.2	38.2	41.1	35.7	>0.01	2.33
	October	42.5	39.7	38.7	41.4	38.0	0.10	NS
	November	43.8	44.7	44.4	46.7	40.9	0.48	NS
	December	52.3	49.8	43.7	46.7	46.0	-	-
	January	49.9	46.7	41.7	43.7	45.2	-	-
	February	51.3	56.3	47.8	48.3	43.0	-	-
	March	62.4	60.8	56.1	50.4	52.6	-	-
	April	48.8	46.3	46.6	spelled	45.2	-	-
	May	46.6	46.0	42.2	43.5	43.2	-	-
2007/08	September	41.9	36.6	40.1	43.7	38.1	>0.01	3.22
	October	37.5	35.2	37.8	38.7	35.4	0.33	NS
	November	41.0	36.4	40.5	41.5	39.2	0.08	NS
	December	51.4	53.8	48.5	51.5	51.8	0.14	NS
	January	48.9	49.7	48.4	51.2	46.2	-	-
	February	50.3	49.6	51.2	51.9	51.2	-	-
	March	48.6	47.2	42.4	47.5	45.8	-	-
	April	49.7	48.3	45.2	50.0	46.7	-	-

Appendix 8 Mean monthly acid detergent fiber (%) of herbage on offer from five pasture treatments at Lincoln University in 2006/07 and 2007/08.

Year	Date	Cf/bal	Cf/sub	Cf/Cc	Cf/wc	Rg/wc	Significance	LSD
2006/07	September	21.4	20.4	20.8	21.0	19.0	>0.01	1.15
	October	22.2	21.5	20.7	21.6	20.6	0.58	NS
	November	22.3	24.0	24.3	24.3	22.3	0.52	NS
	December	31.0	27.4	25.3	25.4	25.1	-	-
	January	30.5	26.6	26.1	25.6	28.4	-	-
	February	28.3	30.6	28.1	28.7	26.8	-	-
	March	33.3	33.1	31.5	27.3	30.9	-	-
	April	23.2	22.0	23.2	spelled	22.3	-	-
	May	24.4	25.2	23.0	22.9	20.8	-	-
2007/08	September	21.6	20.0	20.9	21.8	19.3	>0.05	1.69
	October	20.0	19.4	20.3	19.8	18.7	0.28	NS
	November	22.6	21.0	22.1	21.7	21.1	0.07	NS
	December	27.6	28.4	26.0	27.1	28.8	0.25	NS
	January	23.0	24.9	24.5	25.8	25.0	-	-
	February	24.7	23.8	24.8	26.1	25.8	-	-
	March	24.9	24.8	22.9	24.1	24.4	-	-
	April	25.0	23.9	22.0	24.8	23.9	-	-

Appendix 9 Mean macro nutrient concentrations of five pasture treatments at Lincoln University in early spring (September-October) 2006 and 2007.

Year	Treatment	Macro nutrient concentrations (%)						
		N	P	K	S	Ca	Mg	Na
2006	Cf/bal	3.9	0.39	3.0	0.32	0.48	0.16	0.12
	Cf/sub	3.9	0.39	2.8	0.31	0.56	0.17	0.16
	Cf/Cc	3.7	0.37	2.9	0.29	0.60	0.16	0.09
	Cf/wc	3.7	0.39	2.8	0.31	0.49	0.15	0.13
	Rg/wc	3.5	0.35	3.0	0.26	0.61	0.17	0.16
2007	Cf/bal	4.2	0.47	3.1	0.44	0.61	0.17	0.10
	Cf/sub	4.5	0.45	2.9	0.39	0.81	0.20	0.15
	Cf/Cc	4.0	0.43	3.0	0.40	0.68	0.17	0.09
	Cf/wc	4.2	0.45	3.1	0.42	0.56	0.17	0.11
	Rg/wc	4.3	0.46	3.2	0.41	0.65	0.18	0.12
Recommended levels in pasture*			0.20	0.36	0.15	0.29	0.12	0.09

*Grace (1983)

Appendix 10 Mean micro nutrient concentrations of five pasture treatments at Lincoln University in early spring (September-October) 2006 and 2007.

Year	Treatment	Micro nutrient concentrations (mg/kg)			
		Fe	Mn	Zn	Co
2006	Cf/bal	156	140	29	7
	Cf/sub	174	120	28	6
	Cf/Cc	142	120	25	6
	Cf/wc	147	120	25	7
	Rg/wc	135	68	21	4
2007	Cf/bal	176	150	38	8
	Cf/sub	199	140	40	8
	Cf/Cc	164	120	33	7
	Cf/wc	242	140	35	8
	Rg/wc	221	88	28	6
Recommended levels in pasture*		30	25	25	0.11

*Grace (1983)

Appendix 11 Metabolisable energy (MJ ME/kg DM), crude protein (%), digestible matter in dry matter (%), neutral detergent fiber (%) and acid detergent fiber (%) concentration in spring 2006 under low (8.3 ewes/ha) and high (13.9 ewes/ha) stocking rates.

Stocking rate	Date	ME	CP	DOMD	NDF	ADF
HS	20/09/2006	12.0	21.8	77.2	34.1	16.9
	27/09/2006	11.5	20.7	72.8	41.8	16.1
	5/10/2006	11.5	18.9	73.0	45.2	15.2
	12/10/2006	11.3	17.2	72.1	47.1	14.3
	20/10/2006	11.2	16.8	70.8	49.1	14.0
	27/10/2006	11.1	16.0	69.8	50.4	13.5
	2/11/2006	11.2	14.7	70.8	49.8	12.9
	10/11/2006	11.1	14.0	70.5	51.4	12.6
	23/11/2006	10.9	15.1	68.8	52.4	13.0
	4/12/2006	10.5	14.2	65.3	56.9	12.3
LS	20/09/2006	12.1	22.8	77.5	32.4	17.5
	27/09/2006	11.4	20.7	72.3	41.2	16.1
	5/10/2006	11.6	20.1	74.0	41.8	15.9
	12/10/2006	11.5	19.6	73.2	41.4	15.5
	20/10/2006	11.3	19.2	71.5	44.5	15.2
	27/10/2006	11.3	18.0	71.5	44.9	14.6
	2/11/2006	11.5	16.5	73.2	44.8	14.0
	10/11/2006	11.4	14.8	72.7	47.7	13.1
	23/11/2006	11.1	13.0	70.6	51.5	12.1
	4/12/2006	11.0	12.2	69.5	52.7	11.6

Appendix 12 Metabolisable energy (MJ ME/kg DM), crude protein (%), digestible matter in dry matter (%), neutral detergent fiber (%) and acid detergent fiber (%) concentration in spring 2007 under low (8.3 ewes/ha) and high (13.9 ewes/ha) stocking rates.

Stocking rate	Date	ME	Protein	DOMD	NDF	ADF
HS	23/08/2007	11.3	24.3	72.6	37.0	17.8
	30/08/2007	11.3	22.7	72.2	36.3	17.0
	6/09/2007	11.0	20.4	70.6	40.5	15.7
	13/09/2007	11.0	21.9	69.6	42.1	16.4
	20/09/2007	10.8	23.4	68.9	44.1	17.1
	26/09/2007	11.1	22.9	71.2	41.7	17.0
	3/10/2007	11.0	20.8	70.4	45.3	15.9
	12/10/2007	11.1	22.8	70.9	42.1	17.0
	19/10/2007	11.1	22.6	71.1	42.2	16.8
	25/10/2007	11.5	24.1	74.1	38.8	17.8
	1/11/2007	11.2	24.1	72.0	42.6	17.6
	11/11/2007	10.9	18.3	69.1	49.1	14.6
LS	23/08/2007	11.2	24.6	71.8	35.6	17.9
	30/08/2007	11.2	23.6	72.1	36.2	17.4
	6/09/2007	11.2	22.5	71.4	36.6	16.8
	13/09/2007	11.0	23.2	69.9	39.6	17.1
	20/09/2007	11.1	25.2	70.5	39.3	18.1
	26/09/2007	11.4	25.0	73.2	34.5	18.2
	3/10/2007	11.5	25.8	73.7	35.0	18.7
	12/10/2007	11.7	25.6	75.0	33.4	18.7
	19/10/2007	11.5	23.9	73.9	35.8	17.7
	25/10/2007	11.5	24.7	73.2	34.5	18.1
	1/11/2007	11.5	23.6	73.3	36.5	17.5
	11/11/2007	11.3	18.7	71.8	44.2	15.0

Appendix 13 Mean diet macro nutrient concentrations of herbage on offer over three periods in spring 2006 grazing season under low and high stocking intensities at Ashley Dene.

	SR	Period	Macro nutrient concentrations (%)						
			N	P	K	S	Ca	Mg	Na
2006	HS	19 Sept-16 Oct	2.9	0.35	2.5	0.31	0.81	0.16	0.12
		16 Oct-10 Nov	2.4	0.32	2.2	0.32	0.63	0.13	0.11
		10 Nov-05 Dec	2.1	0.33	2.1	0.30	0.64	0.14	0.11
		Mean	**2.5**	**0.33**	**2.3**	**0.31**	**0.69**	**0.14**	**0.11**
	LS	19 Sept-16 Oct	3.2	0.33	2.6	0.30	0.94	0.17	0.12
		16 Oct-10 Nov	2.7	0.29	2.3	0.28	0.75	0.15	0.10
		10 Nov-05 Dec	2.0	0.26	2.1	0.25	0.65	0.13	0.08
		Mean	**2.6**	**0.29**	**2.3**	**0.28**	**0.78**	**0.15**	**0.10**
2007	HS	23 Aug-16 Oct	3.4	0.40	2.4	0.31	0.75	0.17	0.10
		16 Oct-19 Nov	3.3	0.45	2.4	0.34	0.64	0.17	0.12
		Mean	**3.4**	**0.43**	**2.4**	**0.33**	**0.70**	**0.17**	**0.11**
	LS	23 Aug-16 Oct	3.7	0.37	2.4	0.27	0.82	0.18	0.10
		16 Oct-19 Nov	3.4	0.35	2.6	0.26	0.90	0.17	0.12
		Mean	**3.6**	**0.36**	**2.5**	**0.27**	**0.86**	**0.18**	**0.11**
Recommended levels in pasture*				0.20	0.36	0.15	0.29	0.12	0.09

*Grace (1983)

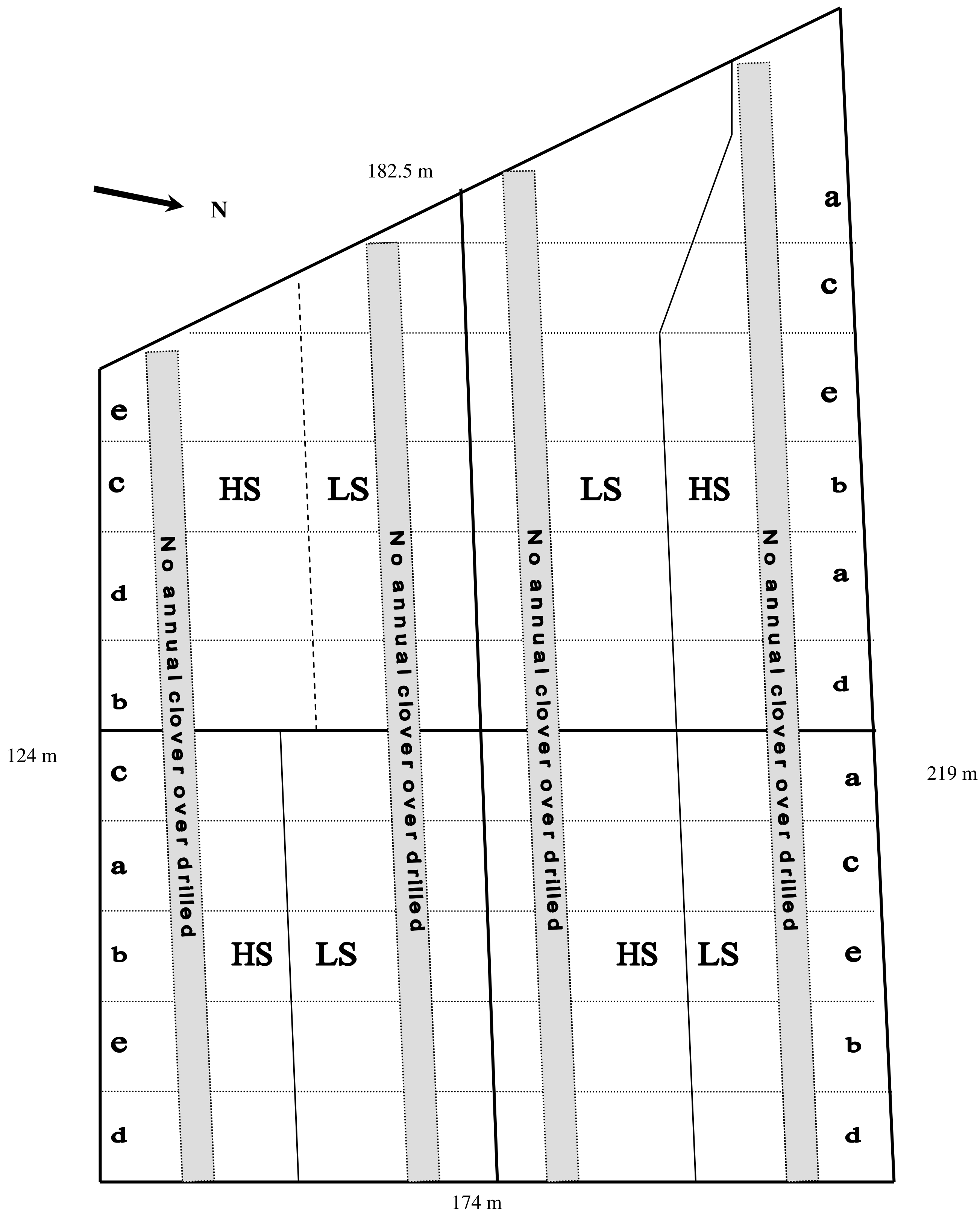
Appendix 14 Mean diet micro nutrient concentrations of herbage on offer over three periods in spring 2006 grazing season under low and high stocking intensities at Ashley Dene.

Year	SR	Period	Micro nutrient concentrations (mg/kg)			
			Fe	Mn	Zn	Co
2006	HS	19 Sept-16 Oct	152	110	23	5
		16 Oct-10 Nov	167	110	20	5
		10 Nov-05 Dec	273	120	24	5
		Mean	**197**	**113**	**22**	**5**
	LS	19 Sept-16 Oct	141	110	27	5
		16 Oct-10 Nov	138	95	20	5
		10 Nov-05 Dec	96	93	20	4
		Mean	**125**	**99**	**22**	**5**
2007	HS	23 Aug-16 Oct	368	160	29	6
		16 Oct-19 Nov	561	190	33	7
		Mean	**465**	**175**	**31**	**7**
	LS	23 Aug-16 Oct	248	120	30	5
		16 Oct-19 Nov	218	110	27	5
		Mean	**233**	**115**	**29**	**5**
Recommended levels in pasture*			30	25	25	0.11

*Grace (1983)

Appendix 15 Seasonal DM production (kg/ha) of ryegrass (RG) and cocksfoot (CF) pastures with (+AC) and without annual clovers (-AC), grazed at low (LS) and high (HS) stocking rates at C9(A)S Ashley Dene from 2006 to 2008. Measurements from ryegrass pastures without annual clovers started on 3 September 2007.

Harvest	HS CF		HS RG		LS CF		LS RG		Effect	Significance	L.S.D
date	+AC	-AC	+AC	-AC	+AC	-AC	+AC	-AC			
17/10/06	1904	716	2387		2003	915	2330		PT	<0.01	374.2
20/11/06	2106	1546	2770		2226	1372	2699		PT	<0.01	540.6
25/12/06	1263	934	2014		1308	1231	1504		NS	-	-
8/02/07	1929	1879	2061		1826	1251	2071		NS	-	-
12/04/07	731	413	682		914	750	775		NS	-	-
29/05/07	1055	502	1211		1432	897	1334		PT	<0.05	398.1
3/09/07	1268	486	1423		1420	389	1594		PT	<0.01	308.4
4/10/07	1904	781	2057	1200	2069	734	2536	1247	G A	<0.01 <0.01	225.4 301.1
6/11/07	1888	1521	2098	2182	2018	2154	2769	1975	SR*G*A	<0.05	663.9
9/01/08	558	1101	576	544	719	630	625	577	SR*G*A	<0.05	456.4
12/03/08	888	740	610	554	825	745	590	529	G	<0.01	125.1
24/04/08	776	619	1189	771	578	724	1093	653	NS	-	-
26/06/08	511	256	457	479	421	173	327	222	G*A	<0.01	273.8
7/09/08	2143	1640	1580	1060	2006	1082	2672	1284	SR*G*A	<0.05	830.6



Appendix 16 Sowing rate and grazing experiments design at paddock C9(A)S Ashley Dene. a= 2 (wc) 2 (cf), 0 (rg) kg/ha, b= 2 (wc) 2 (cf), 5 (rg) kg/ha, c= 2 (wc) 2 (cf), 10 (rg) kg/ha, d=2 (wc) 2 (cf), 15 (rg) kg/ha, e=2 (wc) 0 (cf), 10 (rg) kg/ha.