The effect of spring grazing management on yield, animal liveweight gain and root reserves of lucerne (*Medicago sativa* L.).

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Disclaimer

For the purpose of data collection and trial involvement for this honours dissertation, I was involved with all measurements, data collection and collation from February 9 2011 until the November 1 2011. This meant that I was not involved with any of the spring and early summer grazing of the lucerne prior to this time in the 2010-11 season.

Abstract

Lucerne (*Medicago sativa* L.) is a common pasture legume grown in New Zealand. Rotational grazing is recommended for ensuring stand production and persistence. However, during lambing set stocking ewes and lambs is the preferred management practice. Two grazing experiments were conducted to quantify the effect of spring grazing management treatments on animal and plant production with emphasis on the amount and composition of perennial (crown and root) dry matter. Rotationally grazed plots had an average yield of 15 t DM/ha. Mean annual liveweight production was reported as 1702 kg LW/ha/yr for all stock which grazed lucerne under a rotational regime for the 2010/11 season. Set stocked and semi set stocked mean annual liveweight production was 1452 and 1355 kg LW/ha/yr, respectively. Plant population was found to be 205/m² under in lucerne semi set stocked in spring. Water soluble carbohydrates in the crown portion of the root were higher under rotational grazing at 145 kg/ha. Values for set stocked and semi set stocked grazing were also different with 110 and 122 kg/ha for each treatment respectively. Set stocked and semi set stocked lucerne had liveweight production comparable to rotational during spring, however the management practices resulted in reduced perennial root reserves, and suggested reduced persistence of the stand in the long term.

Keywords: Alfalfa, dryland, dry matter, grazing, lucerne, management, *Medicago sativa*, perennial reserves, persistence, roots, rotational grazing, set stocked, sheep, water use, weeds.

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1 Introduction

Lucerne (*Medicago sativa* L.) is a commonly grown pasture legume in dryland areas of New Zealand. Lucerne is a perennial legume species with an extended taproot that allows the plant access to water deep in the soil profile. This gives it superior drought tolerance and dry matter production in comparison with perennial ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.) pastures in many summer dry areas.

Lucerne has been shown to give liveweight gains that were up to 70% greater than on ryegrass/white clover pastures (Douglas, 1986). Under Canterbury dryland conditions, Mills *et al*. (2008b) found sheep rotationally grazing lucerne to have an average annual liveweight production of 833-1110 kg/ha for the first five years after establishment of the stand. This was 33-42% higher than grass based pastures in the same trial, and was a result of higher daily liveweight gains, thus stock met liveweight targets over a shorter grazing period.

The superior nature of lucerne in comparison with other dryland pastures is well reported in literature. In a five year trial under dryland conditions in Canterbury, Mills *et al*. (2008a) found the annual yield of a range of common dryland grass/clover pastures to be between 9.4 and 11.6 t DM/ha/yr. Lucerne grown in Canterbury soils with a plant available water capacity of 150-200 mm/m was shown to have an average yield of 20 t DM/ha/yr by Brown *et al*. (2003). The advantage for lucerne was primarily attributed to the ability to extract water from greater depths in the soil profile in comparison with shallower rooted species, but also because it had greater water use efficiency (Brown *et al*., 2005).

Unlike many conventional dryland pastures, lucerne requires careful grazing management to ensure maximum production and stand longevity. Rotational grazing throughout the year is recommended. This is primarily because lucerne grows from the tip of the stem rather than the base of the plant, and thus continuous grazing allows stock to remove new lucerne shoots and restricts the ability of the plant to regrow.

However, specific grazing management is one of the main deterrents for farmers looking to use lucerne on a significant proportion of their dryland property. During lambing, ewes and lambs are often set stocked on grass/clover pastures for ease of management. Thus it would be preferable if lucerne could be managed in a similar manner during spring, without negatively impacting upon subsequent production and stand persistence.

A disadvantage of lucerne is its lack of winter and early spring growth. However, much of the work of Teixeira *et al*. (2007b) has highlighted the importance of appropriate autumn management in determining the productivity of early spring growth. This involves imposing an autumn grazing management strategy that allows the lucerne crop to recover root carbohydrate reserves. These are then available for rapid remobilisation in spring, allowing rapid stem expansion, and earlier spring dry matter production (Moot *et al*., 2003).

The focus of this dissertation is to examine the effect of spring grazing management (frequency and spelling time), on animal production and the lucerne crop. Rotational grazing is compared with two unconventional, not recommended, lucerne management practices being set stocked and semi set stocked (10 day alternate shifts between two paddocks) grazing regimes during spring. At the conclusion of spring grazing, set stocked and semi set stocked paddocks were grazed rotationally in an attempt to allow plants to recover from poor early season management.

Therefore the main aim of the experiment is to determine whether greater flexibility can be incorporated into lucerne crops. The objectives are to quantify the effect of spring grazing management treatments on animal and plant production with emphasis on the amount and composition of perennial (crown and root) dry matter. These will be used as a surrogate to indicate the impact of grazing on lucerne stand persistence.

The dissertation comprises of six chapters, which include an introduction, literature review, materials and methods, results, discussion and general discussion.

2 Review of Literature

This chapter reviews the literature on the potential to increase dryland production through the use of lucerne. It then goes onto review the concepts of environmental influences on yield, and the influence of grazing management practices on the persistence and productivity of the crop.

2.1 Introduction

Lucerne (*Medicago sativa*), also known as alfalfa, is a temperate, perennial legume species originating from central Asia (Langer, 1973) and is a member of the Fabaceae family (Charlton & Stewart, 2000). It has an erect growth habit, making it suitable for grazing by sheep, cattle and deer (Charlton & Stewart, 2000). It has been promoted in New Zealand as the most suitable forage species for intensive dryland sheep pastures for over 100 years (Moot *et al*., 2003).

Perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) in combination, are the two most commonly used pasture species in New Zealand pastures (Brown *et al*., 2006). As long as water supply is adequate, the production of these pasture species is high and complementary. However, when water becomes limiting, growth quickly diminishes as a result of shallow root systems, and they are susceptible to heat stress. Lucerne is a deep tap rooted plant, and thus holds a production advantage in areas where summer dry periods limit pasture production.

White (1982) suggested 40-60% of the farm area should be planted in pure swards of lucerne to achieve maximum growth rates. Using data from a survey of Canterbury and North Otago properties, Kirsopp (2001) showed that lucerne occupied less than 20% of the farm area on the majority of the 67% of farms that grew the crop. This shows that despite the benefits of growing such a high producing crop, farmers were reluctant to plant large proportions of their farms in lucerne. Aside from the perception of problems with disease and persistence, the main deterrents were the lack of crop growth during the winter months and requirements for special grazing management throughout the year (Brown, 2004).

Rotational grazing is the preferred method of defoliation in lucerne stands. It ensures that the crop is grazed in a uniform manner, yet newly developing nodes are not removed by stock which would negatively affect subsequent regrowth (Moot *et al*., 2003).

For farmers that use lucerne in their livestock production systems, lambing was delayed for at least a fortnight to match animal demand with feed supply (Kirsopp, 2001). This is a disadvantage as early lambs gain a premium price at the meat works. Furthermore, rotational grazing of lucerne does not allow for the same ease of management during lambing, and can increase the incidence of mismothering, particularly with ewes that have multiple lambs. Therefore, in many cases, set stocking ewes and lambs during lambing is the preferred management by many farmers.

The creation of more flexible grazing management rules has been the focus of research at Lincoln University for over 10 years, and this study explores the impacts of set stocking and rotational grazing on growth and lucerne production and persistence.

2.2 Potential to increase dry matter production

In New Zealand, moisture stress is common in dryland pastoral environments, particularly during the summer/autumn period (Mills *et al*., 2008a). Dryland farmers in these regions often incorporate a deep taprooted species, such as lucerne, into their production system as a way of converting the limited amount of annual rainfall into high quality forage (Kearney *et al*., 2010).

During the 1980s, lucerne was predominantly found growing in the Central North Island, Marlborough, Canterbury/North Otago and Central Otago, with 43% of the total national lucerne area being found in Canterbury (Douglas, 1986). Dryland environments in the majority of these regions are subject to low to moderate annual rainfall and/or free draining soil types, thus a pronounced soil water deficit during summer is common.

Shallow-rooted pasture species such as ryegrass and white clover, which loses its taproot after 2-3 years (Widdup *et al*., 2003) are unable to use water from greater soil depths, and therefore have reduced drought tolerance in comparison with lucerne. Over the last 15 years much of dryland Canterbury has been irrigated with a drop in dryland sheep production. However, lucerne remains a viable option for (Moot *et al*., 2011) many dryland regions.

2.3 Growth and development

Vegetative growth of a lucerne stand occurs in the form of nodes and attached leaves on growing points found at the tip of the stem. When these growing points are removed, either by cutting or grazing, the growth of the stem stops, and the plant begins to regenerate in the form of new stems growing from basal buds on the crown of the plant (Moot *et al*., 2003).

Initiation of basal buds and the occurrence of early growth are primarily driven by the remobilisation of reserves stored in the crown and tap root of the plant (Moot *et al*., 2003).As new leaves are formed, and temperatures increase, light interception and plant growth begin to increase linearly. Factors which may limit this linear growth pattern include temperature and insufficient water supplies.

The patterns of growth observed in the lucerne plant mean that during the spring, roots loose dry weight primarily as a result of remobilisation of carbohydrate and amino acid reserves. During summer, herbage production is decreased as the plant attempts to regain some of these root reserves for growth in the following spring (Teixeira *et al*., 2007a;b).

2.4 Liveweight gains in sheep

Lucerne has been shown to produce liveweight gains that were up to 70% greater than on ryegrass white clover pastures (Douglas, 1986; Ulyatt, 1978). Early New Zealand studies on spring grazing by lambs gave liveweight gains in excess of 300 grams per day

(Jagusch & McConnell, 1971; Nicol & McLean, 1970). Liveweight gains over the duration of the grazing season were shown to decrease, with the average gains approximately 240 and 140 g/d for November and January, respectively (Douglas, 1986). The decline in the liveweight gain from spring to summer follows a seasonal pattern (Brown, 2004), whereby digestibility of the lucerne stem declines over time. For rapid growth in lambs during the late summer/early autumn period, grazing should not be as hard, only allowing for the removal of leaves and the top of the stems where digestibility remains the highest (Fletcher, 1976).

Brown *et al*. (2006) showed a similar trend, whereby liveweight gains of 550 kg LW/ha were observed in sheep grazing dryland lucerne between December and February. Gains were 200 kg LW/ha higher than stock grazing grass based pastures over the same period. This followed the spring grazing period, in which lucerne had produced liveweight gains of 400 kg LW/ha despite grazing commencing 40 days later than grass treatments.

The production of newly weaned lambs grazing lucerne was compared with those grazing either red clover (*Trifolium pratense*) or perennial ryegrass by Fraser *et al.* (2004). After a 14 day adjustment period, lambs grazed each treatment plot for a seven day period before shifting to the next replicate. Any remaining vegetation was topped to maintain a uniform vegetative growth stage for the next rotation. Lambs remained grazing plots until they reached specified slaughter weights.

While lambs grazing either clover or lucerne showed significantly higher liveweight gains than ryegrass (121 and 59 g/d respectively) clover also gave better production than lucerne. Lambs grazing the clover had a liveweight gain of 305 grams per day, taking only 38 days to reach the required slaughter weight, while those on the lucerne sward grew at 184 g/d, and thus took a further 28 days to reach the required slaughter weight. This suggests that the benefits of grazing lucerne are seen later in the season, where clover may be limited by soil moisture deficits, and lucerne production remains strong.

In more recent research, Mills *et al*. (2008b) found lucerne, rotationally grazed by sheep to have an average annual liveweight production of 833-1110 kg/ha for the first five years after establishment. This was 33-42% higher than the grass based pastures, and was achieved by higher daily liveweight gains, over a shorter grazing period. As a continuation of this trial, Mills & Moot (2010) reported the average liveweight gains from the same lucerne stand to be 903 and 1141 kg/ha/yr in years six and seven. It was over the summer period (December – February) that lucerne had the greatest advantage over grass based counterparts, maintaining higher levels of dry matter production per hectare, and thus allowing for greater liveweight gain in stock.

A grazing trial using hoggets by Mills *et al*. (2008b) showed that stock grazing lucerne had an average liveweight gain of 260 g/hd/d compared with195 g/hd/d in those grazing a ryegrass/white clover pasture. However, it was summer grazing with weaned lambs which highlighted the superior average daily weight gains that can be achieved under dryland conditions. Lambs grazing lucerne averaged a 160g daily liveweight gain compared with only 65 g/hd for the ryegrass/white clover. The lucerne was able to maintain higher growth rates during periods of soil moisture deficits which limited pasture growth. It also produced 60% more annual dry matter compared with the grass based pastures during the experimental period.

Mills & Moot (2010) give values for the number of grazing days achieved for lucerne in comparison with a number of grass/clover mixtures. The average number of graze days for two consecutive years was equal to 1531 days per hectare. Lucerne allowed for less grazing days per annum in comparison to all other pasture mixes, except for a perennial ryegrass/white clover sward at 1504 d/ha. Despite the limited number of grazing days observed for lucerne, both annual dry matter and liveweight production were superior ($P<0.001$) to all other pastures.

2.5 Dry matter production and growth

The superior liveweight gains that can be achieved in stock grazing lucerne are partly attributed to the fact that lucerne has superior dry matter production in comparison to many other pasture species and forages in dryland conditions. Furthermore, the timing of the peak in dry matter production often occurs when pasture growth rates begin to slow as a result of soil moisture deficits and farmers require feed to maximise liveweight gain.

The growth pattern of lucerne is strongly influenced by temperature and solar radiation when water is not a limiting factor (Douglas, 1986). Growth rates are high in summer and low in winter (Brown *et al*., 2003). In cooler regions of New Zealand, it has been observed that for 100-120 days of the year, minimal growth occurs as a result of temperature (Douglas, 1986). While dry matter production can be severely limited by lack of water availability in a dryland environment, lucerne will invariable out-yield any grass based pasture through better water extraction, higher water use efficiency (Section 2.8) and faster growth response to summer rainfall (Mills *et al*., 2008a).

Brown & Moot (2004) compared the dry matter production of lucerne with that of chicory (*Cichorium intybus*) and red clover. The results highlight why lucerne is the preferred choice for optimum herbage production and live weight gains in livestock. Mean annual yields of lucerne were 3.9 t/ha/yr higher than both chicory and red clover over a five year experimental period. The lucerne sward also provided 30% greater annual crude protein and metabolisable energy than the other two species, as a result of higher utilisation (80%) combined with higher rates of production at the beginning and end of the growth season (Brown, 2004).

For lucerne, annual yields of 20.6 t DM/ha for dryland crops grown in soils with a high plant available water capacity (PAWC) are common in the North Island (Douglas, 1986). Douglas (1986) used a wide range of other production data, taken from lucerne growing in soils derived from volcanic ash, consolidated sand or basalt to show the average lucerne production was approximately 12-13 t DM/ha across much of the North Island between 1975 and 1985.

Lucerne yields decrease with reduced rainfall, for example, annual yields recorded in Alexandra, Central Otago, varied between 1.9 and 12.3 t DM/ha over a 14 year period (Douglas *et al*.,1987). This is an extreme example of variation in summer rainfall which is the main determinant of dry matter production. A newly established ‘Kaituna’ lucerne stand grown under dryland conditions in Central Otago for two consecutive years yielded

4.2-8.4 t DM/ha/yr, while improved ryegrass/white clover pastures grown under the same conditions produced 3.1-5.3 t DM/ha/yr (Kearney *et al*., 2010). In Canterbury, under irrigated conditions, lucerne has been shown to produce yields as high as 28 t DM/ha/yr (Brown, 2004). However, under dryland conditions in the same region, often a lucerne crop will yield only half of that of an irrigated crop. In a Templeton fine sandy loam, McKenzie *et al*. (1990) reported annual yields of 12.7 t DM/ha/yr.

Also in a Templeton silt loam, of 0.85–1.45 m of soil above alluvial gravels, Mills *et al.* (2008a) found dryland lucerne, averaged between 13.1 and 18.5 t DM/ha/yr in Years 1, 2, 3 and 5 of their five year experiment (Figure 2.1). Following on from this trial, Mills & Moot (2010) found the annual yield of the same lucerne stand to be 14 t DM/ha in Years 6 and 7. Out of the legumes used, lucerne was also found to be the most responsive species to summer rainfall (Mills *et al*., 2008a).

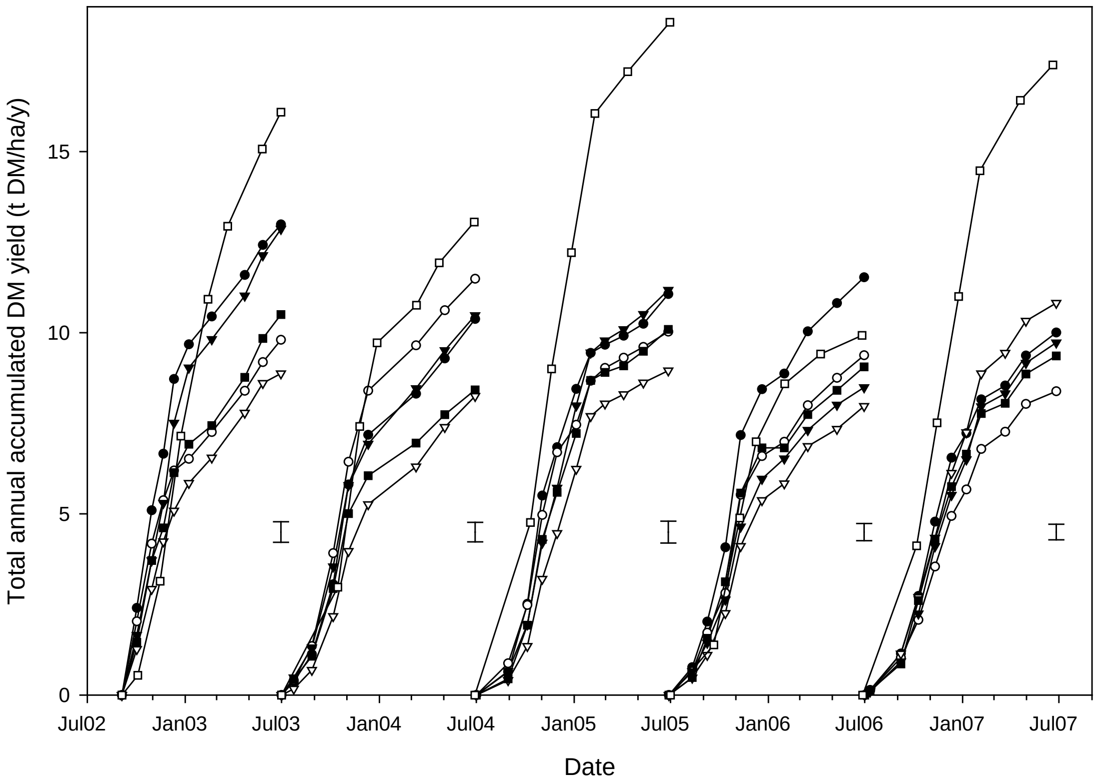

Figure 2.1 Total annual dry matter yield of Cocksfoot /Subterranean clover (●), Cocksfoot/Balansa clover (*Trifolium michaelianum*) (○), Cocksfoot/White clover (▼), Cocksfoot / Caucasian clover (*Trifolium ambiguum)* (▽), Ryegrass/White clover (■) and lucerne (□) pastures of five regrowth seasons(2002-2007). Error bars are SEM for total annual yields for each growth season (Mills *et al*., 2008a).

Of the grass based pastures in the same experiment, a combination of cocksfoot (*Dactylis glomerata*) and subterranean clover (*Trifolium subterraneum*) gave annual yields of 9.9-12.9 t DM/ha/yr. This was greater than or similar to the other grass based pastures in the experiment, which included perennial ryegrass/white clover. Mills *et al*. (2008a) concluded that a cocksfoot/subterranean clover pasture resulted in the most consistent pasture combination to ensure reliable spring growth. This study highlights the potential to include cocksfoot/subterranean clover pastures and lucerne in the farm system for early spring production and reliable summer production when moisture deficits limit pasture growth.

Lucerne yields were still 14-66% greater than the highest yielding grass based pastures grown as part of the same experiment. Brown *et al*. (2003) showed lucerne to consistently yield higher than 20 t DM/ha over the duration of a five year experiment, where lucerne was grown in a Wakanui silt loam, with a plant available water capacity (PAWC) of 150-200 mm/m and deep soils which did not impede root growth to at least 2.3 m depth.

2.6 Pattern of dry matter production

McGowan *et al*. (2003) compared different cultivars of lucerne in a hill country environment, and reported annual production across the year. It was found that annual production was consistent over the five year period, and differences between the cultivars were minor between seasons. Monthly dry matter production of the lucerne cultivar 'Rere' for a five year period was compared with a 20 year old perennial ryegrass (23%) and white clover (10%) pasture adjacent to the lucerne stand. Results emphasised the earlier spring production of the ryegrass/white clover, and lucerne compensates for lower spring production by higher summer growth rates of 62 kg DM/ha/d, compared with 34 kg DM/ha/d for pasture. A similar yield advantage was also observed by Mills *et al*. (2008a) during the summer/autumn period when potential soil moisture deficits are at their greatest.

2.7 Quality

Lucerne is a high quality forage and this is responsible for superior annual liveweight gains. These have been reported as ranging from around 500 (Brown *et al*., 2005) to in excess of 1100 kg LW/ha (Mills *et al*., 2008a). Lucerne quality is characterised by high crude protein and digestibility (Burke *et al*., 2002; Jagusch & McConnell, 1971).

Brown & Moot (2004) compared irrigated lucerne with monocultures of chicory and red clover, and found the utilised portion of the lucerne swards to provide 30% greater crude protein (CP) and metabolisable energy (ME) than the other species. The CP content was found to be 0.29 g/g DM in the leaf while the ME was equal to 10.9 MJ/kg DM. The latter figure was comparable to 11.2 MJ/kg DM found by Mills & Moot (2010). Utilisation of lucerne remained between 72 and 80% over the five year period, with the exception of an average of 65% utilisation in year four, when snow caused significant lodging.

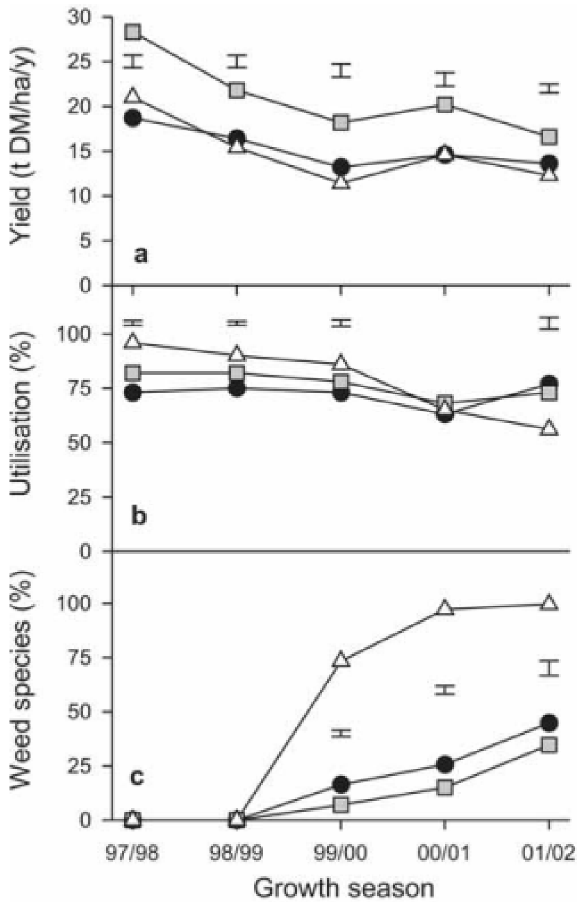

Figure 2.2 Total annual herbage yields (a), stock utilisation (b) and botanical composition (c) of chicory (●), lucerne (■) and red clover (△) swards grown over five regrowth seasons (1 July 1997 – 30 June 2002). Bars represent one SEM for each regrowth season when values were different (Brown & Moot, 2004).

Brown & Moot (2004) showed that the percentage of palatable lucerne herbage declined over the course of a season. Fletcher (1976) indicates that delaying defoliation has the potential to decrease total herbage utilisation. However, Brown & Moot (2004) found a higher proportion of CP and ME in the palatable fraction, thus the deferred grazing was found to have minimal effects on the utilisation of total CP and ME and thus animal production was still able to be maximised. Stock have been shown to selectively graze the sward (White & Cosgrove, 1990) eating the leaf and soft stem fractions first, further reducing the loss of production as a result of delaying defoliation.

Annual intakes of both CP and ME also showed a significant decrease between each of the five regrowth seasons studied by Brown & Moot (2004).Similar results were reported by Coruh & Tan (2008) who found CP to decrease from an initial 17.7% to 16.1% over the course of six years following establishment of a lucerne monoculture.

Following on from this, Coruh & Tan (2008) found both acid detergent fibre (ADF) and neutral detergent fibre (NDF) content in herbage was increased significantly ($P<0.01$) from 16.9% and 23.4% to 24.6% and 33.6% for ADF and NDF respectively between Years 1 and 7 after establishment. These values suggest that as the lucerne stand ages, both digestibility and dry matter intake decrease as a result of increasing ADF and NDF values. This was attributed to a greater proportion of weeds in the stand, in particular grasses. An increased proportion of stem in an aged stand may have also contributed to the increased ADF values.

Mills & Moot (2010) showed lucerne herbage to provide N yields of 510 kg N/ha/yr which were higher than any of the grass based pasture species, including the sown species in the perennial ryegrass/white clover pasture which yielded only 151 kg N/ha in the same year. The higher N content in herbage gives production advantages both in terms of increasing the amount of protein available for animal intake, and also higher growth rates and water use efficiency.

2.8 Water use efficiency

Canterbury has approximately 300,000 ha of shallow soils, which are prone to summer drought (McKenzie *et al*., 1990). While the deep taproots of lucerne give a production advantage over most grass and clover based pastures during drought conditions, its productive advantage is lost when roots are unable to penetrate into the soil as a result of physical or chemical characteristics (Douglas, 1986). In these situations, dry matter production is similar to that of a ryegrass/white clover pasture.

The depth and extent to which lucerne roots grow and extract soil water depends primarily on the soil characteristics, such as soil depth, soil texture, plant species and rooting depth as well as the water supply (McCullum *et al*., 2007).For example, Moot *et al*. (2008) showed that lucerne plants were able to extract more water from a deep Wakanui soil in Canterbury than a shallow stony Lismore soil in the same region. The difference in water holding capacity was 339 and 130 mm for the Wakanui and Lismore soils, respectively. During periods of rainfall, field capacity would be reached faster, thus extra water would flow through and drain from the soil profile, and the stony nature is likely to affect the formation and structure of taproots (Scott, 2003).

In general, lucerne roots will absorb water from the top metre of soil first, due to a high root concentration in this zone. However the long taproots go many times this depth to allow extraction as the top soil layers dry out. Under dryland conditions, the root system has been shown to grow to greater depths and become more branched, in comparison with an irrigated situation (Teixeira *et al*., 2008). Moot *et al*. (2008) reported lucerne rooting to a depth of 2.3 m compared with perennial ryegrass, which had a maximum rooting depth of 1.5 m. While the lucerne used its extensive taproot to extract a larger volume of water from greater depths within the soil profile, the ryegrass used its fibrous root system to extract more water from the top layers of the soil profile.

Lowe (2009) states that in areas of the Australian subtropics, where irrigation is the key resource needed for production, lucerne is one of the few species which can survive under rain-fed conditions. Brown *et al.* (2003) found that lucerne was able to extract 358 mm to a depth of 2.3 m on a Wakanui soil at Lincoln, Canterbury (Figure 2.3).

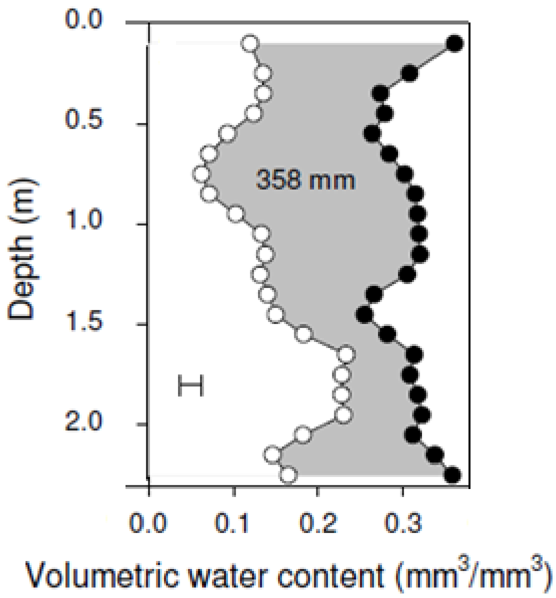

Figure 2.3 Volumetric water content of soil upper (●) and lower (○) limits of lucerne water extraction measured to 2.3m depth from 18 August 1997 – 29 May 1998 at Lincoln University, Canterbury. Note: Shaded area and numbers represent the total water extraction. (Brown *et al.*,2003).

Moot *et al*. (2008) found lucerne to have a spring water use efficiency (WUE) of 24 kg DM/ha/mm and produced 6.1 t DM/ha from 250 mm of stored water and rainfall. The ryegrass/white clover pastures had water use efficiencies that ranged from 2.6 to 18.8 DM/ha/mm, while unimproved pastures varied between 0 and 3.7 kg DM/ha/mm at a range of sites. Kearney *et al*. (2010) showed that lucerne sown into an intensive commercial pasture renewal programme in Central Otago had a water use efficiency of approximately 16.0 kg DM/ha/mm compared with 3.5 kg DM/ha/mm for a browntop (*Agrostis capillaries*) dominant pasture.

These values, showing the greater WUE of lucerne in comparison with grass based pastures, illustrate the ability of the plant to access water at greater depths but more importantly the greater level of dry matter production per unit water. Mills *et al*. (2008a) showed lucerne to be the most responsive species to summer rainfall. It out-yielded a cocksfoot/subterranean clover pasture by 6.6 t DM/ha/yr in two out of five years where rainfall over the October – December period was in excess of 200 mm. The study also highlighted the fact that dry matter production over the growth period is dependent on the soil water recharge in the previous winter. Insufficient soil water resulted in the dry matter production of lucerne being similar to that of grass based pastures over the summer/autumn growth period.

Following on from the findings of Mills *et al*. (2008a), the same lucerne crop was shown to have an annual WUE of 22.6 kg DM/ha/mm in Year 8 by Morris (2011). Surprisingly, this value was not a result of lucerne extracting more water from the soil profile, but rather the plants were able to produce more dry matter per unit water.

Water use efficiency can also be influenced by the plant species being grown, and their subsequent nitrogen content. This is because species with higher nitrogen content in the herbage have greater photosynthetic abilities, and thus more potential dry matter production. Moot *et al*. (2008) compared the spring WUE of both lucerne with that of a perennial ryegrass/white clover pasture.

Martin (1984) explains that the WUE can increase when the plant canopy is closed, and soil evaporation is reduced. Highest levels of water use efficiency are often found to be in spring, due to daytime temperatures being adequate for growth, yet overnight temperatures and evapotranspiration rates are lower than those in summer.

2.9 Persistence

Lodge (1991) reports that lucerne stands have been known to survive for 20-25 years, in the absence of pests and diseases and when managed correctly. Regeneration by seeding is uncommon and thus persistence is dependent on the maintenance of the original stand. In most environments there is a strong relationship between soil moisture and stand survival. Brownlee (1973) showed a rapid decline in lucerne plant population density under drought conditions, while plants do equally poorly when water-logged (Lodge, 1991).

Management practices like severe or frequent defoliation have also been suggested to result in a decreased plant population (Lodge, 1991). This was illustrated by Belesky and Fedders (1997) who reported a decline in plant population from 400 to 80 plants/m² over a three year period under an intensive grazing regime.

However, more recent research in Canterbury by Teixeira (2006) showed the reduction in plant population was not found to be caused by frequent defoliation, but was explained as a self-thinning process. Similar findings are commented on by Palmer (1982).They found that partial compensation for the decline in plant population occurred in some yield components such as individual shoot mass, stems and/or plant weight (Teixeira, 2006; Teixeira *et al*., 2007b). In their case, under 28 versus 42 day grazing regimes plant populations decreased exponentially from 120 plants/m² to 60 plants/m² over the space of two years. Over the same time, the number of shoots per plant increased from 5.5 to 50. Teixeira *et al*. (2007b) concluded with the suggestion that 43 plants/m² is the minimum plant population required to main the production potential of lucerne.

Lodge (1991) suggests that it may be a combination of the effects of both soil moisture status and grazing regime that ultimately determines the persistence of a lucerne crop. In addition to this, often a wide range of weeds, pests and/or diseases contribute to the decline in plant population (Sheath & Hay, 1989), as is summarised in the following sections.

2.9.1 Weeds

Coruh & Tan (2008) produced data to suggest that lucerne dry matter yield decreased significantly with stand age. This yield reduction was shown to range from 5.5 t DM/ha in the first year, to 3.0 t DM/ha in the seventh year of the experiment. These decreases were partly attributed to the loss of plant density, which in turn allowed more space for weeds to enter the stand over subsequent years, further impacting upon plant production. The effect of grazing management was found to influence the botanical composition of the lucerne sward by Leach *et al*. (1984). They noted that grazing too frequent and/or without sufficient resting intervals increased the proportion of weeds entering the sward over time.

Weeds are a major problem in lucerne as they reduce the quality, yield and persistence of a stand as they compete with lucerne for light, water and nutrients (Langer, 1973; Leach *et al*., 1984). Morris (2011) reported reduced water use efficiency in a lucerne stand between Years 7 and 8. This was thought to be attributed to thinning of the stand which allowed for greater weed invasion, and thus more of the water available for the lucerne was used up by the weeds.

Lucerne which is ‘well managed’, or with long (35-42 day) periods between cuttings or grazings will usually predominate during the summer, as it has the ability to out-compete summer weeds, such as fathen (*Chenopodium album*) and shepherds purse (*Capsella bursa-pastoris*) for light and moisture (Palmer, 1982). However, during the winter when lucerne growth is less rapid, gaps between the plants allow for annual winter weeds, like storksbill *(Erodium cicutarium*), and barley grass (*Critesion murinum*) to germinate and grow.

Crops are most susceptible to rapid weed succession when grown in less than favourable conditions (e.g. water-logged areas with high rainfall), with poor soil fertility and/or under a set stocked grazing regime (McGowan *et al*., 2003). Factors such as pests and diseases that cause damage to the crop can also result in increased weed incidence over a shorter duration of time.

Control of weeds in lucerne is often possible through the use of chemical herbicides, however often a range of chemicals need to be applied, often at different times of the year to achieve control of all weed species (Charlton & Stewart 2000). Palmer (1982) proposes that while spraying out weeds in a lucerne crop can result in reduced yield as weeds no longer contribute to dry matter production, but the overall quality of the sward will be increased.

While weed infestations during establishment can result in the thinning of the stand, making it more susceptible to weed competition in later years, it is often poor management which contributes to an increased weed population. Both frequent grazing, and/or grazing to a low residual are common mis-management practices which can result in increased weed incidence in a lucerne stand (Leach *et al*., 1984). Both reduce the ability of the lucerne stand to out-compete spring weeds as the plant experiences the continuous removal of newly developing shoots. There is then a need for constant development of new basal shoots, resulting in a reduced ability to achieve a sufficient canopy of leaves required to do so.

2.9.2 Pests and diseases

Weeds, in a combination with pests (e.g. aphids), diseases (e.g. root rot), unfavourable environmental conditions (e.g. waterlogging) and/or competition between plants often results in a reduced stand density (Coruh & Tan, 2008; Lodge, 1991).

Prior to the 1960's, there is little suggestion in any New Zealand literature that pests were a serious threat to lucerne stands. Literature from the 1970's and 1980's indicates that lucerne was highly susceptible to insect pests such as Sitona weevil (*Sitona discoideus*), stem nematodes (*Ditylenchus medicaginis*) and aphids (*Aphidoidea* spp.) (Langer, 1973; Leach 1978). In many cases, breeding for resistance against these pests has lessened their impact upon production (Moot *et al*., 2004; Milne, 2011). Goldson *et al*. (2005) also make mention of the use of the biological control agent *Microctonus aethiopoides*, which has been successful in reducing weevil populations to well below threshold levels.

There have been several lucerne diseases identified in New Zealand lucerne crops (Wynn-Williams, 1991). Douglas (1986) notes that bacterial wilt (*Corynebacterium insidiosum*), verticillium wilt (*Verticillium albo-atrum*), and crown rot which is caused by a range of fungi, were major problems for lucerne stands in the 1970's. Many diseases appear to be more of an issue when irrigation, high rainfall or a high water table which increases the incidence of disease (Douglas *et al*., 1987).

2.10 Grazing Management

Unlike pasture species such as perennial ryegrass, which tolerates a wide range of grazing methods, lucerne requires specific management and grazing to ensure it persists and performs adequately (Lodge, 1991). Lucerne grows from the tip of the stem rather than the base of the plant, and it is for this reason that the plant does not survive under continuous set stocking (Peart, 1968; Brownlee, 1973; Moot *et al*., 2003). It is well known that frequently defoliated crops exhibit a reduction in shoot growth rates, and limited accumulation of both carbon and nitrogen reserves in the crown and taproots (Teixeira *et al*., 2007c).

2.10.1 Set stocking

In an Australian experiment, Peart (1968) grazed wethers at a stocking rate of 12.5/ha under either one of two rotational grazing regimes or set stocked on lucerne. They concluded that continuous set stocking resulted in the death of the lucerne crop within a seven month period. Grazing using a four paddock rotation, with 12 days grazing in each paddock reduced the lucerne plant density by 17%, from 6.5 to 5.4 plants/m^2, while an eight paddock rotation, with four days per paddock only resulted in a 6% decline in plant population.

2.10.2 Rotational Grazing

A number of studies recommend a short grazing period of 7-10 days, and a spell of at least 35 days (Lodge, 1991). Stanley *et al*. (2002) state that it is generally accepted that for optimum management of a lucerne crop, grazing should not occur until the stand exhibits 10% flowering. Moot *et al*. (2003) strongly dispute this claim on the basis that flowering can be delayed by day length and thus the timing of cutting or grazing should be determined by crop growth. Following on from this, Moot *et al*. (2003) suggest, spring grazing of lucerne can occur when plant height is approximately 0.2 m, equivalent to ～1500 kg DM/ha.

Rotational grazing is widely recommended as the best management practice for lucerne (Brownlee, 1973; Cosgrove & White, 1990; Knight, 1987; Lodge, 1991; Moot *et al*., 2003;

Pecetti *et al*., 2006; Sewell *et al*., 2011;Teixeira *et al*., 2007b), and is integral for ensuring persistence of the stand (McGowan *et al*., 2003; Milne, 2011). Lucerne has been shown to be intolerant of set stocking (Brownlee, 1973; Cosgrove & White, 1990; Leach, 1978; Smith *et al*., 1989; Teixeira *et al*., 2007b) with such a practice resulting in reduced production and stand longevity, even if grazed at low stocking rates. When grazed correctly, lucerne grown under dryland conditions has been shown to outlast perennial ryegrass pastures (Milne, 2011).

Cosgrove & White (1990) compared lucerne which was grazed for a three day period with that grazed over a longer duration of 12 days. When the peaks in stem number were compared from the start of each grazing, grazing in the 12 day treatment did not affect the regrowth until about day 10 when some of the crowns were able to be decapitated. For this reason, the authors concluded that a 10-12 day grazing duration would eliminate the crown shoot decapitation, while maximising the grazing potential of the crop. However, the plant may be able to tolerate grazing durations of up to 14 days if the plant is grazed at a later stage within the regrowth cycle.

In a second paper by White & Cosgrove (1990) using the same experiment, they found that stock subjected to the 12 day grazing duration had an initial intake that was 29% greater than those grazing over a three day duration. However, due to active selection for more palatable components in the sward during the first period of grazing, the last third of the 12 day duration required stock to consume lower stem material. This was shown to have lower digestibility, resulting in a dry matter intake which was not sufficient for meeting animal maintenance requirements. It was therefore once again recommended that a 10 day grazing duration would be preferable for achieving high liveweight gains, particularly when young stock were involved. Moot *et al*. (2003) also state that grazing periods in excess of 10 days have the potential to damage newly developing basal buds.

2.10.3 Spring Grazing

On the majority of dryland properties running sheep, the start of lambing is matched to the time when spring pasture growth begins so as to ensure sufficient feed for lactating ewes and lambs. In situations where spring pasture growth is insufficient for matching the high demands of lactating ewes with lambs, there is a risk that grazing lucerne in the early spring is inevitable, particularly when lucerne equates to more than 30% of the total farm cover.

Early grazing has the potential to remove the growing points of lucerne, and thus can result in significant decreases in yield (Purves & Wynn-Williams, 1994), which often becomes evident between late October and early December grazings (White & Lucas, 1990). Moot *et al*. (2003) suggest that in situations where this must occur, lucerne crops which are aged and/or showing reduced persistence and thus are closer to renewal should be grazed first. Where possible, grazing at a height of 0.2-0.3 m acts as a good compromise between maximising the rapid stem extension during early spring, while ensuring sufficient feed for stock.

Spring grazing of lucerne should aim to maximise liveweight gains in lambs, while at the same time having minimal impact upon the longevity and production of the stand. In the past, emphasise has been on the use of rotational grazing during this period, aiming to remove all herbage within 7-10 days of entering the paddock. Extending grazing periods beyond this means that stock will graze newly developed basal buds. This will impact on dry matter production in the following regrowth period.

2.10.4 Summer Grazing

During the summer period, provided water is not limiting to growth, lucerne has the ability to provide significant advantage over pasture in terms of dry matter production and liveweight gains in stock (Moot *et al*., 2003). However, if soil water reserves do become depleted, the lucerne plant begins to transpire less, and both phenological development and senescence are accelerated, thus reducing the quality of the herbage.

In these situations, Moot *et al*. (2003) advises grazing the sward hard to remove the majority of leaves which would continue to lose water through transpiration, and prevent yield losses through leaf senescence. Even at this stage, set-stocking is not an option as slowly developing basal buds can be damaged by grazing, and subsequent crop growth following rainfall would be negatively affected.

2.10.5 Autumn Grazing

It is during autumn that grazing management of lucerne should begin to focus on maintaining plant production in subsequent years, rather than animal performance. Late summer/autumn flowering is critical to stand performance in the following seasons, because it is at this time that the plant changes the priority of assimilate partitioning from above the ground components to the root (Moot *et al*., 2003). Moot *et al*. (2003) suggested that the crop needs to reach at least 50% flowering to maximise the restoration of root reserves.

The requirements for specialised grazing management to maximise partitioning of dry matter to the roots is heavily emphasised in much of the work of Teixeira *et al*. (2007a; 2007b; 2007c; 2008; 2009), much of which is summarised in Section 2.11.

2.10.6 Winter Grazing

Wynn-Williams *et al.* (1991) describes the negative effects that winter grazing of lucerne can have in terms of treading of the crown, allowing crown and root rot fungal diseases to enter the plant. In addition to this, the effect of growing lucerne in either a 'winter-wet' or 'winter-dry' site had on the incidence of a number of rotting diseases. Crown rot was found to be the most prevalent disease.

In a more recent publication, Moot *et al.* (2003) suggests that winter is the time for weed control, and ensuring the crop regrowth in the spring occurs as vigorous as possible. Apart from a 'clean up' graze, 7-10 days prior to herbicide application, it is recommended that no stock graze lucerne over the winter months.

Chemical control of lucerne is possible in an established stand. There are a wide range of chemicals available, most of which can eliminate the majority of weeds when used in combination. The New Zealand Agrichemical Manual (2012) outlines Atrazine, Classic, (*Fluazifop-P-butyl*), Gallant, Haloxyfop, Kerb 500, Metribzin, Nu-Trazine 900 DF (Atrazine), Preside, Propyzamide, Quizalofop, Reglone (Diquat), Simazine, Spinnaker, Trifluralin and Viper as some of the possible chemicals to control weeds in lucerne crops.

2.11 Partitioning of dry matter to roots

It is the partitioning of dry matter to the roots during autumn that determines the allocation, distribution and transport of assimilates from their sites of storage (sink) to their sites of utilisation (source) in the following spring (Teixeira, 2006). When photosynthesis exceeds the requirements for carbon, excess carbohydrates are stored in lucerne perennial organs (taproots and crowns) mainly in the form of starch (McAdam and Nelson, 2003). Similarly, nitrogen, mainly in the form of amino acids and soluble proteins, are also stored in the perennial organs (Teixeira, 2007a). During periods of rapid growth, these reserves are remobilised from the source (perennial organs) to the growing shoots and expanding nodes accumulated through the winter. This is most common in the spring period, or after grazing(Avice *et al*., 2003; Moot *et al*., 2004) and can result in more than 80% of the nitrogen based compounds in newly growing lucerne to be mobilised from the root and crown reserves of the plant (Avice *et al*., 1996).

It is in the autumn that the majority of the accumulation of root reserves occurs as high levels of carbon assimilation coincide with high partitioning rates of biomass to roots (Teixeira *et al*., 2006). The elevated rates of carbon assimilation are a result of high temperatures and incoming radiation which ensures rapid canopy closure. It is for this reason that infrequent defoliation (>35 days) can be used as an effective management tool in replenishing root reserves.

Teixeira (2006) sampled and examined root samples to a depth of 0.3 m at the beginning of each season. In August a winter sample was taken, prior to any grazing treatments being applied to the plots. It was found that the average perennial dry matter was equal to 4.5 t/ha. This value was shown to decrease across all grazing treatments, so that the average weight of the perennial reserves was equal to 2.5-3.0 t DM/ha in early-midsummer (December). This increased to an average of 5.0 t DM/ha by May-June (mid-autumn). The pattern shown in these results emphasises the change in root mass over the duration of the year, as reserves are mobilised and remobilised as part of natural growth processes.

Teixeira *et al*. (2006; 2007a) showed that frequent grazing, every 28 days throughout the growing season reduced both the perennial dry matter by 20-30% and the concentration and amount of soluble sugars, starch and nitrogen in taproots in comparison with a crop grazed every 42 days. Subsequently, the annual yield of the frequently grazed crop was 14 t/ha in comparison with the longer grazing interval which achieved an annual yield of 23 t/ha. Reduced root reserves available for mobilisation during rapid spring growth resulted in limited canopy expansion, thus reduced radiation interception and dry matter production. This highlights the importance of ensuring the accumulation of these endogenous compounds in the perennial organs during autumn, in terms of obtaining high levels of dry matter production in the following season.

While frequent grazing throughout the spring/summer period gave a significant reduction in accumulation of perennial reserves, Teixeira *et al*. (2007a) showed that a mid-season switch between the 28 day and 42 day grazing regimes, restored 25-30% more carbon and nitrogen into the taproot in comparison with a crop that crop remained under the 28 day defoliation frequency. This reiterates the high rates of carbon assimilation later in the growing season, which influence the accumulation of reserves in perennial organs, thus emphasising the need for less frequent grazing come late summer/autumn.

Moot *et al*. (2004) highlights the need for prioritising the requirements of recharging the perennial root reserves during the autumn period. It is recommended that an extended flowering period during February or March should be allowed, letting the crop to reach 50% flowering prior to cutting or grazing, and thus maximising root reserves. Furthermore, when conditions have been dry, delaying the grazing of the lucerne stand after a significant rainfall episode allows for greater build up of reserves.

Winter annual weeds often germinate at this time, and refraining from grazing following a drought-breaking rainfall limits weed establishment through lack of water, as a result of the high water requirements of the developing canopy out-competing the shallow-rooted weeds.

2.12 Conclusions

- Lucerne is a deep taprooted species, capable of converting limited available water into high quality forage.

- Water use efficiency for lucerne stand grown in Canterbury has been reported to be 22-24 kg DM/ha/mm.

- Initiation of basal buds and early spring growth primarily driven by remobilisation of stored reserves in the crown and taproot of the plant.

- Sheep grazing dryland lucerne in Canterbury have been shown to consistently have annual liveweight production of 830-1110 kg/ha, which is 30-40% greater than stock grazing grass/clover pastures.

- Set stocking lucerne allows for stock to remove and/or damage newly developing basal buds thus reducing the ability of the plant to grow.

- Rotational grazing is the recommended practice for ensuring prolonged dry matter production and stand persistence, provided all herbage is removed within 7-10 of stock entering the paddock.

- It is integral that autumn management focuses on replenishing carbohydrates in root reserves which are then available for rapid remobilisation in spring, allowing rapid stem expansion, and earlier spring dry matter production.

3 Materials and Methods

I was involved with all measurements of dry matter, perennial reserves and liveweight gain between the dates of 9 February 2011 and 30 June 2011. For the period from 1 July 2010 to the start of my involvement with the trial, measurements were primarily carried out by Malcolm Smith, and other staff from the Lincoln University Field Service Centre.

3.1 Experimental site:

The experiments were grown at Ashley Dene Research Farm, Home Block, Paddock H7, Canterbury, New Zealand (43˚65' S, 172˚32 E, 35 m a.s.l.) within a 5.2 ha area of flat land (Appendix 1). The soil type is a combination of a Lowcliffe moderately deep and a Lowcliffe stony soil, both of which are imperfectly drained (Webb & Bennett, 1986). The depth to stones ranges from approximately 0.2 – 0.45 m and the approximate depth to sandy gravels can range from 0.6 to 1.1 metres. These soils have a total moisture holding capacity of 100-120 mm and 70-100 mm per metre of soil, respectively (McLenaghen *et al*., 2011).

3.2 Experimental area:

The experimental site previously contained a 'Grasslands Moata' (*Lolium multiflorum*) pasture in 2007/2008. Prior to sowing in November 2008, the paddock was ploughed, roto-crumbled, harrowed and rolled. Two lucerne (*Medicago sativa*) grazing experiments were sown on 3, 4 and 5 November 2008 using an Øyjoord single cone seeder, with three runs per sub-plot.

Experiment 1 used three lucerne cultivars - 'CW85087' (PGGW), 'Runner II' (Kiwi Seeds Co.), and 'Stamina' (PGGW). Experiment 2 had seven lucerne cultivars sown into sub-plots. Three of these were the same as in Experiment 1, the additions were 'Kaituna' (PGGW), 'Rhino' (Kiwi Seeds Co.), 'Grazing Tolerant' (AgResearch) and a 'High Preference' (AgResearch) line.

PGGW Seed supplied their three lines as pelleted seed with a Superstrike seed treatment. Seed from Kiwi Seeds Co. was supplied and inoculated with ALOSCA®prills. AgResearch seed was supplied by their breeder, and these four seed lines were bare seed.

'Stamina' was common to both experiments and was used to study the effect of grazing method on root mass, dry matter production and analysis of storage components between the experiments.

3.3 Experimental design and treatments:

3.3.1 Experiment 1

In Experiment 1 the three lucerne cultivars previously stated were sown into 48 x 89 m paddocks replicated four times. The total treatment area was 1.71 ha. Each replicate was halved using a temporary fence, and one of two severe grazing treatments was imposed to each half. Treatment 1 was 'set stocking' in a single paddock while Treatment 2 was alternatively grazing the paddocks in a 'semi set-stocked' manner, moving between each paddock every 10 days. Post weaning, both areas were combined and rotationally grazed for the rest of the spring, summer and autumn (Appendix 2).

3.3.2 Experiment 2

Experiment 2 was established immediately adjacent to Experiment 1 with a conventional six paddock grazing rotation established over the entire area of 2.6 ha. Each paddock was 0.43 ha (48 x 89 m) and consisted of the seven lucerne cultivars, sown into 6.3 x 24.5 m plots. Each of the six paddocks contained four replicates of each cultivar, thus there were 24 replicates for each cultivar and 144 plots in total (Appendix 3).

In both experiments, grazing treatments were first imposed on 8 September 2010, with ewes and lambs. Aside from the grazing treatments, all other factors remained constant between the two adjacent experiments.

3.4 Soil fertility:

A separate soil test was taken for each experiment in July 2010, to a depth of 75 mm. A second soil test across the whole experimental area was taken in May 2011 to a depth of 100 mm. Based on these results (Table 3.1); no fertiliser was applied to either experimental area throughout the duration of the experiment.

Table 3.1 Soil test results for both Experiments (Exp) 1 and 2 taken in July 2010 and May 2011, from paddock H7 at Ashley Dene Research Farm.

Soil test results		Jul-10		May-11
	*Optimum range	Exp 1	Exp 2	Whole area
pH	6-6.5	5.5	5.3	5.8
Olsen P	20-30	21	22	16
K me/100 g	6-12	0.75	0.82	0.48
Ca me/100 g	0.5-12	7.1	6.2	6.9
Mg me/100 g	0.8-3	0.98	1	0.98
Na me/100 g	0.1-0.5	0.12	0.1	0.2
CEC me/100 g	20-25	16	16	14
Total Base Saturation	55-75	55	52	59
Volume Weight	0.6-1	0.93	0.93	0.84
Sulphate Sulphur (mg/kg)	10-20	5	14	6

3.5 Fertiliser:

Prior to sowing in November 2008, lime was applied at a rate of 2 t/ha and Super Sulphur at a rate of 125 kg/ha.

3.6 Meteorological data:

Mean monthly air temperatures (°C) collected from the Broadfields meteorological station (43˚62 ‘S, 172 ˚47 ‘E) are presented in Figure 3.1a. Long-term means for temperature are also given for the period 1975-2009, taken from the same station. This weather station is located approximately 14 km north-east of the experiment site.

Total monthly rainfall (mm) recorded at the Burnham sewage plant (43˚62 'S, 172 ˚31 'E) is presented in Figure 3.1b. Long term means shown are for the period 1953-2009, and have been recorded at the same location. This is located approximately 14 km north-west of the experiment site.

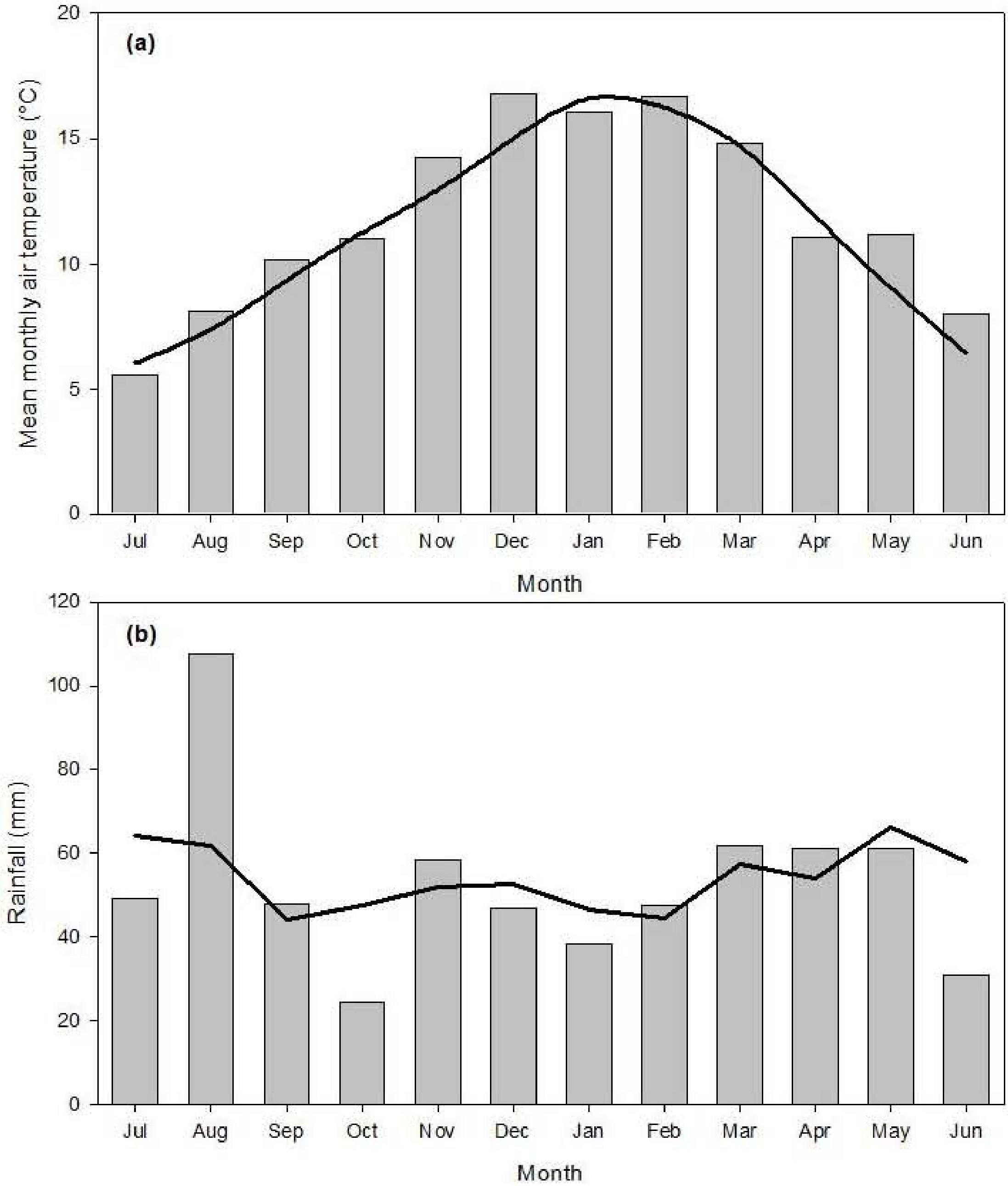

Figure 3.1 Mean monthly air temperature (a) and (b) total monthly rainfall for 2010/11 (▆). Long-term means (▬) are for the period 1975-2009 for temperature from Broadfields meteorological station (43˚62 'S, 172 ˚47 'E) and for the period 1953-2009 for rainfall from Burnham (43˚62 'S, 172 ˚31 'E).

3.7 Potential soil moisture deficit

Figure 3.2 shows the development of the potential soil moisture deficit between 1/7/2010 and 30/6/2011. The PSMD was returned to zero for the beginning of the growth season on 1/7/2010 and then accumulated where:

Equation 3.1 Today's PSMD = Yesterdays PSMD + (Today's Peman PET – Today's rainfall).

The PSMD was not permitted to return negative values. Rainfall was sourced from the Burham Sewage Plant weather station (Cliflo database, Agent No. 4880) which was the closest station to the experiment where rainfall was recorded. Penman potential evapotranspiration (PET) was from the Broadfields meteorological station near Lincoln (Cliflo database, Agent No. 17603). The PSMD increased from zero in winter to a maximum of 529 mm on 2/5/2011.

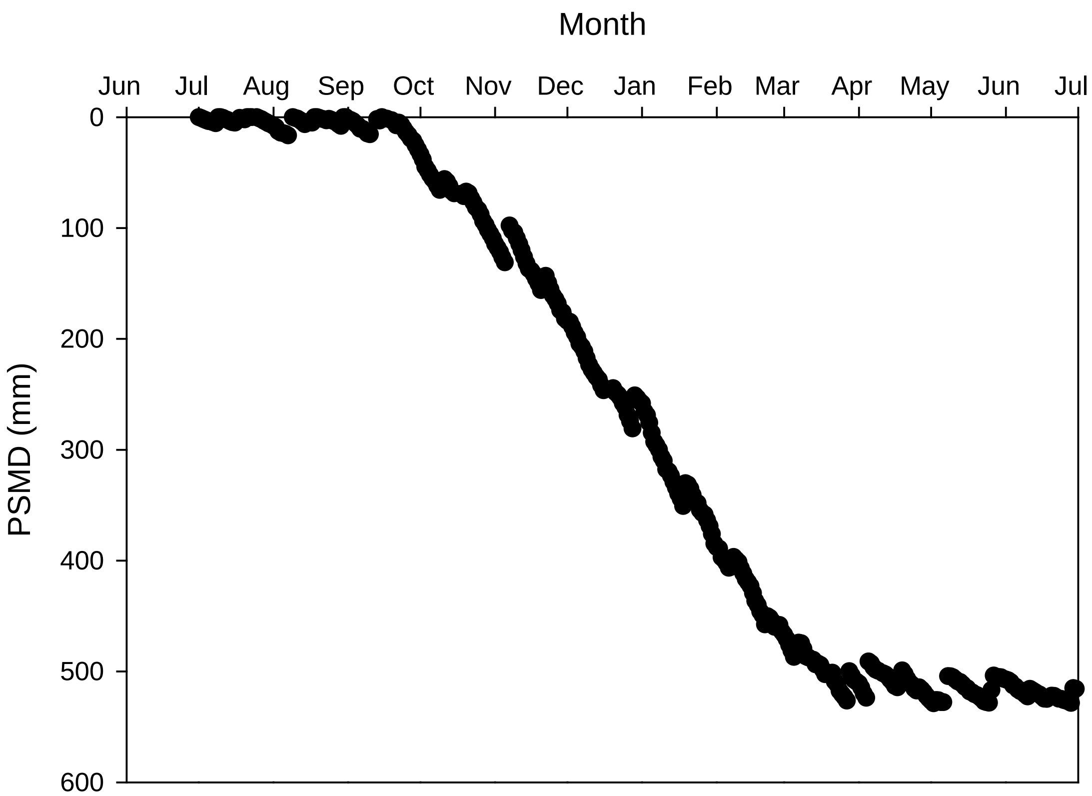

Figure 3.2 Development of the potential soil moisture deficit (PSMD, mm) between 1/7/2010 and 30/6/2011. The PSMD reached a maximum of 528.8 mm on 2/5/2011.

3.8 Water holding capacity/ field capacity:

There was no water extraction data measured for paddock H7 at Ashley Dene during the experimental period. Figure 3.3 shows the estimated soil water in the soil profile based on measurements taken from other experiments on the same soil type, within the vicinity of this experiment. The upper limit (soil at field capacity) data were collected using time domain reflectometry (TDR) in the top 200 mm and then neutron probe thereafter. The lower limit has been taken from Moot *et al*. (2008) who reported data from nearby paddocks at Ashley Dene on a similar soil type. Plant available water (the difference between the upper and lower limits) was measured to a depth of 2.3 metres, and the soil was found to hold 150 mm within this fraction. The soil profile shows that up to 0.5 m the soil holds 63 mm of plant available water (Figure 3.3). Below this, water holding capacity is reduced as most of the soil is gravel with only a few silt particles.

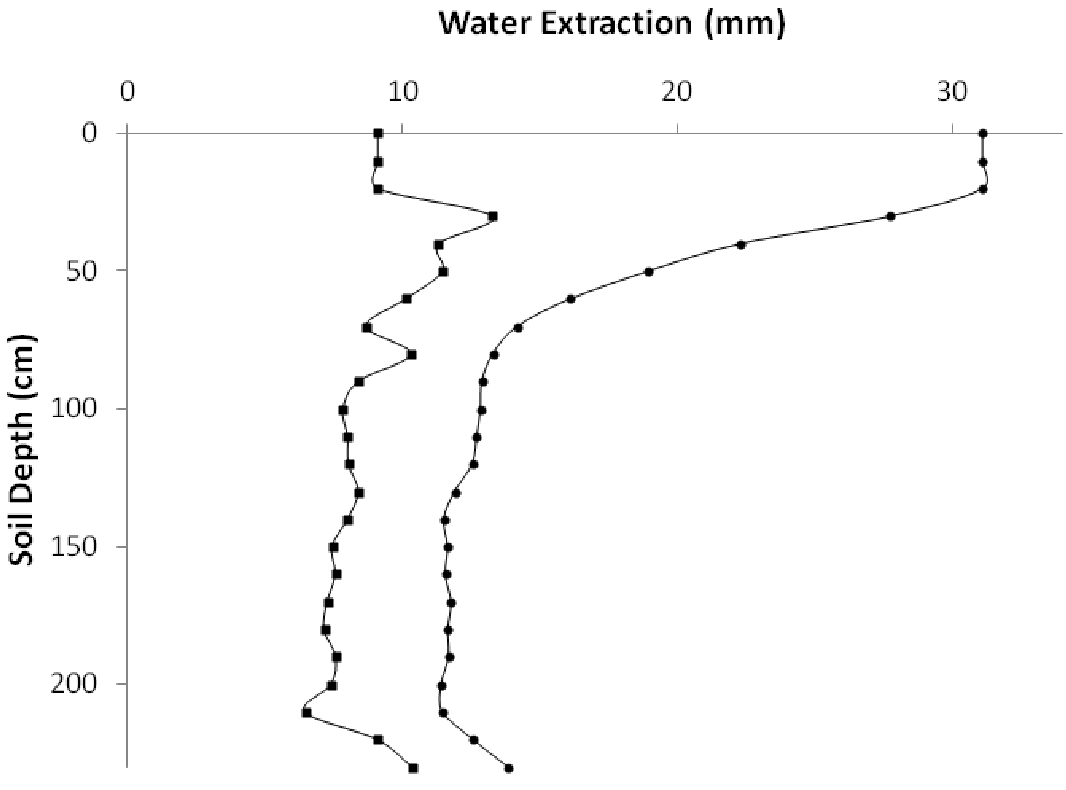

Figure 3.3 Water extraction pattern of lucerne roots in the soil profile, to a depth of 2.3 m, where (●) is the upper limit and (■) lower limit (mm) for plant available water, in the Lowcliffe moderately deep and Lowcliffe stony soils at Ashley Dene.

3.9 Animals:

All stock used in the experiments were from the Lincoln University Coopworth stud flock. When grazing commenced on 8 September 2010, a total of 62 mixed age ewes with twin lambs, aged between one and three weeks were selected. Prior to lambing, ewes had been grazing pasture. After weaning, the lambs used for grazing were those that had been grazing the experiment with their mothers. These were known as ‘core’ lambs. When ‘core’ lambs were insufficient to maintain the required stocking rates, lambs that had been grazing lucerne elsewhere on the property were brought into the experiments, and are referred to as ‘grazers’. For calculating the liveweight gain, it is assumed that the grazers grew at the same rate as the measurement lambs in the experiment. Hoggets were selected from the Ashley Dene flock for grazing between February and June.

3.10 Weed control:

Nodding thistles (*Carduus nutans*) and horehound (*Marrubium vulgare*) were controlled by grubbing. No chemical herbicides were applied to the experimental area over the duration of measurements.

3.11 Management:

3.11.1 Experiment 1

There were six distinct grazing periods throughout the year from 1 July 2010 to 30 June 2011. Grazing periods and total number of graze days have been summarised in Table 3.2.

No stock were on the experimental sites in July and August 2010.

Table 3.2 Summary of grazing periods for each stock class in Experiment 1 for set stocked (SS) and semi set stocked (Semi SS) grazing regimes. Ewes and lambs are denoted 'E & L'. Hoggets 1 and 2 are different groups.

Paddock	Treatment	Stock	No stock	Date on	Date off	Graze days
7,8,9,10	SS	E & L	9	8/09/2010	1/11/2010	486
7,8,9,10	Semi SS	E & L	9	8/09/2010	20/09/2010	108
7,8,9,10	Semi SS	E & L	9	20/09/2010	30/09/2010	90
7,8,9,10	Semi SS	E & L	9	30/09/2010	11/10/2010	99
7,8,9,10	Semi SS	E & L	9	11/10/2010	22/10/2010	99
7,8,9,10	Semi SS	E & L	9	22/10/2010	1/11/2010	90
7	SS + Semi SS	Lambs	46	11/11/2010	17/11/2010	276
7	SS + Semi SS	Lambs	46	17/11/2010	18/11/2010	46
7	SS + Semi SS	Lambs	111	18/11/2010	20/11/2010	222
9	SS + Semi SS	Lambs	111	20/11/2010	23/11/2010	333
9	SS + Semi SS	Lambs	89	23/11/2010	26/11/2010	267
10	SS + Semi SS	Lambs	89	26/11/2010	30/11/2010	356
10	SS + Semi SS	Lambs	89	30/11/2010	3/12/2010	267
8	SS + Semi SS	Lambs	53	3/12/2010	7/12/2010	212
8	SS + Semi SS	Lambs	53	7/12/2010	12/12/2010	265
7	SS + Semi SS	Lambs	53	13/12/2010	16/12/2010	159
7	SS + Semi SS	Lambs	53	16/12/2010	18/12/2010	106
9	SS + Semi SS	Lambs	53	18/12/2010	19/12/2010	53
9	SS + Semi SS	Lambs	53	19/12/2010	20/12/2010	53
7	SS + Semi SS	Hoggets 1	26	10/02/2011	18/02/2011	208
7	SS + Semi SS	Hoggets 1	26	18/02/2011	23/02/2011	130
9	SS + Semi SS	Hoggets 1	26	23/02/2011	28/02/2011	130
9	SS + Semi SS	Hoggets 1	26	28/02/2011	4/03/2011	104
10	SS + Semi SS	Hoggets 1	26	4/03/2011	8/03/2011	104
10	SS + Semi SS	Hoggets 1	26	8/03/2011	12/03/2011	104
8	SS + Semi SS	Hoggets 1	26	12/03/2011	17/03/2011	130
8	SS + Semi SS	Hoggets 1	26	17/03/2011	21/03/2011	104
7	SS + Semi SS	Hoggets 2	15	13/04/2011	18/04/2011	75
7	SS + Semi SS	Hoggets 2	15	18/04/2011	23/04/2011	75
9	SS + Semi SS	Hoggets 2	15	23/04/2011	29/04/2011	90
9	SS + Semi SS	Hoggets 2	15	29/04/2011	4/05/2011	75
10	SS + Semi SS	Hoggets 2	15	5/05/2011	11/05/2011	90
10	SS + Semi SS	Hoggets 2	15	11/05/2011	18/05/2011	105
8	SS + Semi SS	Hoggets 2	15	18/05/2011	24/05/2011	90
8	SS + Semi SS	Hoggets 2	7	24/05/2011	30/05/2011	42
8	SS + Semi SS	Hoggets 2	15	30/05/2011	8/06/2011	135

In the eight weeks of early spring from September 8 to November 3, 2010, three ewes with twin lambs were grazed on each of the four set-stocked and four semi set-stocked grazing plots, at a rate of 14.1 ewes per hectare. The semi set-stocked groups spent approximately 10 days in each paddock, giving a rotation length of 20 days with 10 days for regrowth recovery between grazings.

On November 3, 2010 the lambs were weaned. At this time, the two grazing treatments used in Experiment 1 over the early spring period were discontinued. The weaned lambs were then rotationally grazed around both treatments from November 11 until December 16, 2010.

At this point, 'grazer' lambs that had been previously grazed on lucerne were added to each group in the experiment, in order to. The length of time between shifts was determined by the amount of t shorten the length of time required to grazed each paddock. Paddocks were to a residual of approximately 1000 kg DM/ha, and thus stock were shifted every 8 – 10 days.

As lucerne growth declined through the spring, stock numbers were reduced. Specifically, on November 23, 2010, the total number of stock were reduced to 89, with the removal of some of the 'grazer' lambs. A further reduction to 53 head was made on December 3 2010, by the removal of 'grazer' lambs from the plots. The 'core' livestock remained in the experiment over the duration of this grazing period. Experiment 1 was de-stocked between December 20, 2010 and February 10, 2011.

Ram hoggets (Hoggets 1) were introduced to the experimental plots on February 10, 2011. Similar to the lambs, the 26 hoggets were rotationally grazed around the experiment for the duration of the grazing period. Shifting occurred every 7-10 days, or when the paddocks appeared to be grazed to a residual of approximately 1000 kg DM/ha. The hoggets were removed from the plots on March 21, 2010.

Another group of ram hoggets (Hoggets 2) were used for a final autumn graze of the lucerne plots between April 13 and May 30, 2011 after which point stock were removed from the experimental area.

3.11.2 Experiment 2:

Grazing periods and total number of graze days for Experiment 2 have been summarised in Table 3.3, where each section represents a separate grazing period by each of the various stock classes used over the duration of the trial period.

Between September 8 and November 11 2010, ewes and lambs rotationally grazed plots in Experiment 2. Over this period, one complete rotation (six paddocks) was completed, and four paddocks were grazed in the second rotation before lambs were weaned from the ewes. The same weaned lambs were returned to the experimental site, and completed rotations two and three. At this time, there were 53 lambs grazing Experiment 2, however on November 18 'grazer' lambs were added in order to graze each paddock within the rotation in 10-12 days of entering the paddock. Lambs were removed from the experimental area on December 3, 2010. Lambs were weighed on both entry and exit of the grazing period.

Lambs were returned to the Experiment 2 on December 20, 2010 and were grazed in the same manner as had previously been used. On removal from Experiment 2 on January 9 2011, lambs were weighed for the final time, in order to calculate liveweight gains over the grazing period.

Table 3.3 Summary of grazing periods for each stock class rotationally grazed in Experiment 2. Ewes and lambs are denoted 'E & L'. Hoggets 1 and 2 are different groups of hoggets.

Paddock	Rotation	Stock	Number of stock	Date on	Date off	Graze days
5	1	E & L	114	8/09/2010	13/09/2010	570
4	1	E & L	114	13/09/2010	18/09/2010	570
1	1	E & L	114	18/09/2010	22/09/2010	456
2	1	E & L	114	22/09/2010	24/09/2010	228
2	1	E & L	81	1/10/2010	6/10/2010	405
3	1	E & L	81	6/10/2010	12/10/2010	486
6	1	E & L	81	12/10/2010	20/10/2010	648
5	2	E & L	81	20/10/2010	27/10/2010	567
4	2	E & L	81	27/10/2010	1/11/2010	405
1	2	E & L	81	1/11/2010	7/11/2010	486
2	2	E & L	81	7/11/2010	11/11/2010	324
3	2	Lambs	53	11/11/2010	18/11/2010	371
3	2	Lambs	153	18/11/2010	20/11/2010	306
6	2	Lambs	153	20/11/2010	23/11/2010	459
5	3	Lambs	122	23/11/2010	27/11/2010	488
4	3	Lambs	122	27/11/2010	1/12/2010	488
1	3	Lambs	122	1/12/2010	3/12/2010	244
2	3	Lambs	73	20/12/2010	24/12/2010	292
3	3	Lambs	73	24/12/2010	27/12/2010	219
6	3	Lambs	73	27/12/2010	30/12/2010	219
5	4	Lambs	73	30/12/2010	1/01/2011	146
4	4	Lambs	73	1/01/2011	5/01/2011	292
1	4	Lambs	73	5/01/2011	9/01/2011	292
2	4	Hoggets 1	35	10/02/2011	18/02/2011	280
3	4	Hoggets 1	35	18/02/2011	24/02/2011	210
6	4	Hoggets 1	35	24/02/2011	2/03/2011	210
5	5	Hoggets 1	35	2/03/2011	8/03/2011	210
4	5	Hoggets 1	35	8/03/2011	14/03/2011	210
1	5	Hoggets 1	35	14/03/2011	20/03/2011	210
2	5	Hoggets 2	21	13/04/2011	21/04/2011	168
3	5	Hoggets 2	21	21/04/2011	28/04/2011	147
6	5	Hoggets 2	21	28/04/2011	4/05/2011	126
5	6	Hoggets 2	21	5/05/2011	11/05/2011	126
4	6	Hoggets 2	21	11/05/2011	18/05/2011	147
1	6	Hoggets 2	21	18/05/2011	24/05/2011	126
1	6	Hoggets 2	17	24/05/2011	30/05/2011	102

Ewes with twin lambs were rotationally grazed around the six plots between September 8, and November 7, 2010. Initially, there were a total of 114 ewes and lambs grazing the experiment. On September 24, some stock were removed, to give 81 ewes and lambs, as an estimated 25% of dry matter production had been lost due to flooding of several plots in Paddock 3.

On November 11, 2010, lambs were weaned and returned to the treatment that they had been grazing. 'Grazer' lambs were added on November 18, 2010, so that the number of stock grazing the experiment was. Stock were shifted approximately every 6-8 days. On November 23 some of the 'grazer' lambs were removed as feed supply was reduced. A further reduction to 73 lambs was made on December 20, 2010. All remaining stock grazed the experimental plots until December 24, 2010.

The experimental plots were de-stocked between December 24, 2010 and February 10, 2011.

Ram hoggets (denoted Hoggets 1) began grazing the experimental plots on February 10 2011, as part of the late summer grazing. The 35 head were rotationally grazed until March 21, 2011, at which point they were removed from the experiment.

An autumn graze of the plots began on April 13, 2011, with another group of 21 ram hoggets (Hoggets 2) rotationally grazing the lucerne. No stock were on the experimental sites in July and August. The number of graze days were calculated using the same method as for Table 3.2.

For both experiments, the grazing areas were fenced into paddocks using a combination of permanent netting and electrified 'Flexinet', according to the treatments to be imposed. Water was supplied in small plastic troughs in each paddock. Grass borders ran between replicates, aiding in easy identification and fencing of plots.

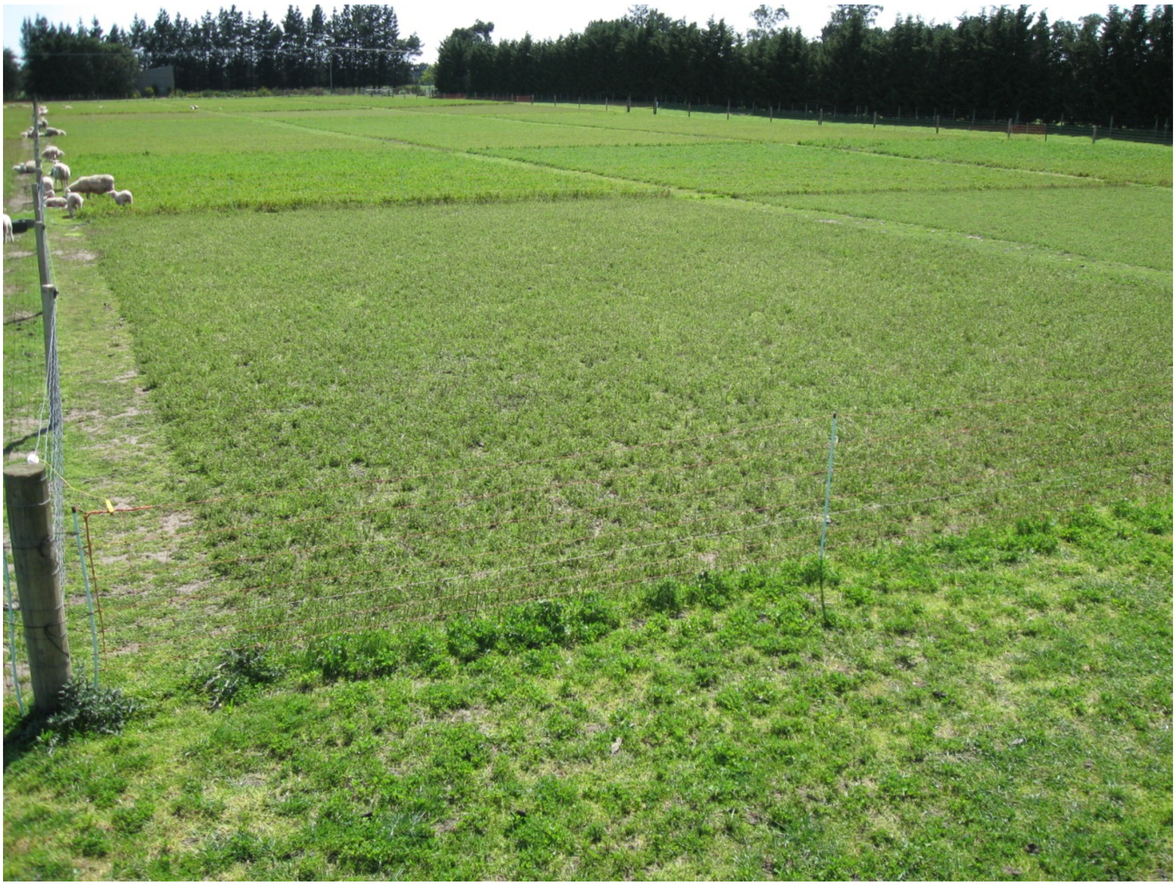

Plate 1 View of ewes and lambs grazing semi set stocked treatment in foreground, on 9/9/2010. Set stocked paddock can be observed in background.

3.12 Measurements:

3.12.1 Dry matter

Both pre and post-grazing sward height was measured for each cultivar, in both experiments using an automated sward stick. Within Experiment 2, 20 measurements were taken per cultivar in each replicate using the sward stick. There were also 20 measurements per cultivar plot under the semi-set stocking regime in Experiment 1, while 50 measurements were taken in each plot for set stocked treatments. All measurements using the sward stick were taken on a diagonal across the individual plots. Start and end readings were recorded by the user for each cultivar, and were determined by the height from the top of the shaft down to the sward. The difference between the travel of the slide tube and the total length of travel to ground level is the height of the sward. A simple formula was used to convert the readings to an average sward surface height for each plot.

At strategic intervals during grazing, dry matter calibration cuts were taken from five 0.2 m^2 quadrats placed in each one ‘Stamina’ plot per replicate to determine the relationship between height and dry matter (Appendix 5). The quadrat was placed on a representative site within the plot, horizontal to the drill rows and so that it included only whole crowns. It was ensured that shoots which were attached to crowns found within the quadrat were included in the dry matter cut. The average height of the lucerne plants within the quadrat was measured using a metre ruler.

Shoots were cut above crown level with a set of hand shears, and placed in a paper bag. Samples were transported to a cool store (4 °C), for later processing. Dead material was removed from the samples and discarded. Samples were dried in a forced air draft oven at 65 °C for at least 48 hours to a constant weight. On removal they were weighed using Mettler Toledo P131502 electronic scales.

A comparison between values obtained from the dry matter cuts, and the values obtained from the height measurements were entered into Equation 2, to give a ‘calibration’ height value based on that of Cayley & Bird (1996).

Equation 2: DM Yield = slope x height (cm)

The purpose of calculating the calibration height value is to develop a method whereby a farmer is able to estimate the amount of accumulated dry matter present in a lucerne crop, based on a height value. For the purpose of the dissertation only results from the ‘Stamina’ plots, common to both experiments, are presented.

Plate 2 View of height measurement in stamina plot prior to grazing on 19/10/2010.

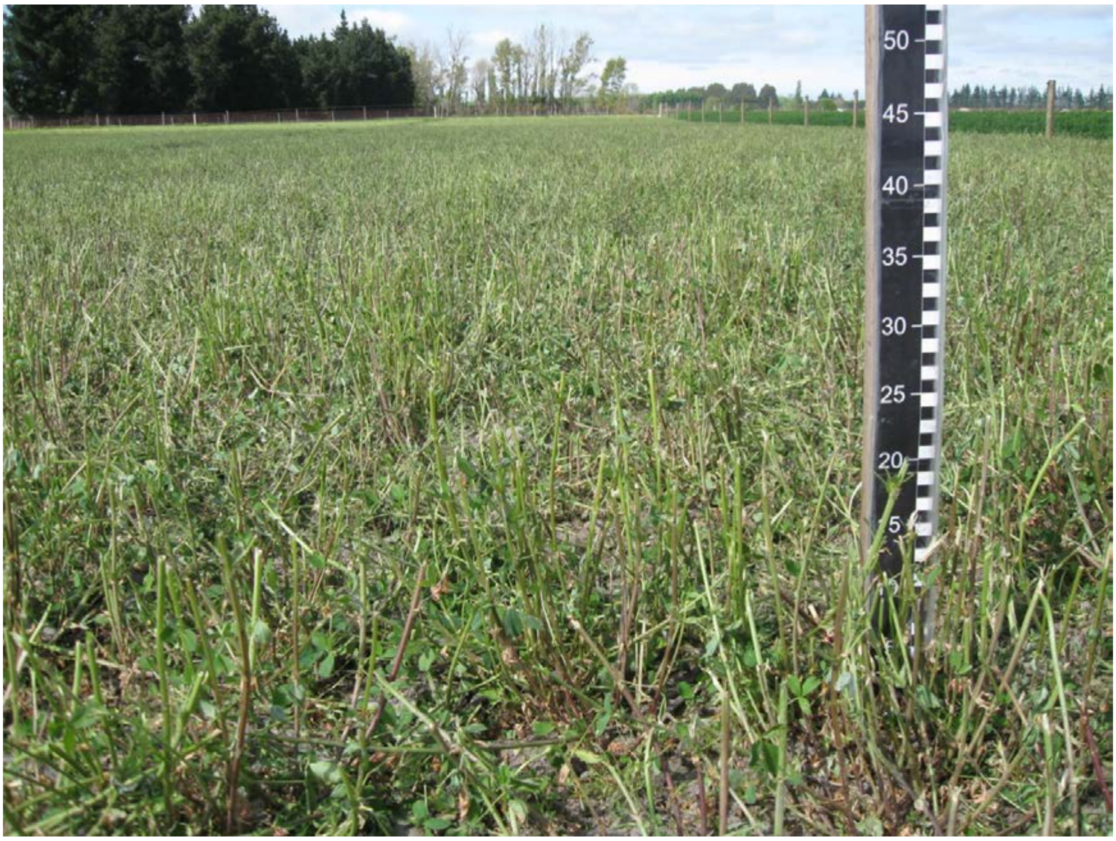

Plate 3 View of height measurement of post graze residual insemi set stocked stamina plot on 9/10/2010.

3.13 Liveweight measurements:

Stock were weighed using a Gallagher Smart Scale 600 system, attached to a Prattley weigh crate. With the exception of ewes and suckling lambs at the beginning of the experiments, all stock were fasted for approximately 18 hours overnight before weighing. Ewes and lambs grazing the experimental plots were weighed on 8 September, 4 October and 1 November 2011. Stock in Experiment 2 remained rotationally grazing allocated plots until 11 November, at which point they were weaned. These stock were not re-weighed after the 10 day period. Liveweight gains were extrapolated from the data obtained from the three previous weighing dates.

All treatments were compared with a control group, consisting of ewes and lambs grazing an old perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pasture at a low stocking rate equal to 3 ewes/ha. After the third weighing, this control group continued grazing the pasture until 8 November, at which point they were removed, weaned, and liveweight gain data was extrapolated for the period between the last weighing and the date of removal.

3.14 Graze Days

Graze days were calculated from the number of days stock spent grazing each paddock, multiplied by the number of stock present in each. No allowance was made for the difference between ewes and lambs or hoggets in calculations.

3.15 Perennial Dry Matter Samples:

Perennial dry matter is defined as root tissue of the lucerne plant, obtained from below ground and dried to remove all water content. For calculation purposes it was assumed that the sampled tissue represented 80% of total perennial dry matter (Khaiti and Lemaire, 1992).

In late June 2011, perennial dry matter samples were harvested from a 0.2 m^2 quadrat, randomly placed in a position which was horizontal to the drill rows in each plot. Shoots were cut above crown level with a set of hand shears and discarded. A spade was used to dig around the edges of the 0.2 m² quadrat, forming a trench whereby crowns and taproots to a depth of 280 mm could be accessed. Crowns and taproots were separated from soil and immediately placed on ice and transported to a cool store (4 °C) for further processing. The material was washed thoroughly to remove all soil under a stream of warm water. Crowns were cut from the taproot at the transition zone between tissues. The top 50 mm of the root was removed, and separated from the remainder of the root. All root components were dried in a forced air draft oven at 65 °C for 35 days.

Dried samples were ground using a Retsch Precision Mill Grinder. Subsamples were put into individually labelled pottles for analysis.

Plate 4 View of perennial root harvesting in Experiment 1 on 24/06/2011.

Plate 5 View of 0.2 m^2 trench dug to a depth of 0.28 m for harvesting of perennial dry matter, 24/06/2011.

3.16 Analysis of perennial root reserve samples:

Samples were analysed for carbohydrates, starch, crude protein, nitrogen and carbon by way of wet chemistry at the Analytical Laboratory Unit (Lincoln University).

3.16.1 Low molecular weight carbohydrates

For extraction of low molecular weight water soluble carbohydrates, a ~25 mg sample was weighed into a 2 ml screw cap tube, and 1 ml of 80% ethanol was added. Each sample was replicated twice. Samples were shaken at 65 °C, before being placed in a centrifuge for 15 minutes at 13,000 rpm. A pipette was used to remove supernatant into a 2 ml eppendorf tube. Another 1 ml of 80% ethanol was added to the residue and this was shaken for a further 30 minutes at 13,000 rpm. Supernatants were combined, before being stored at -20 °C for analysis.

3.16.2 High molecular weight carbohydrates

In addition to this process, extraction of high molecular weight water soluble carbohydrates required 1 ml of water to be added to the residue, and this was shaken for 30 minutes at 65 °C. Samples were then centrifuged for 15 minutes at 13,000 rpm. Supernatant was pipetted into another 2 ml eppendorf tube, and 1 ml of water added to the residue. This was shaken for 30 minutes at 13,000 rpm and supernatants were combined. Samples were stored at -20 °C for analysis.

An anthrone reagent was made using 30 ml of 100% ethanol which had been cooled on ice, and 50 ml of concentrated sulphuric acid. Once cooled, 100 mg of anthrone reagent was added and mixed well.

Analysis for low molecular weight carbohydrates required 12 µl extracts to be put into a microwell, and 188 µl of water to be added to create master diluted samples. This was mixed and 40 µl of diluted extract removed to a new microwell. Sucrose standards of concentrations of 0, 10, 20, 30, 40, 50, 75 and 100 µl/ml were used, 200 µl of anthrone reagent was added, and three replicates of each concentration was made. Samples were shaken and incubated at 65 °C for 25 minutes. Absorbance was read at 620 nm.
Analysis for high molecular weights used the same process, however it began with putting 40 µl extracts into the microwell and adding 160 µl of water to make the master diluted samples.

3.16.3 Total Carbohydrates

Total carbohydrates were calculated by adding values for both high and low molecular weights together.

3.16.4 Starch

For starch analysis, a 0.25 g of each sample was weighed into 50 ml centrifuge tubes. A standard control was also included as one of the samples. Exactly 10 ml of 80% ethanol was added to each tube, and it was ensured that the sample was completely wetted. Samples were put into a water bath at 60 °C for 30 minutes, and tubes were swirled after

15 minutes. Samples were then centrifuged at 4000 rpm for five minutes then the extracted sugar supernatant was removed using a vacuum extraction tube.

Another 10 ml of 80% ethanol was added and the above steps were repeated, however the supernatant was discarded. Deionised water (5 ml) and 0.570 ml of thermostable α-amylase (Sigma A3403-5MU) was added to each tube and swirled. Tubes were capped, and placed in an oven at 100 °C for two hours. It was at this time that a procedural blank was begun.

After two hours in the oven, samples were cooled by removing caps and adding 5 ml of 0.2 M sodium acetate buffer (pH 4.5) and 10 µl of amyloglucosidase, diluted by one half. Tubes were then re-capped, and placed in a Sanyo incubator for eight hours, at 55 °C, swirling after the first 30 minutes.

The centrifuge tubes were cooled and transferred to a 50 ml volumetric flask. Solids were allowed to settle for two hours before 0.5 ml sample vials were filled, and analysed using a newly calibrated Cobra Mira analyser.

3.16.5 Total Nitrogen and Carbon

Samples of dried, ground material were weighed out, and the weights recorded. Total carbon & nitrogen were analysed in plant and soil material using an Elementar Vario-Max CN Elemental Analyser.

The sample was combusted at 900 °C in an oxygen atmosphere. The combustion process converted elemental carbon and nitrogen into CO_2, N_2 and NO_x.

The NO_x species was subsequently reduced to N_2. These gases were then passed through a Thermal Conductivity cell to determine CO_2 and N_2 concentrations and the %C and %N was calculated from the sample weights.

3.17 Calculations:

The number of grazing days was calculated from the number of days that were spent grazing each of the treatments, multiplied by the number of stock used for grazing in each rotation.

3.18 Statistical Analysis:

Statistical analysis was carried out using Genstat statistical software Release 13. To enable statistical analysis and comparison between both Experiments 1 and 2, four of the six replicates in Experiment 2 were averaged. Replicates 1 and 6, and 3 and 4 were averaged and used in analysis along with replicates 2 and 5.

This meant a balanced analysis of variance would be used with means of separation based on least significant difference tests at $\alpha = 0.05$.

Sigmaplot Release 12, was used to graph results.

4 Results

4.1 Liveweight production

For liveweight production, there was no replicate data and thus analysis of variance was not carried out. Average liveweight gain for each period is given for each stock class, grazing on one of the three treatments (set stocked, semi set stocked or rotational grazing). Liveweight gain data from ewes and lambs grazing an aged ryegrass/white clover pasture in a paddock adjacent to the experimental site has been included for reference in Periods 1 and 2, however other details with regard to both stock and pasture management were unavailable.

Liveweight production has been split into six distinct periods as defined in Table 4.1. Both ewes and lambs were weighed full for all liveweight measurements over the duration of Periods 1 and 2.

Table 4.1 Summary of the duration of grazing for each stock class, within liveweight periods 1-6.

Liveweight Period	Duration of Period	Stock Class
1	8/09/2010-4/10/2010	Ewes & Lambs
2	5/10/2010-1/11/2010	Ewes & Lambs
3	2/11/2010-20/12/2010	Weaned Lambs *
4	9/2/2011-23/3/2011	Ram Hoggets (1)
5	13/4/2011-5/5/2011	Ram Hoggets (2)
6	6/5/2011-2/6/2011	Ram Hoggets (2)

* Liveweight data is mean liveweight gain of all lambs as stock were inadvertently mixed up part-way through grazing period.

4.1.1 Ewes

Ewes grazing the ryegrass based pasture during Period 1 produced 417 kg LW/ha, compared with 400 kg LW/ha for set stocked lucerne, and 300 kg LW/ha for rotationally grazed lucerne (Figure 4.1a).

During Period 2, liveweight production in rotationally grazed ewes was 202 kg LW/ha compared with 102 and 40 kg LW/ha for set stocked and semi set stocked treatments, respectively. Ryegrass based pastures during Period 2 resulted in production of 250 kg LW/ha.

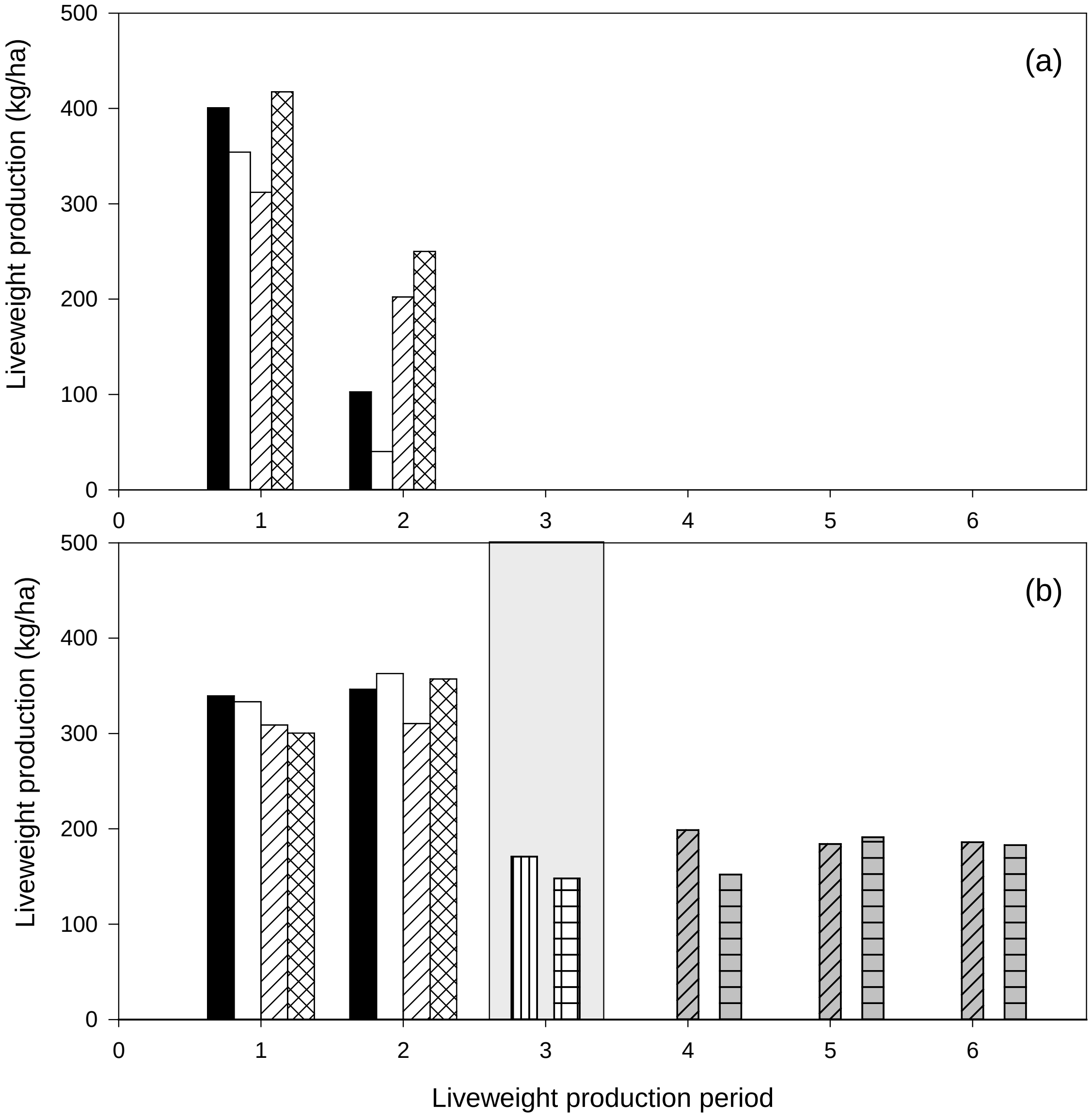

Figure 4.1 Liveweight production of ewes (a) and lambs (b) under set stocked (■), semi set stocked (□), rotational (▨) grazing regime, and grazing a ryegrass based pasture(⊠) . Area in grey for LW Period 3 indicates mean LW gain of all lambs was applied to grazing days for paddocks which were subject to set stocked and semi set stocked (▥) or rotational (▦) grazing regimes during spring. For Periods 3, 4 and 6 (b) hoggets rotationally grazed paddocks which were previously set stocked and semi set stocked in spring (▨) or continued rotational (▤) grazing.

Average total liveweight gain of ewes grazing lucerne throughout the duration of the trial are presented in Table 4.2. Ewes that grazed under a rotational regime showed 23% greater total liveweight gain in comparison with which those were semi set stocked, with average total liveweight gains of 514 and 394 kg, respectively. Rotationally grazed ewes had an average liveweight production of 113 kg over the same total grazing duration.

Table 4.2 Average total liveweight production (kg/ha) for ewes, lambs and ram hoggets under set stocked, semi set stocked and rotational grazing treatments. Liveweight data for weaned lambs grazing during Period 3 have not been included as data were unreliable.

Grazing Treatment	Ewes	Lambs	Ram Hoggets	TOTAL
Set stocked	503	686	526	1715
Semi set stocked	394	696	526	1616
Rotational	514	619	569	1702

The average liveweight of ewes and lambs both pre and post spring grazing under the set stocking, semi set stocking and rotational regimes are shown in Table 4.3. Ewes that had been rotationally grazed on lucerne had an average liveweight of 76.5 kg at the end of Period 2. These ewes entered plots at a weight of 60.9 kg, and thus liveweight increase of 15.6 kg was achieved over the 84 day duration of spring grazing. Average increases of 13.3 and 10.3 kilograms per head were found for ewes grazing set stocked and semi set stocked plot respectively. However, is important to note that these stock were weighed full as they had lambs at foot.

Table 4.3 Summary of liveweight gain (LWG) for ewes and lambs weighed full, at the start of Period 1 (8/9/2010), and at the conclusion of Period 2 (1/11/2010). Stock grazing under set stocked, semi set stocked and rotational grazing regimes during these periods.

	Ewes liveweight (kg)			**Lambs liveweight (kg)**		
Grazing Treatment	Pre-treatment	Post-treatment	Average LWG/hd	Pre-treatment	Post-treatment	Average LWG/hd
Set stocked	64	77.3	13.3	8.3	26.9	18.6
Semi set stocked	64.9	75.2	10.3	9.1	28	18.9
Rotational	60.9	76.5	15.6	8.5	28.3	19.8

4.1.2 Lambs

Figure 4.1b shows lamb liveweight production was 300 kg/ha or above during Period 1, regardless of the grazing treatment imposed. Set stocked lambs showed production of 339 kg LW/ha during this 28 day grazing period (Table 4.1). This was only 6 kg LW/ha greater than lambs grazing lucerne under a semi set stocked regime.

In Period 2, lamb liveweight production ranged from 362 kg LW/ha in semi set stocked treatments, to 311 kg LW/ha under rotational grazing. Between Period 1 and 2, liveweight gains had increased for all treatments, with the most significant increase (15%) observed in lambs grazing the ryegrass based pasture.

Total annual production in lambs was found to be 696, 686 and 619 kg LW/ha/yr for semi set stocked, set stocked and rotationally grazed lucerne, respectively (Table 4.2).

4.1.3 Ram Hoggets

During Periods 4, 5 and 6, ram hoggets rotationally grazed both experimental areas. Where rotational grazing had been continued from the spring management period, the average liveweight gain over the duration of each of the three periods was 190 kg LW/ha. The total annual liveweight production for hoggets grazing this treatment was equal to 569 kg LW/ha (Table 4.2).

In contrast, stock grazing plots which had been previously set stocked or semi set stocked during spring had a total liveweight production of 526 kg LW/ha (Table 4.2).

4.1.4 Total annual liveweight production

Average total liveweight gain was 1702 kg LW/ha/yr under the rotational grazing regime. Set stocked lucerne had an average total liveweight gain of 1715 kg LW/ha/yr. Semi set stocked plots produced 1616 kg LW/ha/yr, which was only 80% of that produced by rotationally grazed plots in the same year.

In general liveweight gain (kg LW/ha) was shown to decline, following a seasonal pattern. Highest liveweight gains were observed during spring in ewes and lambs. Lucerne at this time of the year is likely to be high quality, with a small unpalatable stem fraction, and thus higher intakes can be obtained, thus higher liveweight gains achieved.

4.2 Dry matter production

4.2.1 Accumulated dry matter of rotationally grazed lucerne

The total accumulated dry matter in 'Stamina' plots within the six paddock experiment increased at a linear rate from 0 kg DM/haon 1 July 2010 to 10,500 kg DM/ha on 3 December 2010 (Figure 4.2).

Over this period of time, the average growth rate was 68 kg DM/ha/d. Between 3 December 2010 and 1 February 2011, the rate of dry matter production was equal to 32 kg DM/ha/d. From February onwards, growth rates slowed further, to an average of 22 kg DM/ha/d. Dry matter measurements were not made after stock were removed from the trial on 30 May 2011. The total accumulated dry matter for the 2010-11 growth season was 15,000 kg DM/ha.

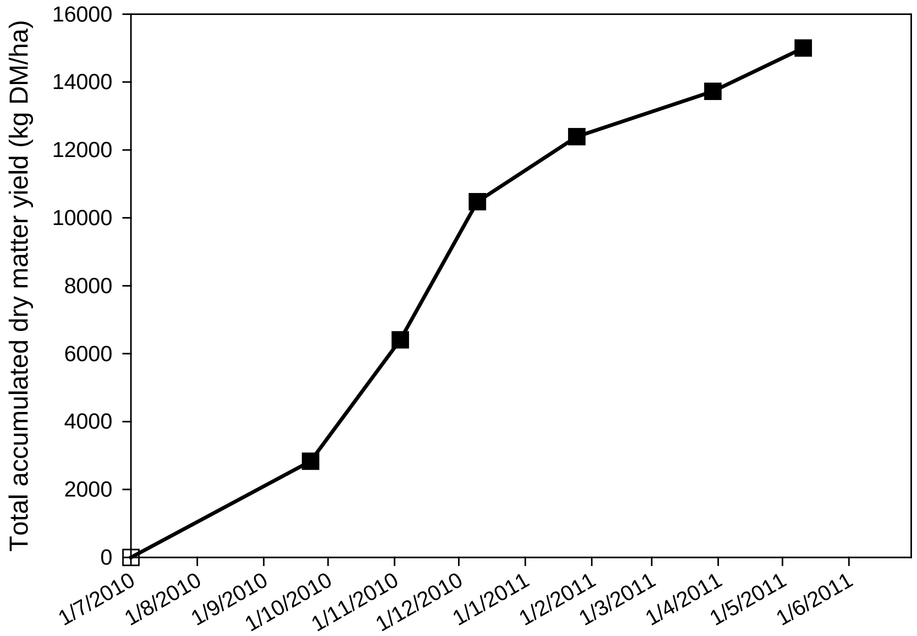

Figure 4.2 Total accumulated dry matter (kg DM/ha) for 'Stamina' plots under rotational grazing throughout the 1 July 2010- 30 June 2011 growth season. No measurements were made for the month of June.

4.2.2 Dry matter of individual paddocks under rotational grazing

Figure 4.3 shows grazing management of the six paddock rotation in Experiment 2 over the duration of the 2010-11 growth season. Ewes and lambs started grazing in Paddock 1 in early September 2010. The dry matter increased from 2000 kg DM/ha to approximately 2475 kg DM/ha before entry into Paddock 2. By the time stocked reached Paddocks 5 and 6 in the first rotation, the standing yield was approximately 3900 kg DM/ha. This gave an average daily growth rate of 56 kg DM/ha/d during the first rotation.

The post grazing residual (stem) is the amount of herbage that was left behind by stock when they were shifted between paddocks. On leaving Paddock 1 of the first rotation, the post graze residual was equal to 500 kg DM/ha. At the end of the first rotation, the post graze residual was approximately 1200 kg DM/ha.

Over the duration of the second rotation, the standing dry matter present as stock entered each paddock was between 500 and 1000 kg DM/ha higher than in the first rotation. By the time ewes and lambs reached Paddock 6 in the second rotation, the standing yield was 4500 kg DM/ha.

Lambs began grazing lucerne at the start of the third rotation, but were destocked on 3 December 2010, as a lack of dry matter production meant they ran out of feed. Post grazing residuals were not recorded for Rotations 3, 4 and 5. The average daily dry matter production was equal to 29 kg DM/ha between 30 December 2010 and 18 May 2011, during which time grazing rotations 3, 4 and 5 occurred.

Standing dry matter ranged from 1500 to 2400 kg DM/ha between Paddocks 1 and 6 in the fourth rotation. Dry matter production in Rotations 5 and 6 averaged approximately 1500 kg DM/ha. In the final rotation, stock grazed the lucerne to an average residual of 500 kg DM/ha.

Paddock 1 produced 10.4 t DM/ha across the first three rotations, compared with 13.7 t DM/ha for Paddock 6. Over the whole duration of the 2010/11 growing season, Paddock 1 was shown to have total dry matter production equal to 12.1 t DM/ha/yr. Paddock 4, which was grazed in the middle of the rotation gave an annual yield of 11.5 t DM/ha/yr, while Paddock 6 yielded 17.5 t DM/ha/yr.

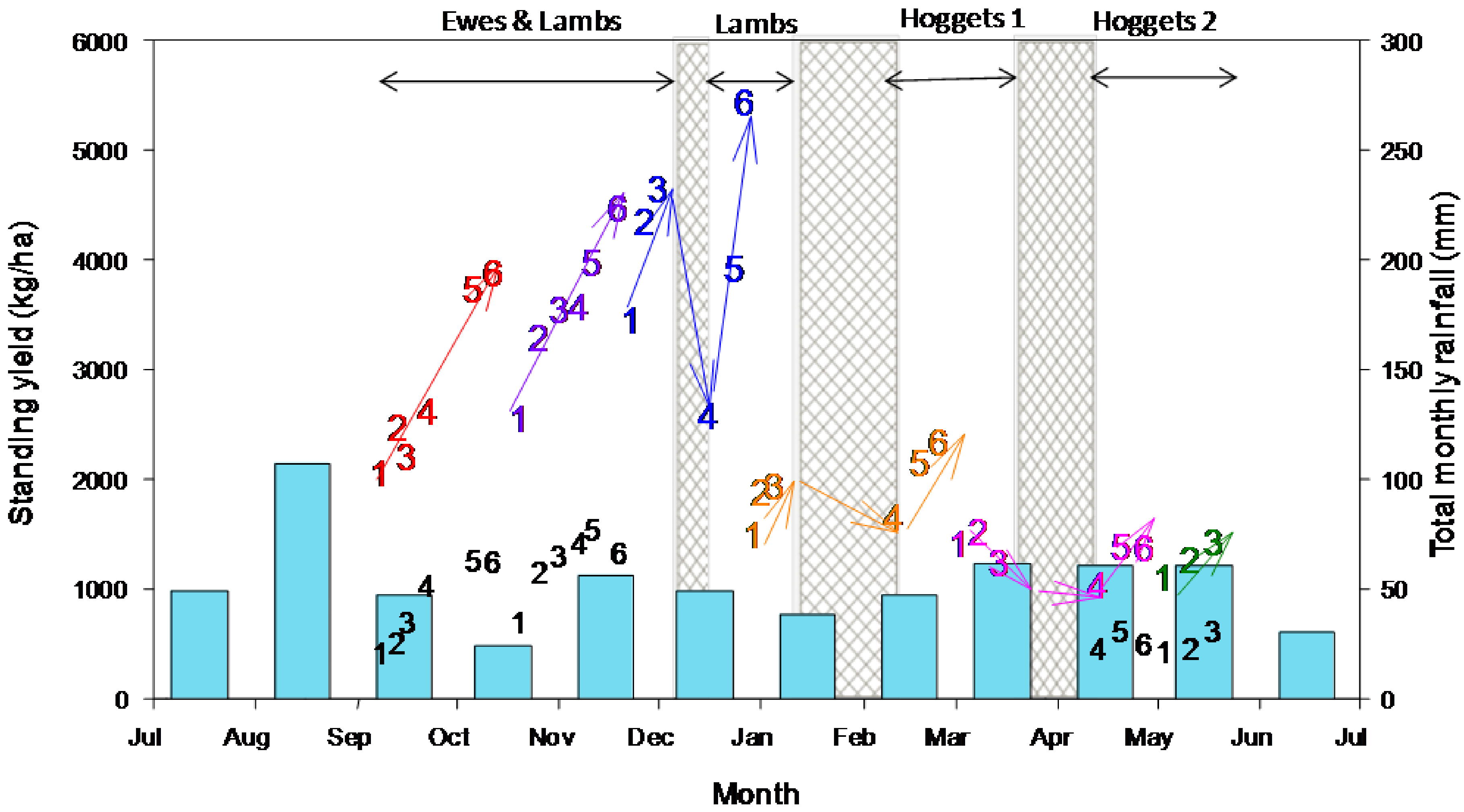

Figure 4.3 Standing dry matter (kg/ha) in Experiment 2, for paddocks 1 to 6, over six rotations during the 2010-11 growth season in H7, Ashley Dene, Canterbury, New Zealand. Numbers in black are the post graze residuals (stem) for each paddock, over the duration of each rotation. Blue bars represent the total monthly rainfall. Periods when the stand was destocked (▨).

4.2.3 Dry matter yield of set stocked and semi set stocked lucerne

Dry matter production was measured in both set stocked and semi set stocked plots intermittently from 13 July 2010 until the beginning of grazing on 14 September 2011. Over this period, standing dry matter increased to 1850 kg DM/ha at which point stock were introduced to treatments.

Under the set stocked regime, grazing by ewes and lambs did not reduce dry matter below levels recorded at the beginning of grazing for the first three weeks. From mid-September onwards, standing dry matter was reduced to 1110 kg DM/ha late October, soon after which, ewes and lambs were removed from the treatment.

Semi set stocked plots continued to produce dry matter at a higher rate than consumption once stock began grazing the treatment. Dry matter yield peaked at 2400 kg DM/ha on 20 September, 2010. After this time, yield declined to 1200 kg DM/ha at the start of October, before showing another increase in mid-October, followed by final decline to 850 kg DM/ha in late October. This was the last measurement before ewes and lambs were removed from experimental plots on November 1, 2010.

The pre graze standing dry matter yields for lambs and ram hogget grazing cycles indicate that when grazing management was changed from either set stocked or semi set stocked to rotational grazing, the dry matter yield showed an initial increase in December. Measurements taken in January, March and early May show that dry matter yield slowly decreased from 1800 to 1400 kg DM/ha over this period.

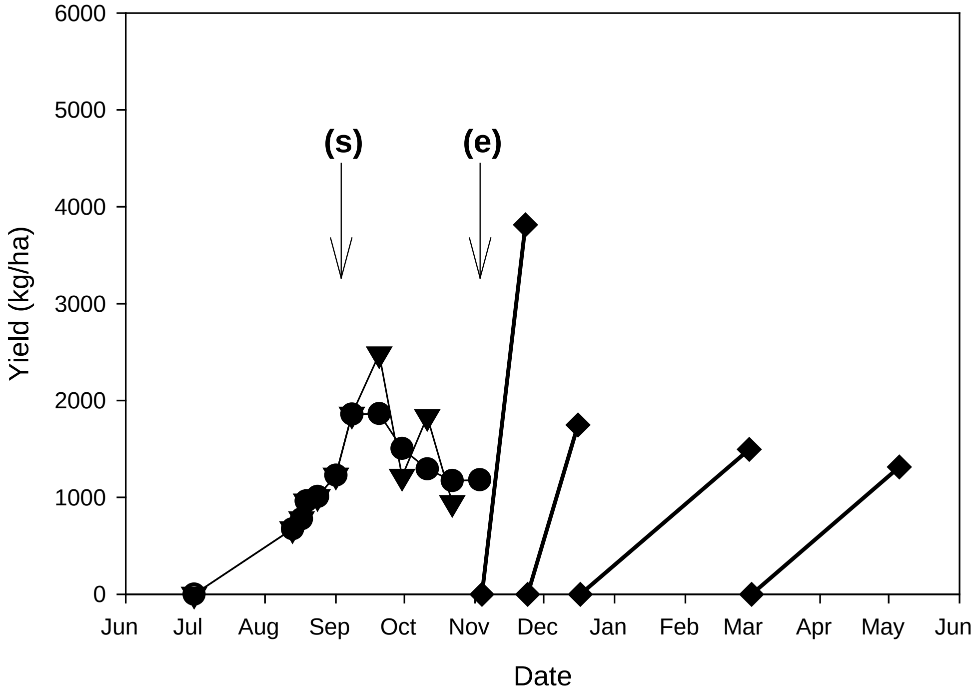

Figure 4.4 Standing yield (kg DM/ha) of 'Stamina' lucerne managed under set stocking (●) or semi set stocking (▼) in early spring (September – November 2011) by ewes with twin lambs at foot. Arrows indicate the start (s) and end (e) of spring grazing management. Pre graze standing dry matter yields (◆) for rotationally grazed ‘Stamina’ plots which were previously set stocked or semi set stocked during spring. Only four pre graze measurements were made between November 1 and May 30 2011.

4.3 Plant population

Lucerne plant populations were highest (P<0.05) in treatments which were semi set stocked over the spring period, with a plant population of 205 plants/m². Set stocked and rotationally grazed treatments had plant populations which were similar to each other, and were reduced by approximately 25% in comparison with semi set stocked plots.

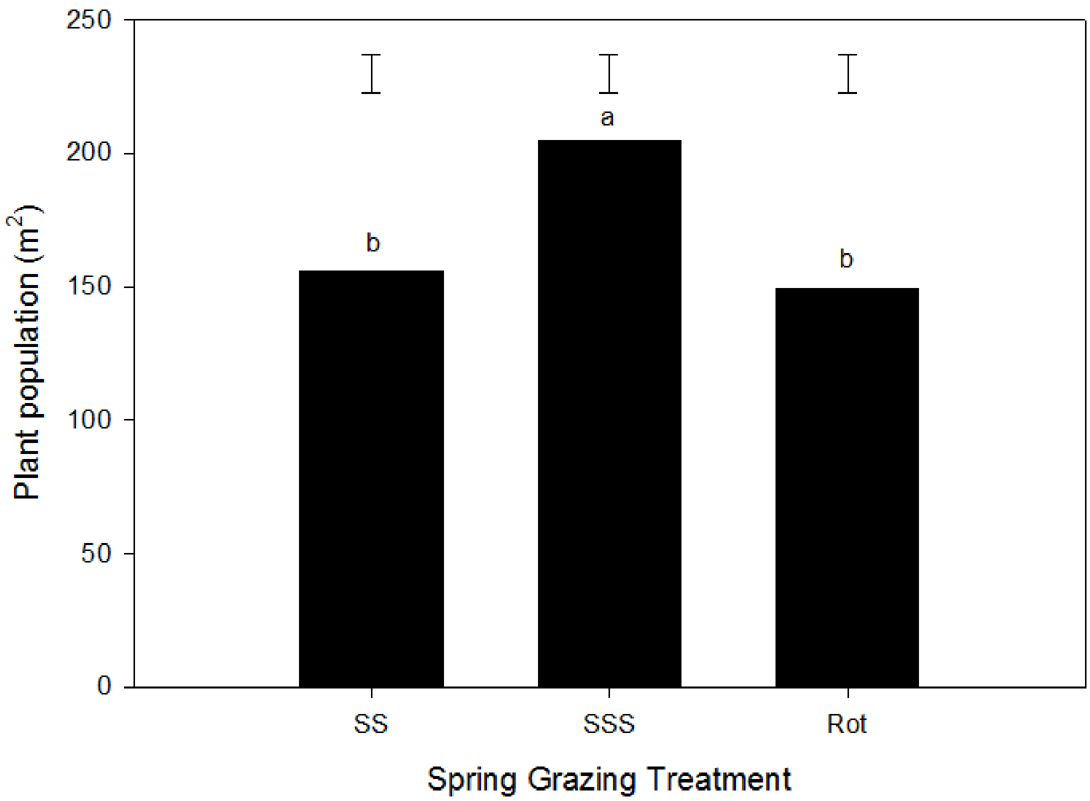

Figure 4.5 Lucerne plant population (m²) in swards which were set stocked (SS), semi set stocked (SSS) or rotationally (Rot) grazing during spring. Error bars indicate least significant difference between each measurement (P<0.05). The same letter above treatment means indicate that they are not significantly different at α=0.05.

4.4 Dry weights of plant components

4.4.1 Root

There was no significant difference between root dry weight (Figure 4.6) in samples taken in the winter of 2011, however there was a positive trend which suggested that total root dry weight increased between set stocking and rotational grazing treatments ($P<0.125$). The total root dry weight across all spring grazing regimes was 3.70 $\pm$ 0.30 t DM/ha. The 0-50 mm root zone of the root weighed an average of 1.70 ± 0.10 t/ DM/ha across all spring grazing treatments. The proportion of root in the 50-280 mm zone was on average 1.96 $\pm$0.19 t DM/ha.

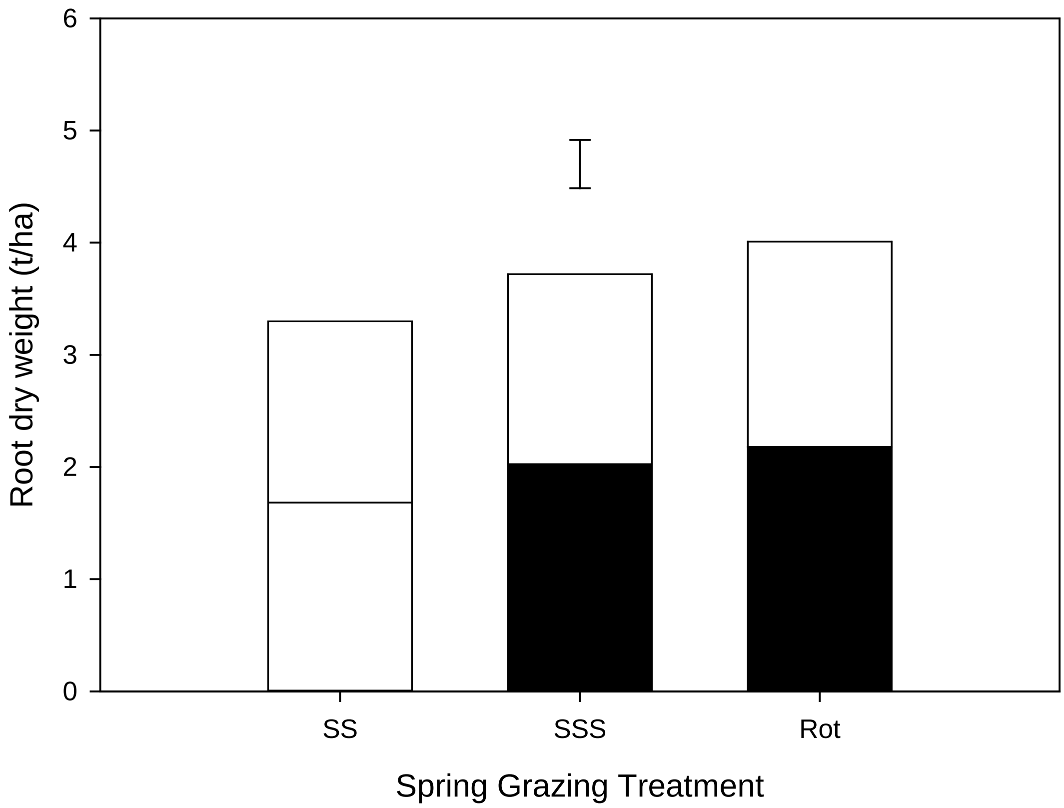

Figure 4.6 Dry weight (t/ha) of lucerne root in the 0-50 mm zone (□) and 50-280 mm (■) for set stocked (SS), semi set stocked (SSS) and rotational (Rot) spring grazing treatments. The full bar represents the total mean dry weight of root harvested in June 2011. Error bar indicates least significant difference between each measurement for total root dry weight (t/ha) ($P<0.05$).

4.4.2 Crown

The mean crown dry weight across all treatments was 1.7 ± 0.15 t DM/ha. There was a positive trend (P<0.118) evident which suggests that the crown dry weight increased with the length of the interval between grazing, as is observed with set stocked and rotationally grazed (28 days between grazing) treatments.

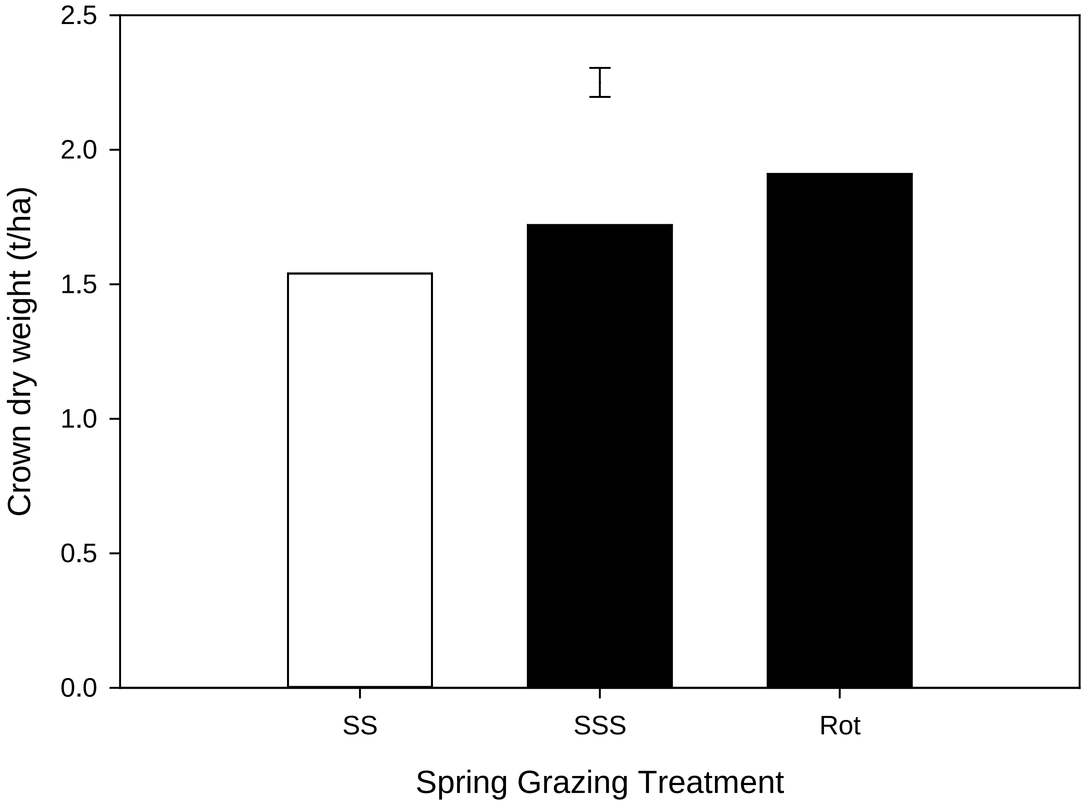

Figure 4.7 Crown dry weight (t/ha) in June 2011 for lucerne plants grazing under set stocked (SS), semi set stocked (SSS) and rotational (Rot) grazing treatments during spring. Error bar indicate least significant difference between each measurement (P<0.05).

4.5 Nutritive content of crown and 0-50 mm root zone.

4.5.1 Crude protein yield

In the crown, the mean crude protein yield was 321±25.7 kg/ha and was similar (P<0.259) amongst treatments (Figure 4.4). The crude protein yield was 251±24.4 kg/ha in the upper portion of the root (0-50 mm).

Table 4.4 Crude protein of crown and 0-50 mm root zone samples taken in late June 2011, from each of set stocked, semi set stocked and rotational grazing regimes during spring.

	Crude Protein Yield (kg/ha)	
Spring grazing treatment	Crown	0-50 mm root zone
Set stocked	287	246
Semi set stocked	323	246
Rotational grazing	354	261
SEM	25.7	24.4
P value	0.259	0.881

4.5.2 Starch yield – crown

Rotationally grazed lucerne plants had an average starch yield in the crown of 75±19.1 kg DM/ha. Set stocked and semi set stocked treatments were found to yield ～52±19.1 kg DM/ha, respectively (Figure 4.8).

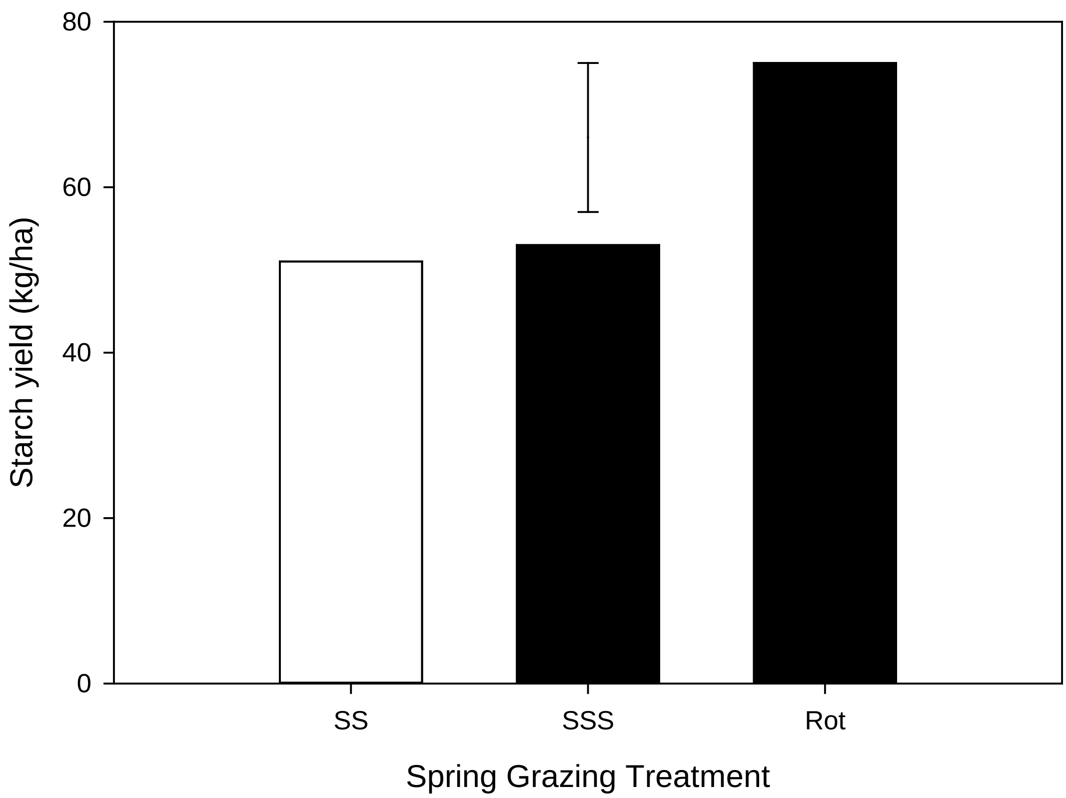

Figure 4.8 Starch yield (kg/ha) of lucerne crown samples, June 2011, for set stocked (SS), semi set stocked (SSS) and rotational (Rot) spring grazing treatments. Error bars indicate least significant difference between each measurement (P<0.05).

4.5.3 Starch yield – 0-50 mm root zone

Starch yield in the 0-50 mm root zone of lucerne plants was similar across all three spring grazing treatments with a mean yield of 295±42.2 kg/ha. Starch yields in this section of the root were at least 300% higher than values for the crown portion of the same plants (Figure 4.8).

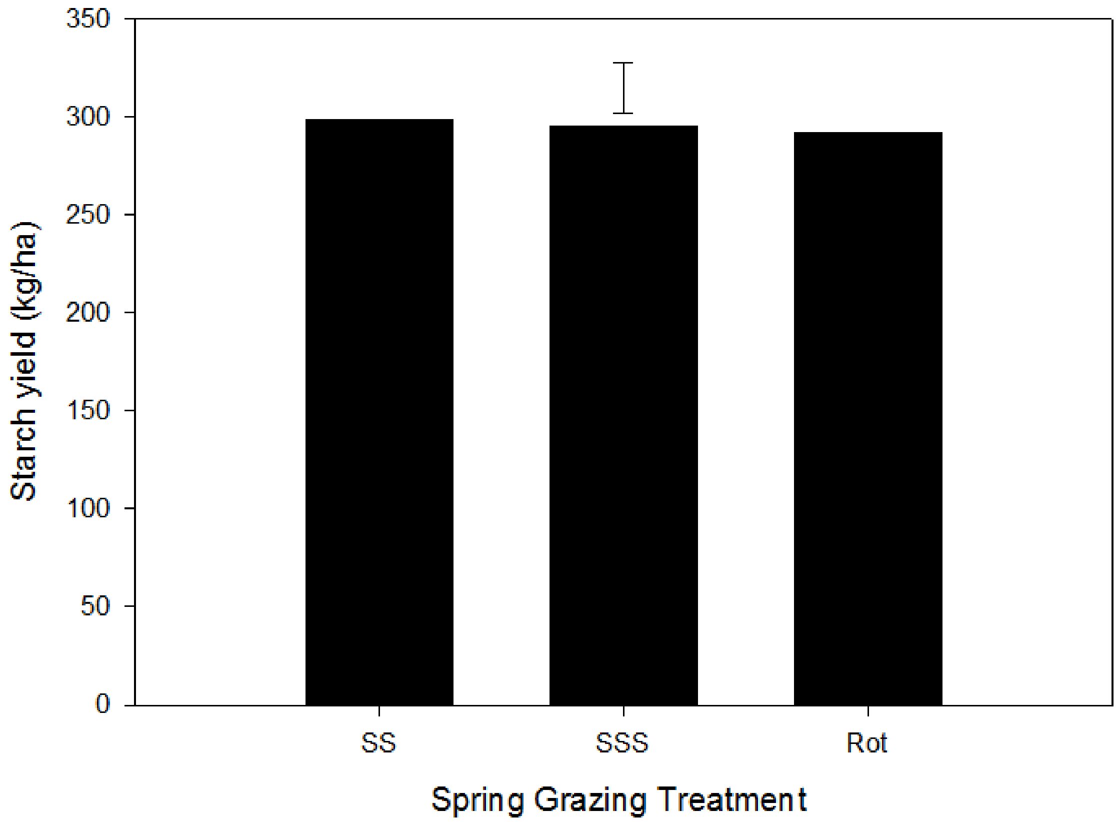

Figure 4.9 Starch yield (kg/ha) in 0-50 mm root zone for set stocked (SS), semi set stocked (SSS) and rotational spring grazing treatments. Error bars indicate least significant difference between each measurement (P<0.05).

4.5.4 Water soluble carbohydrates – crown

Total water soluble carbohydrates (WSC) in June 2011 were higher (P<0.05) for lucerne plants which were rotationally grazed during spring with total WSC of 145 kg/ha. Values for set stocked and semi set stocked spring grazing were also different (P<0.05) with 110 and 122 kg/ha for each treatment, respectively (Figure 4.10).

4.5.5 Water soluble carbohydrates – 0-50 mm root zone

Water soluble carbohydrates in the 0-50 mm root zone had a mean value of 233 ± 14.2 kg/ha (Figure 4.11).

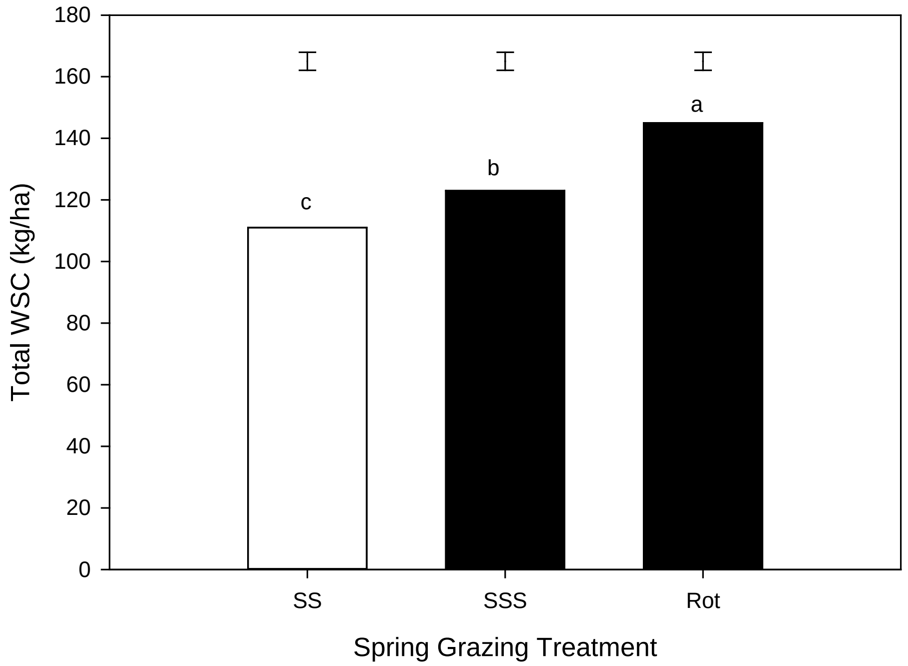

Figure 4.10 Total water soluble carbohydrates in crown, for set stocked (SS), semi set stocked (SSS) and rotational spring grazing treatments. Error bars indicate least significant difference between each measurement (P<0.05).

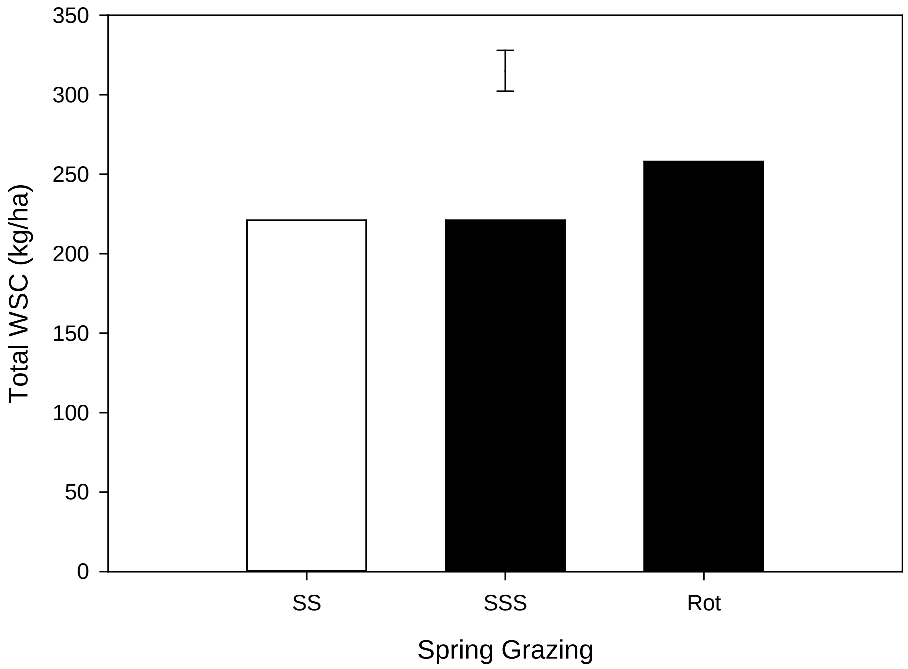

Figure 4.11 Mean total water soluble carbohydrates in the 0-50 mm root zone, for set stocked (SS), semi set stocked (SSS) and rotational spring grazing treatments. Error bars indicate least significant difference between each measurement (P<0.05).

5 Discussion

5.1 Liveweight gains

As 'Stamina' was common between both experiments, it was used for analysis and comparison of dry matter and production component, however in stock which were used to calculate the liveweight gain under each grazing regime. All cultivars were grazed to different post grazing residuals, and with a different order of preference. For this reason, for the purpose of this discussion any comparison between dry matter production and liveweight assumes that all lucerne cultivars in each of the experiments had similar growth patterns and dry matter production.

5.1.1 Ewes

During Period 1, lactating ewes that grazed an aged ryegrass based pasture adjacent to the experimental sites had liveweight gains of 417 kg LW/ha, although details of pasture growth rates, composition and stocking rates were unavailable, making comparison difficult with lucerne on a total annual liveweight production basis. Ewes that grazed set stocked lucerne treatments had liveweight gains of 400 kg LW/ha, while ewes grazing lucerne under a rotational regime were shown to have an average liveweight gain of 311 kg LW/ha.

Prior to the start of liveweight Period 1, ewes allocated to the set stocked grazing regime had an average liveweight of 60.9 kg (weighed full) (Table 4.3). Rapid liveweight gains, resulted in ewes leaving the treatments at the end of Period 2 an average of 15.6 kg heavier than when they began grazing, despite mothering twin lambs.

Liveweight production (kg/ha) between Period 1 and 2 was reduced by 89% in ewes grazing semi set stocked plots, to 40 kg LW/ha (Figure 4.1a). Set stocked plots showed the second largest reduction in the rate of liveweight gain, with ewes having an average liveweight production of 102 kg LW/ha in Period 2. At this time, lambs were competing with ewes for herbage, the availability of which was dependent on the growth rates of the crop. During Period 2, the average standing dry matter was approximately 1100 kg DM/ha, (Figure 4.4).

The majority of literature which looks at sheep grazing lucerne focuses on liveweight gains in weaned lambs and hoggets under a conventional rotational regime. For this reason, liveweight data collected for lactating ewes in this trial is hard to compare with other work. In general, lactating stock rapidly lose liveweight while feeding young stock, as the energy requirements for milk production cannot be met by feed intake. Liveweight gains would therefore be expected to be minimal, or at least not in the range of 300-400 kg LW/ha as observed in Period 1. These results from Period 1 suggest that ewes across all treatments took advantage of the fresh herbage on offer, high in quality and palatable components and thus benefited from luxury intakes.

5.1.2 Lambs

During Period 1, suckling lambs grazing lucerne alongside their mothers under set stocked grazing had liveweight production equal to 339 kg LW/ha. Those grazing the ryegrass based pasture had a liveweight production of 300 kg LW/ha. Semi set stocked and rotational treatments had production that was intermediate to these at 333 and 309 kg LW/ha, respectively.

Once again, much of the literature does not include suckling lambs in liveweight production measurements. As in this experiment, young suckling stock are not fasted, and thus weighing animals full causes problems in accurately determining the liveweight production achieved within this period.

Liveweight gains observed for suckling lambs in this trial are comparable to many of those summarised by Douglas (1986) where lambs (presumably weaned) in September and October had liveweight gains ranging from 243 to 340 grams per day.

Lambs grazing all treatments showed an increase in liveweight gain between Period 1 and 2. These increases ranged from 21 kg LW/ha for lambs in rotational grazed lucerne to 57 kg LW/ha in the ryegrass based pasture. Semi set stocked lambs showed a liveweight production of 362 kg LW/ha, which was 14% higher than rotationally grazed lambs in the same period with an average liveweight production of 311 kg LW/ha.

Liveweight production in ewes during Period 1 was shown to be on average 13% higher than that of lambs in the same period (Figure 4.1). However, in Period 2 lambs had an average liveweight production of 344 kg/ha, which was 43% higher than ewes. This shows the competition between ewes and lambs within periods, however Table 4.2 shows that under the semi set stocked regime, lambs contributed 66% of the total spring liveweight production which suggests that this management practice may have been the most beneficial for lamb production.

Weaned lambs were inadvertently mixed up at an unknown stage within Period 3. For this reason, mean liveweight gain for all weaned lambs was applied to the number of grazing days for paddocks which were subject to either set stocked and semi set stocked during spring, or rotationally grazed. Results suggested that weaned lambs grazing treatments which were rotationally grazed during spring had an annual liveweight production that was 20 kg LW/ha less than treatments which had previously been set stocked/semi set stocked (Figure 4.1b).

5.1.3 Hoggets

After weaning, stock were not returned to the ryegrass based pasture due to insufficient feed supply. Therefore comparison between lucerne under different management regimes, and this pasture ceased at this point.

5.2 Dry matter production

5.2.1 Accumulated dry matter of rotationally grazed lucerne

Figure 4.2 showed that over time, dry matter production increased, with two distinct changes in the gradient, representing a change in growth rates. Between mid September, and early December, daily dry matter production was approximately 68 kg DM/ha/d, after which point daily growth rates were further reduced ～25 kg DM/ha. The decline in the latter half of the growth season, it is likely that this can be attributed to soil moisture deficits limiting plant growth.

Because soil moisture was not measured on site it was not possible to quantify site specific information. This means growth cannot be accurately related to known periods of water stress which would have periodically inhibited the potential rate of dry matter production. However, as Figure 4.3 indicates, rotationally grazed lucerne was destocked in early December as a result of insufficient rainfall in October, combined with increasing summer temperatures. The amount of regrowth in Paddocks 4 and 5 of Rotation 3 shows the level of dependency that the lucerne plant had on in season rainfall, as standing dry matter in Paddock 4 was shown to decrease from 3500 to 2500 kg DM/ha. Further into the season, annual rainfall also fell below the long term mean.

5.2.2 Dry matter of individual paddocks under rotational grazing

Figure 4.3 shows the timing of production from each paddock varied across the season, and this appeared to be related to the timing of the first (and therefore subsequent) grazing. Paddock 1, which was the first to be grazed in the 2010-11 season, was shown to have total dry matter production equal to 12.1 t/ha/yr. Standing yield was consistently lower than both Paddocks 4 and 6 within the first three grazing rotations during spring. Annual yields for Paddocks 4 and 6 were 11.5 and 17.5 kg DM/ha/yr respectively, exhibiting a strong linear trend for higher annual production with later start of grazing in spring.

This suggests that the beginning the trial on September 9 2010 may have been earlier than preferable in terms of maximising total annual production from the lucerne stand. However it is likely that if Paddock 1 had been left longer before grazing, the quality in the last of the paddocks grazed in the first rotation would have been compromised. If quality data had been able to be obtained, it would be expected that a higher level of stem production would have decreased the quality of the forage. This would be a result of a longer growing period before grazing, therefore a greater standing herbage mass on entry into the paddock, giving higher post grazing residuals, decreasing the quality of the lucerne, particularly in the second and third grazing rotations. This highlights the requirement for close observation of the lucerne crop prior to the first grazing, and the need for compromise between early spring grazing resulting in reduced dry matter production, and later grazing which allows for higher dry matter yields, yet lower quality material.

5.2.3 Dry matter yield of set stocked and semi set stocked lucerne

For the period of spring grazing management values shown do not account for herbage grown and ingested during the grazing period. Therefore it is hard to get an accurate account of the correct growth rates without the use of pasture cages or another method of measuring the amount of herbage being eaten by stock.

5.3 Plant population

In winter 2010, while sampling perennial reserves, the plant population in each 0.2 m^2 quadrat were recorded for each of the set stocked, semi set stocked and rotationally grazed plots. Semi set stocked plots had an average plant population of 205 plants per square metre, which was higher ($P<0.05$) than plant populations in both set stocked and rotational grazing treatments which had ~ 150 plants/m^2.

Belesky & Fedders (1997) also reported plant population of a lucerne stand to rapidly decline by 80% over a three year period, when grazed intensively. Teixeira (2006) carried out the same procedure in a Canterbury lucerne stand during June, for two consecutive years. He compared lucerne which had been grazed under a 28 day rotation with another stand which was grazed every 42 days. Over the biennial trial period, plant population in the stand with the more frequent grazing rotation, exhibited an exponential decline in plant population from 120 to 60 plants/m^2. Surprisingly this was attributed to a 'self-thinning' process, rather than attributed directly to grazing management.

The 25% decline in plant population suggested in this trial by the results from both set stocked and rotationally grazed treatments, suggests that while grazing may have influenced the result, the primary cause was most likely due to self-thinning, thought to be a result of overcrowding (Teixeira *et al.*, 2007b). If it were, it would be set stocked plots, which were grazed the most intensely, to exhibit the lowest plant population, and rotational grazing would be the most beneficial to maintain plant population.

Conclusions from plant population studies in lucerne by Teixeira (2007b) suggest that 43 plants/m² is the minimum plant population before production potential is negatively affected by population declines. While plant populations remain higher than this, plants have adequate branching to compensate for losses in plant numbers, and dry matter production is not significantly reduced. If plant populations are measured for the same grazing treatments in following winters, it may be clearer as to the effect that grazing management has on plant populations, and the levels at which the plant can tolerate inadequate grazing before persistence of the stand begins to suffer. If current trends continue, the decline would be exponential and it could be expected that set stocked and/or rotational plots could have populations below 43 plants/m² within the next two years of production.

5.4 Dry weights of plant components

5.4.1 Root

The total root dry weight across all spring grazing treatments was found to be 3.70±0.30 t DM/ha. In a very similar sampling procedure to the one used in this trial, Teixeira (2006) reported the average of 4.5 t/ha for samples dug in August, and noted that that samples in taken in June averaged 5.0 t DM/ha. This latter value was 26% greater than the average values presented in Figure 4.6. However, Figure 4.6 also suggests that there was a positive trend ($P<0.05$) whereby root dry weight (kg DM/ha) increase between set stocked (intensive) and rotational (infrequent) grazing management systems, with semi set stocked treatments having root dry weights in between these two points.

Root dry weight is a key indicator of the amount of stored reserves present to support growth and production, particularly in early spring. Ideally, lucerne should never be set stocked as continuous removal of basal buds quickly depletes root reserves and thus limits shoot production and subsequent dry matter production (Brown *et al*., 2006). Measurements of perennial reserves in June should give a fairly accurate idea of 'how well prepared' the lucerne plant is for the oncoming spring, as assimilate partitioning to the roots would have occurred ceased with plant growth in late autumn, and new growth not yet begun.

5.4.2 Crown

The mean crown weight across treatments was 1.7±0.15 t DM/ha. The work of Teixeira *et al*. (2007a) found that crown dry matter was higher is lucerne which had been grazed in a long (42 day) rotation for the duration of the growing season in comparison to treatments where the length of rotation was consistently 28 days. Teixeira *et al*. (2007), highlighted a positive linear relationship between root and crown dry matter (t/ha). An average crown yield of 1.7 ± 0.15 t DM/ha as observed in Figure 4.7 would theoretically result from a taproot yield of 2.0 t DM/ha across all grazing treatments. However, the taproot yield in this trial was found to be 3.7±0.30 t DM/ha (Figure 4.6), which was in the upper range results for 42 day rotations examined by Teixeira *et al*. (2007).

5.5 Nutritive content of crown and 0-50 mm root zone

5.5.1 Crude protein yield

There was no significant difference in crude protein (CP) between treatments for both the crown and the 0-50 mm root zone. However, the mean crude protein content recorded for the upper portion of the root was 251±24.4kg/ha, equal to ~2.3% of the total dry matter for the 0-50 mm fraction of the root. This is higher than the ~1.8% DM reported by Teixeira *et al*. (2007a) for autumn measurements of nitrogen content in perennial root reserves. It is possible that the difference between the findings of this trial and that of Teixeria *et al*. (2007a) are a result of a lower nitrogen supply to the plant, which in turn affects the nitrogen concentration observed in this portion of the root.

In the crown the mean crude protein yield was 321±25.7 kg/ha. This was 1.4% of the total crown dry weight (kg/ha). While crude protein yield in the crown was not shown to be significant in this trial, there appeared to be a positive linear trend which showed crude protein to increase in the crown between set stocked and rotationally grazed treatments, suggesting crude protein content was influenced by defoliation frequency. The mean values reported for each of set stocked and rotationally grazed crude protein yield in the crown suggest a 19% difference between the grazing regimes. Teixeria *et al*. (2007a) found that frequent defoliation throughout the growth period resulted in a 60-70% reduction in nitrogen concentration in the crown in comparison with grazing treatments with long regrowth cycles.

However, it is important to remember that the set stocked grazing treatment was only imposed during spring in this trial, and thus it would be expected that the percent reduction between grazing regime lies between the 19 and ～65% reported above. This is because it is likely that the change in grazing regime during the autumn period may have allowed for at least partial recovery of lost reserves in the latter part of the grazing season as recommended practices for maximising assimilation partitioning were adhered to. This included allowing a period of extended flowering and delaying further grazing until autumn rainfall ensured that regrowth occurred, thus assisting in the recovery of reserves.

5.5.2 Starch yield – crown

There was no significant difference between starch yield in the crown of the lucerne plant grazing under set stocked, semi set stocked or rotational grazing regimes in perennial samples taken in June 2011. More frequent sampling by Teixeira *et al*. (2007a) throughout the year found short regrowth cycles to consistently reduce the level of starch found in the perennial reserves of the plant, particularly when short periods between defoliation occurred throughout the entire production year.

The average proportion of starch under rotational grazing was 4.4% of the total crown dry weight (kg DM/ha) while it was ～3.1% in plants which had been subject to set stocked or semi set stocked regimes during the spring period. Teixeira *et al*. (2007a) reported starch in the crown to be approximately 10% of total crown dry matter in plants which were grazed under a 42 day defoliation regime over the entire grazing season. Lucerne which was continually grazed under a short defoliation period of 28 days had an average starch concentration of 5%. This is slightly higher than the 3.1% observed in this trial, but it is important to note that Teixeira *et al*. (2007a) did not set stock the lucerne, so lower values may be expected as a result of increased grazing pressure on the plant and contents of reserves.

5.5.3 Starch yield – 0-50 mm root zone

Starch yield in the 0-50 mm zone of the root was shown to have a mean value equal to 295 ± 42.2 kg/ha.

While this showed no significant difference between treatments, the starch yield was 560% higher in the 0-50 mm root zone compared with the crown. This indicates that much of the storage of starch occurred in the top of the root as opposed to in the crown. At other times of the year, it would be expected that set stocking would have resulted in a decline in the %starch as the plant may be assimilating more starch to the shoot compared with the roots, so that it can support frequent defoliation by stock.

5.5.4 Water soluble carbohydrates –crown

Sampling of the perennial root reserves in June 2001 showed that water soluble carbohydrates (WSC) in the crown were significantly higher in rotationally grazed lucerne than in stands which were set stocked or semi set stocked during the spring period.

Water soluble carbohydrates are quickly mobilised from perennial root reserves for rapid spring growth. The fact that rotationally grazed plots were superior to the semi set stocked and set stocked plots suggests that rotational grazing allows for greater accumulation of water soluble carbohydrates in the root, through better management of the plant, and assimilate partitioning.

6 General Discussion

The liveweight gain data emphasises the ability of lucerne to produce high liveweight gain during the spring period, in both ewes and lambs. Kirsopp (2001) stated that the use of lucerne to increase liveweight during early spring was impractical as lambing needs to be later to account for the slower spring production of lucerne compared with pastures. While the ryegrass white clover pasture used as a comparison of liveweight gain against lucerne under different grazing management regimes had liveweight gains which were comparable to those of lucerne, stock did not return to the pasture after weaning in November due to a lack of feed. This was a result of below average rainfall in the month preceding this time, reduced plant available water in the soil and the inability of these pasture species to access water from deeper in the soil profile. This is when lucerne begins to have an advantage over many of the conventional pasture species, maintaining animal growth rates that are up to 70% higher (Douglas, 1986).

6.1 Conclusions

- Rotationally grazed plots had an average yield of 15 t DM/ha.

- The timing of production varied from each paddock across the season under rotational grazing, depending on the start of the first grazing in spring.

- Plant population was found to be 205/m² under in lucerne semi set stocked in spring. This was at least 25% greater than both set stocked and rotationally grazed treatments at the same sampling time.

- Water soluble carbohydrates in the crown portion of the root was higher under rotational grazing at 145 kg/ha. Values for set stocked and semi set stocked grazing were also different with 110 and 122 kg/ha for each treatment respectively.

- Rotationally grazed lucerne showed to have a mean annual liveweight production equal to 1702 kg LW/ha/yr for all stock which grazed lucerne under a rotational regime for the 2010/11 season.

- Set stocked and semi set stocked grazing treatments exhibited higher intakes and liveweight production during early spring grazing, however, mean annual liveweight production was less than rotationally grazed plots at 1452 and 1355 kg LW/ha/yr, respectively.

- Set stocked and semi set stocked lucerne had liveweight production comparable to rotational during spring, however the management practices resulted in trends of declining perennial root reserves, and suggested reduced persistence of the stand in the long term.

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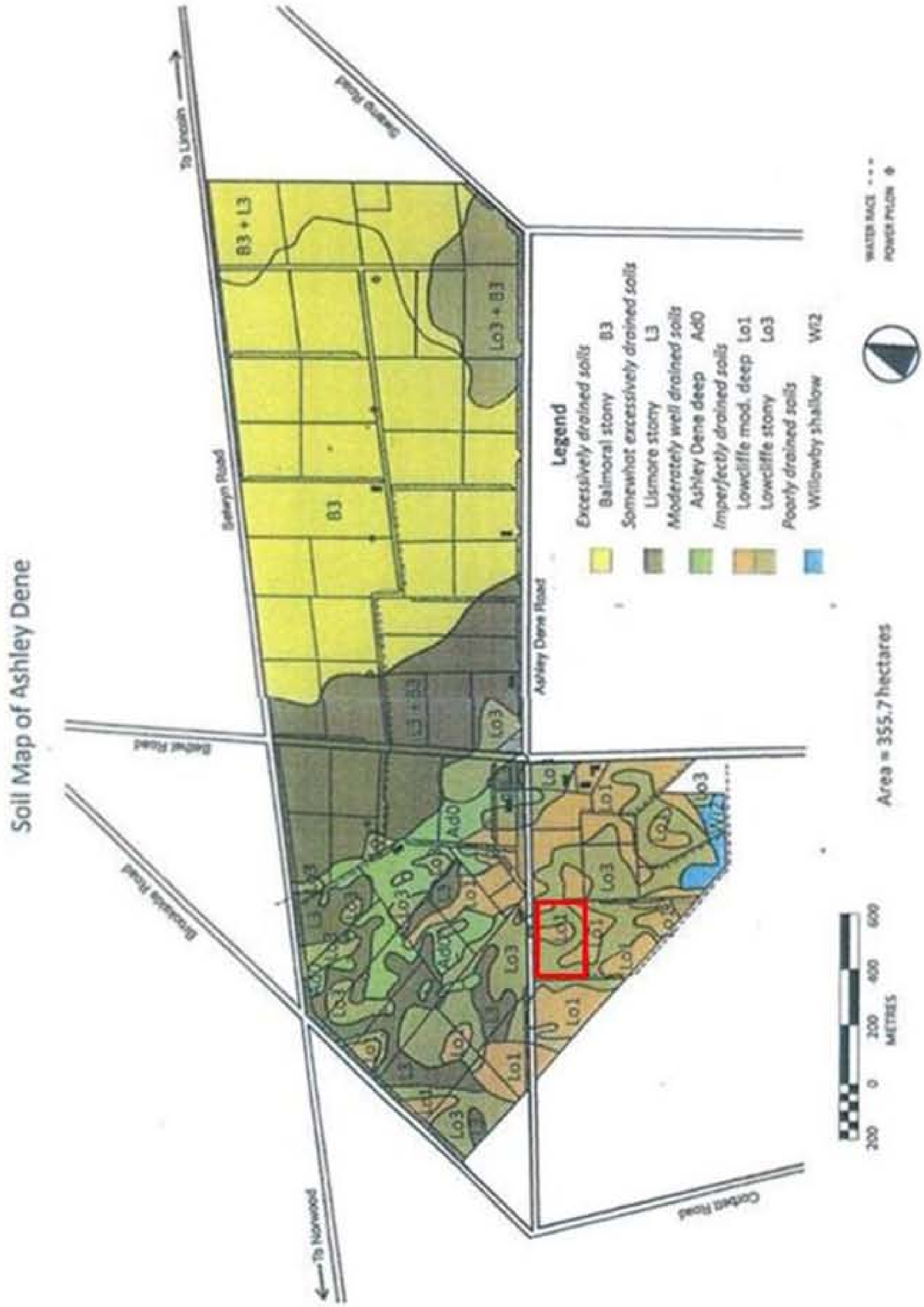
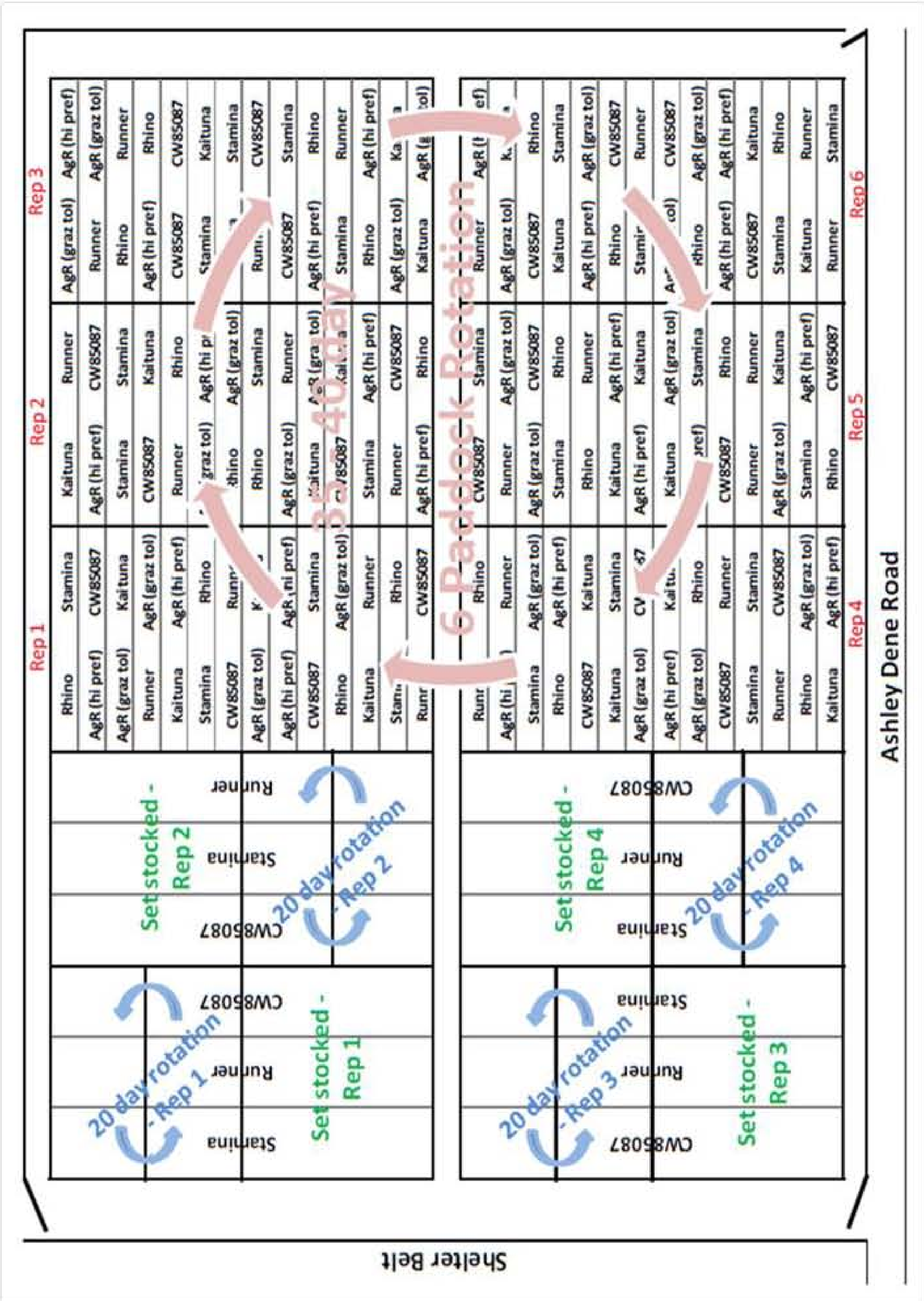
Appendices

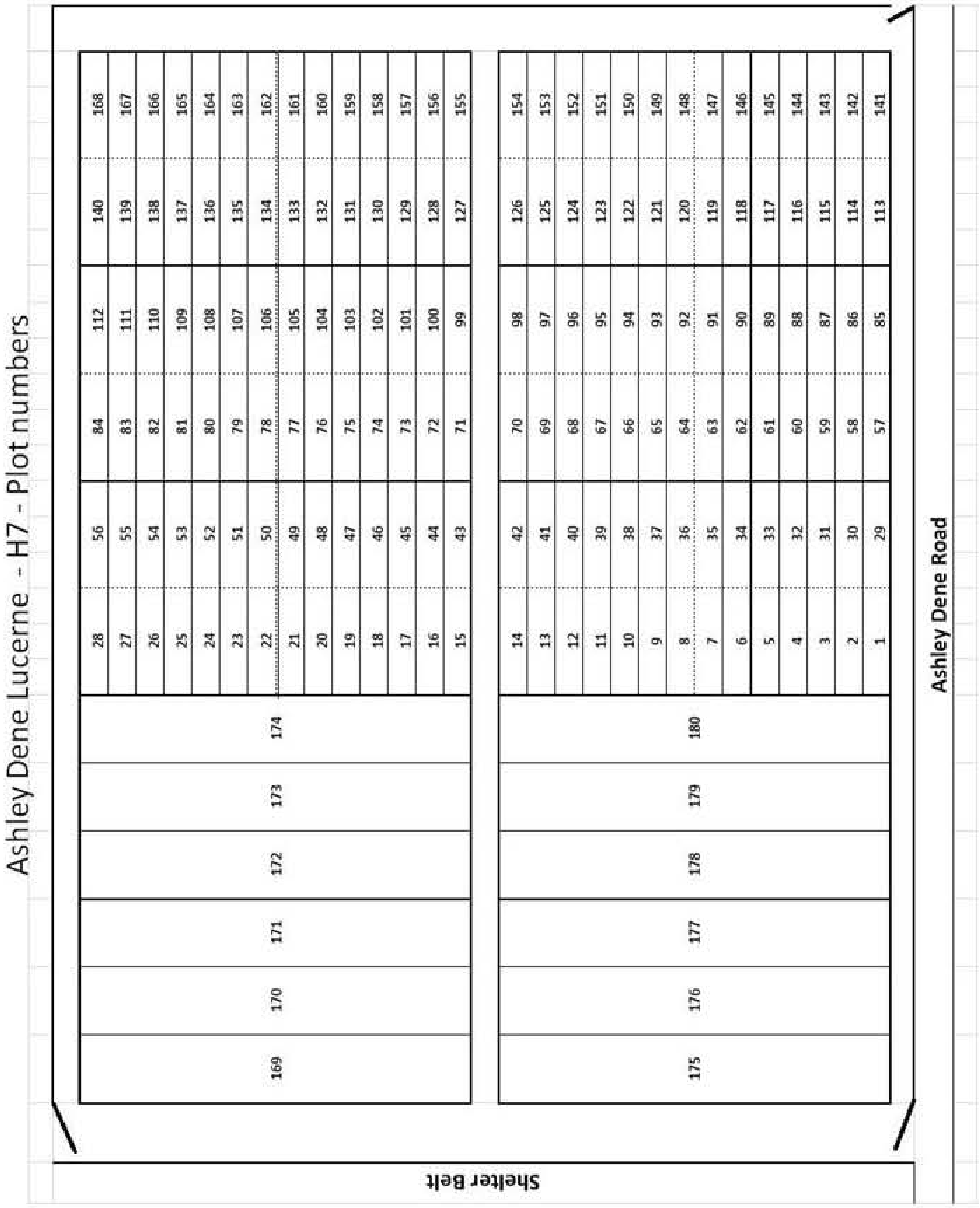
Appendix 1 Soil map of Ashley Dene. (Experimental site marked by red box).



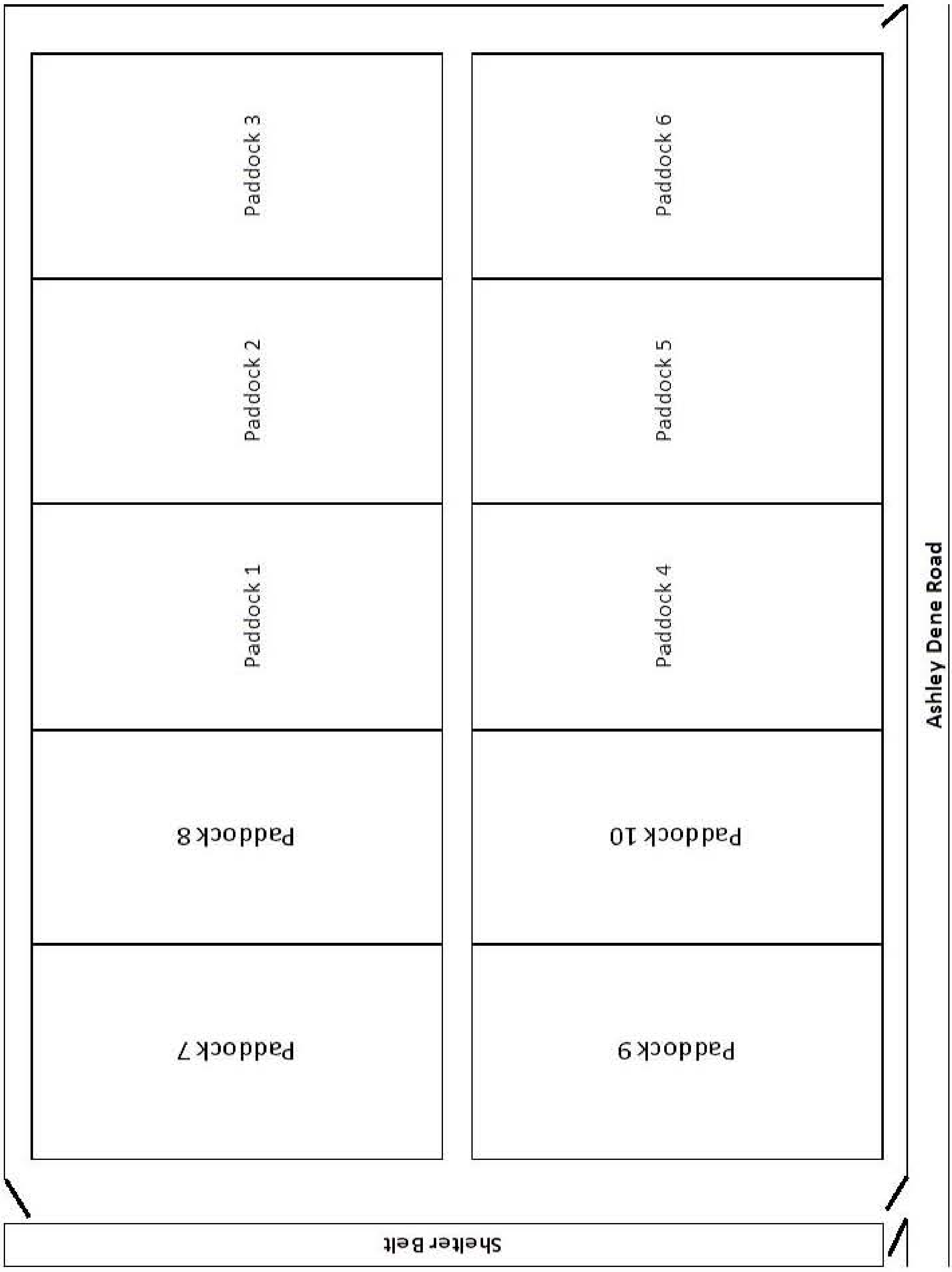
Appendix 2 Trial plan for both Experiments 1 and 2. Each cultivar name represents the plot in which it was sown into. Paddock rotation is shown for each of the two experiments.



Appendix 3 Experimental area, showing plot numbers for both Experiments 1 and 2.



Appendix 4 Experimental area, showing main paddocks for both Experiments 1 and 2.



Appendix 5 Dry matter calibration cuts taken from 0.2 m² quadrats placed in each one 'Stamina' plot per replicate, per sampling date, to determine the relationship between height and dry matter. The equation used for determining the relationship is also stated on the figure.