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Dry matter production of lucerne (Medicago sativa L.) under rotational grazing at Ashley Dene

A dissertation
submitted in partial fulfillment
of the requirement for the Degree of
Bachelor of Agricultural Science with Honours

at Lincoln University
by
S. M. Bennett

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Disclaimer

For the purpose of data collection and trial involvement for this dissertation, I was involved with measurements and data collection from 27 February 2012 to 27 June 2012. I was not involved with any measurements taken from the beginning of the 2011/2012 season until this point or any of the soil water measurements.
Lucerne (Medicago sativa L.) is a key legume for dryland farming systems in New Zealand. This experiment compared dry matter production of seven lucerne cultivars across six paddocks in a rotationally grazed system. Differences were observed in the dry matter production across the entire experiment. ‘Kaituna’ and ‘Stamina 5’ produced total annual yields of 13.3 t DM/ha, compared with 11.4 t DM/ha from ‘Runner’. Season had the greatest influence on yield, with the 48% of annual production occurring in spring. Timing of grazing also impacted on dry matter production. In the first rotation Paddock 6 was grazed 28 days after Paddock 1, thus accumulated a further 2.9 t DM/ha. Paddock 6 also had a greater plant available water capacity (PAWC) than Paddock 1, which created a 1.5 t DM/ha yield difference. The greatest influence on cultivar differences was winter dormancy. ‘Stamina 6’ was more winter active (dormancy rating 6), thus was the highest yielding cultivar in the beginning of spring (3.2 t DM/ha). ‘Runner’ was a winter dormant cultivar (dormancy rating 3), thus produced 2.4 t DM/ha in the first rotation. The average nitrogen content of the cultivars was greatest for ‘Stamina 5’ (544 kg N/ha) and lowest for ‘Rhino’ (503 kg N/ha). It was concluded that ‘Kaituna’, ‘Stamina 5’ or ‘Stamina 6’ could be sown as their winter activity ensured they had greater production in early spring and autumn. These three cultivars had an average nitrogen content of 3.3% and an ME content of 10.4 MJ ME/kg DM. The timing of grazing of the first stand should not be delayed as the impact on the quality of the last stand in the rotation is a serious consequence of this.

**Keywords:** Alfalfa, season, grazing time, water use efficiency, thermal time, quality, nitrogen, rotational grazing, sheep
# Table of Contents

ABSTRACT ........................................................................................................................... i
Table of Contents .................................................................................................................. ii
List of Tables ......................................................................................................................... v
List of Figures ........................................................................................................................ vi
List of Plates ........................................................................................................................ ix
List of Appendices ............................................................................................................... x

1 INTRODUCTION ............................................................................................................. 1

2 REVIEW OF THE LITERATURE .................................................................................. 3
  2.1 Introduction ............................................................................................................. 3
  2.2 Production of lucerne ............................................................................................ 4
    2.2.1 Lucerne growth and development ................................................................. 4
    2.2.2 Seasonal growth and development ............................................................... 6
    2.2.3 Winter dormancy ......................................................................................... 7
    2.2.4 Thermal time ............................................................................................... 8
    2.2.5 Water use ..................................................................................................... 9
      2.2.5.1 Plant available water content ................................................................. 10
      2.2.5.2 Water extraction .................................................................................. 11
      2.2.5.3 Water use efficiency ........................................................................... 13
      2.2.5.4 Soil evaporation .................................................................................. 14
      2.2.5.5 Soil water deficit ................................................................................ 14
    2.2.6 Nitrogen and metabolisable energy .............................................................. 15
  2.3 Grazing of lucerne .................................................................................................. 17
    2.3.1 Rotational grazing ....................................................................................... 17
    2.3.2 Set stocking ................................................................................................ 18
  2.4 Management of lucerne ......................................................................................... 19
    2.4.1 Spring (September-November) ................................................................. 19
    2.4.2 Summer (December-February) ................................................................. 19
    2.4.3 Autumn (March-May) ............................................................................... 20
    2.4.4 Winter (June-August) ................................................................................ 20
  2.5 Experiment ............................................................................................................... 22
  2.6 Conclusions ............................................................................................................ 23

3 MATERIALS AND METHODS ...................................................................................... 24
  3.1 Experimental site ................................................................................................. 24
  3.2 Experimental area ............................................................................................... 24
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3 Experimental design</td>
<td>25</td>
</tr>
<tr>
<td>3.4 Soil fertility</td>
<td>25</td>
</tr>
<tr>
<td>3.5 Fertiliser</td>
<td>26</td>
</tr>
<tr>
<td>3.6 Meteorological data</td>
<td>26</td>
</tr>
<tr>
<td>3.7 Thermal time</td>
<td>28</td>
</tr>
<tr>
<td>3.8 Soil water budget</td>
<td>28</td>
</tr>
<tr>
<td>3.8.1 Potential soil water deficit</td>
<td>28</td>
</tr>
<tr>
<td>3.8.2 Soil water content</td>
<td>29</td>
</tr>
<tr>
<td>3.8.3 Water use</td>
<td>30</td>
</tr>
<tr>
<td>3.9 Lucerne quality</td>
<td>30</td>
</tr>
<tr>
<td>3.10 Livestock and grazing management</td>
<td>30</td>
</tr>
<tr>
<td>3.11 Weed control</td>
<td>33</td>
</tr>
<tr>
<td>3.12 Measurements</td>
<td>34</td>
</tr>
<tr>
<td>3.12.1 Dry matter measurements</td>
<td>34</td>
</tr>
<tr>
<td>3.12.2 Live weight measurements</td>
<td>37</td>
</tr>
<tr>
<td>3.13 Statistical analysis</td>
<td>37</td>
</tr>
<tr>
<td>4 RESULTS</td>
<td>38</td>
</tr>
<tr>
<td>4.1 Animal production</td>
<td>38</td>
</tr>
<tr>
<td>4.2 Dry matter production</td>
<td>38</td>
</tr>
<tr>
<td>4.2.1 Dry matter production of individual cultivars</td>
<td>38</td>
</tr>
<tr>
<td>4.2.2 Dry matter production of individual paddocks</td>
<td>41</td>
</tr>
<tr>
<td>4.3 Thermal time</td>
<td>43</td>
</tr>
<tr>
<td>4.4 Soil water budget</td>
<td>45</td>
</tr>
<tr>
<td>4.4.1 Available water</td>
<td>45</td>
</tr>
<tr>
<td>4.4.2 Soil water content</td>
<td>47</td>
</tr>
<tr>
<td>4.4.3 Water use efficiency</td>
<td>49</td>
</tr>
<tr>
<td>4.5 Lucerne quality</td>
<td>50</td>
</tr>
<tr>
<td>4.5.1 Nitrogen</td>
<td>50</td>
</tr>
<tr>
<td>4.5.2 Metabolisable energy</td>
<td>52</td>
</tr>
<tr>
<td>5 DISCUSSION</td>
<td>55</td>
</tr>
<tr>
<td>5.1 Animal production</td>
<td>55</td>
</tr>
<tr>
<td>5.2 Dry matter production</td>
<td>56</td>
</tr>
<tr>
<td>5.2.1 Dry matter production as influenced by rotation</td>
<td>56</td>
</tr>
<tr>
<td>5.2.2 Dry matter production as influenced by paddock</td>
<td>58</td>
</tr>
<tr>
<td>5.2.2.1 Differences due to PAWC</td>
<td>58</td>
</tr>
<tr>
<td>5.2.2.2 Differences due to timing of grazing</td>
<td>59</td>
</tr>
<tr>
<td>5.2.2.3 Water use efficiency</td>
<td>60</td>
</tr>
</tbody>
</table>
5.2.2.4 Water extraction ................................................................. 60
5.2.2.5 Soil type ............................................................................. 61
5.2.3 Dry matter production as influenced by cultivar ......................... 61
5.3 Thermal time ........................................................................... 62
5.4 Nitrogen status ...................................................................... 63
6 GENERAL DISCUSSION AND CONCLUSIONS ......................... 64
  6.1 General discussion ............................................................... 64
  6.2 Conclusions ......................................................................... 66
Acknowledgements ........................................................................ 67
References .................................................................................... 68
Appendices .................................................................................. 73
List of Tables

Table 3.1 Dormancy rating of cultivars used in the experiment at Ashley Dene, Canterbury: .................................................................................................................. 25
Table 3.2 Soil test results (2010/2011) for H7, Ashley Dene, Canterbury: .......................... 26
Table 3.3 Summary of grazing periods for each rotationally grazed stock class during the 2011/2012 growth season in H7, Ashley Dene, Canterbury. Ewes and lambs are denoted as ‘E and L’. Ewe hoggets denoted by ‘Ewe hghts’. Lambs 1 and 2 are different mobs. ........................................................................................................ 32
List of Figures

Figure 2.1 Mean monthly growth rates of pasture (---) and lucerne (—) over five years (from McGowan et al., 2003). ............................................................................ 4

Figure 2.2 Annual dry matter yields of six dryland pastures grown at Lincoln University. Cf = cocksfoot, Bal = balansa clover, Sub = subterranean clover, Cc = Caucasian clover, Wc = white clover, Rg = ryegrass, Luc = lucerne (from Brown et al., 2006). ............................................................................ 5

Figure 2.3 Dry matter yield in relation to water used for pasture (---) and lucerne (—) calculated from accumulated dry matter, rainfall and potential soil moisture deficit (from Kearney et al., 2010). ................................................................. 6

Figure 2.4 Growth rates of winter active (—) and winter dormant (- - -) lucerne cultivars (from South Australian Research and Development Institute (SARDI), 2012). 8

Figure 2.5 Upper (○) and lower (●) limits of water extraction for ‘Stamina 5’ seedling lucerne to 50% flowering on a Lismore stony silt loam (a) and a Wakanui silt loam (b) at Lincoln University (from Sim et al., 2012). ................................................................. 11

Figure 2.6 Water extraction (mm) for each 0.1 m soil layer from 0-2.3 m depth on a deep Wakanui silt loam (●) or a Lismore very stony loam (○) (from Moot et al., 2008). ......................................................................................................................................... 13

Figure 2.7 Crude protein (a) and metabolisable energy content (b) of the palatable (●) and unpalatable (○) fractions of lucerne herbage in relation to total standing herbage accumulated during different regrowth cycles (from Brown and Moot 2004). ........................................................................................................ 16

Figure 2.8 Nitrogen yield (kg N/ha/year) of six dryland pastures grown at Lincoln University. Cf = cocksfoot, Bal = balansa clover, Sub = subterranean clover, Cc = Caucasian clover, Wc = white clover, Rg = ryegrass, Luc = lucerne (from Mills and Moot 2010). .......................................................................................... 17

Figure 2.9 Spring node appearance (●) and stem height (◇) of a lucerne crop at Ashley Dene, Canterbury (from Moot et al., 2003). ................................................................. 22

Figure 3.1 Mean monthly air temperature (■) (a) and total monthly rainfall (■) (b) for the 2011/2012 growth season with long-term means (─) for the period 1981-2010. Data were obtained from Broadfields meteorological station (43°62’S, 172°47’E). ........................................................................................................ 27

Figure 3.2 Daily thermal time accumulation (°Cd) in relation to temperature (from Teixeira et al., 2011). ........................................................................................................ 28

Figure 3.3 Potential soil moisture deficit (PSMD, mm) between 01/07/2012 – 30/06/2012 (from Speedy, 2012). ........................................................................................................ 29

Figure 4.1 Dry matter yield (kg/ha) of ‘Kaituna’ (■), ‘Stamina 6’ (○), ‘Stamina 5’ (□), ‘AgResearch (grazing tolerant)’ (□), ‘AgResearch (high preference)’ (□), ‘Rhino’ (■) and ‘Runner’ (◇) lucerne plots in each rotation (Rotation 1: 27/09 – 02/11/2011; Rotation 2: 02/11 – 09/12/2011; Rotation 3: 05/12/2011 – 16/01/2012; Rotation 4: 13/01 – 07/02/2012; Rotation 5: 29/03 – 10/05/2012; Rotation 6: 20/06 – 27/06/2012) in H7, Ashley Dene, Canterbury. Error bars are the standard error of the mean (SEM). ...................................................................... 39
Figure 4.2 Total lucerne yields (kg DM/ha) for individual cultivars in spring (1 July 2011 – 30 November 2011) (■), summer (1 December 2011 – 29 February 2012) (□) and autumn (1 March 2012 – 30 June 2012) (kees) in H7, Ashley Dene, Canterbury. Error bar is the standard error of the mean (SEM). ...........................................

Figure 4.3 Standing lucerne dry matter (kg/ha) for Paddocks 1-6 over six rotations during the 2011/2012 growth season in H7, Ashley Dene, Canterbury. Numbers in black are the post-grazing residuals for each paddock and coloured numbers refer to the pre-grazing dry matter. The blue bars represent monthly rainfall (data taken from Broadfields meteorological station (43°62’S, 172°47’E))....

Figure 4.4 Total accumulated dry matter (kg/ha) over time for Paddock 1 (●), Paddock 2 (○), Paddock 3 (▼), Paddock 4 (△), Paddock 5 (■) and Paddock 6 (□) under rotational grazing from 27 September 2011 – 27 June 2012 in H7, Ashley Dene, Canterbury. Error bars are the standard error of the mean (SEM). .......................................................................................................................... 43

Figure 4.5 Dry matter accumulation (kg/ha) of ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (△), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne plots with increasing thermal time (°Cd) in H7, Ashley Dene, Canterbury.................................

Figure 4.6 Water extraction pattern of ‘Kaituna’ lucerne roots in the soil profile to a depth of 2.3 m, where (●) is the upper limit and (○) is the lower limit (mm) for plant available water in Paddock 1 (a) and Paddock 6 (b) in H7, Ashley Dene, Canterbury. ....................................................................................................... 46

Figure 4.7 Total accumulated dry matter (kg/ha) (a) for ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (△), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne plots from 27 September 2011 – 27 June 2012 and soil water content (b) of Paddock 1 (─) and Paddock 6 (---) (mm), monthly rainfall (mm) ( ) and thermal time accumulation (°Cd) in H7, Ashley Dene, Canterbury. Rainfall data are taken from Broadfields meteorological station (43°62’S, 172°47’E). Shaded area represents the period where no water was available for growth and dashed (--) line in (a) represents estimated growth rates based on SWC. Error bars are the standard error of the mean (SEM). ............................................................. 48

Figure 4.8 Water use efficiency (kg DM/mm water used) for ‘Kaituna’ lucerne grown in Paddock 1 (●) and Paddock 6 (□) during the 2011/2012 growth season in H7, Ashley Dene, Canterbury. Equation for regression slope: y = 976 + 34.7x \ R^2 = 0.90. Error bar is the coefficient..........................

Figure 4.9 Nitrogen content (%) of ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (△), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne at four harvest dates in the 2011/2012 growth season in H7, Ashley Dene, Canterbury. * indicates a significant difference (P<0.05) between cultivars. Error bars are the standard error of the mean (SEM). ..................................................................................................... 50

Figure 4.10 Total nitrogen yield (kg N/ha) of ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (△), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne at four harvest dates in the 2011/2012 growth season in H7, Ashley Dene, Canterbury. * indicates a
significant difference (P<0.05) between cultivars, arrows indicate calculated values based on the relationship published in Brown and Moot (2004). Error bars are the standard error of the mean (SEM). ................................................ 52

Figure 4.11 Metabolisable energy (ME) (MJ ME/kg DM) of ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (△), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne at four harvest dates in the 2011/2012 growth season in H7, Ashley Dene, Canterbury. * indicates a significant difference (P<0.05) between cultivars. Error bars are the standard error of the mean (SEM). ................................................................... 53

Figure 4.12 Total metabolisable energy (ME) (GJ ME/ha) of ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (△), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne at four harvest dates in the 2011/2012 growth season in H7, Ashley Dene, Canterbury. * indicates a significant difference (P<0.05) between cultivars, arrows indicate calculated values based on the relationship published in Brown and Moot (2004). Error bars are the standard error of the mean (SEM). ................................................ 54
List of Plates

Plate 1 View of ewe hoggets grazing lucerne in H7, Ashley Dene, Canterbury. Taken 27/04/2012 ................................................................. 33
Plate 2 Automated sward stick used for measuring sward height ........................................ 35
Plate 3 View of pre-grazing sward height in plot number 127 (‘Kaituna’) in H7, Ashley Dene, Canterbury on 9 November 2012. Growth is comparable to that in November 2011 .......................................................... 36
Plate 4 View of post-grazing sward height in plot number 1 (‘Kaituna’) in H7, Ashley Dene, Canterbury on 9 November 2012. Growth is comparable to that in November 2011 .................................................................. 36
List of Appendices

Appendix 1 Experiment plan for H7, Ashley Dene, Canterbury. The cultivar name represents the plot in which it is sown.............................................................73
Appendix 2 Experiment plan for H7, Ashley Dene, Canterbury. Numbers represent individual plot numbers.................................................................74
Appendix 3 Experiment plan showing main paddocks and paddock rotation for H7, Ashley Dene, Canterbury.................................................................75
Appendix 4 Soil map of Ashley Dene, Canterbury (red box outlines H7).................................76
Appendix 5 Change in the relationship between height and dry matter over the 2011/2012 growth season for ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (△), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□), ‘Runner’ (◆) and values published by (Moot and Smith, 2011) (●) for H7, Ashley Dene, Canterbury.................................................................77
1 INTRODUCTION

Perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) are the most commonly sown pasture mix in temperate regions of New Zealand. Under adequate rainfall/irrigation conditions they can be highly productive and persistent (Radcliffe and Cossens, 1974). However, under dryland conditions their shallow roots result in reduced access to water, decreasing the potential yield and persistence of the pasture (Brown *et al.*, 2006). Thus, a ryegrass/white clover mix provides adequate production in a summer moist environment, but their performance is insufficient when moisture and/or temperature become limiting. In particular, spring and summer are critical times in New Zealand farming systems as there is a high feed demand for weaning and stock finishing (Harris and Chu, 1985). Further, recent predictions of increased rainfall variability across New Zealand have developed the need for pastures that can outperform ryegrass in a dryland environment (Moot *et al.*, 2003). Thus, a pasture species that can utilize water efficiently and grow high quality feed in spring and summer is required. Recent research has highlighted the role lucerne (*Medicago sativa* L.) can play in this system.

The area of lucerne planted in New Zealand peaked at 220,000 ha in 1975 but subsequently declined as a result of pest and disease occurrence (Douglas, 1986). The area is currently rising again however, with the realization of the superiority of lucerne in a dryland environment. The appropriate environments in New Zealand are Central-North Otago, North Canterbury, Marlborough and Central North Island, with 90% of lucerne grown in these four regions. Other areas on the east of the main divide may also benefit from growing lucerne.

Lucerne produces superior yields of high quality feed during periods of low rainfall and high temperatures (McGowan *et al.*, 2003). The crop is capable of producing yields as high as 28 t DM/ha under non-limiting conditions (Brown, 2004). However, yield potential is dependent on location because climate and soil types differ across the country. Annual yields of 13-15 t DM/ha in North Island hill country were reported by McGowan *et al.* (2003), which is 22-130% higher than pasture yields achieved in the same area (Douglas, 1986). Annual rainfall in this region is 800-1600 mm, with free-draining soils resulting in prolonged periods of drought throughout the summer. Annual lucerne yields in the South
Island were reported to be 5-23 t DM/ha on soil types ranging from stony loess to deep alluvium silts. The average yield increase over pasture in the South Island was 55%.

Lucerne is a high quality feed, with the crude protein (CP) and metabolisable energy (ME) content found to be greater than for chicory or red clover in an experiment at Lincoln University (Brown and Moot, 2004). The crude protein content of lucerne was 0.29 g/g DM over 5 years, which was 61% higher than chicory and 16% higher than red clover over six growth seasons, from 1996-2002. The ME of lucerne averaged 11.6 MJ/kg DM, which was similar to red clover and chicory. However, the overall yield advantage of lucerne meant it produced 30% more protein and energy than the other two species and was therefore selected for ongoing research, including this study.

The primary objective of this experiment is to determine the dry matter production of seven lucerne cultivars under rotational grazing. The production will be assessed in terms of individual cultivar and paddock yields. The physiological bases for yield differences will be investigated, including the time of the start of growth in the first grazing, a soil water budget of the paddocks and thermal time requirements for each cultivar. The nitrogen and ME content of each cultivar over the 2011/2012 growth period will also be examined to determine the quality of the feed consumed and whether variation in growth at the beginning of the season has an impact on herbage quality. Using this information, recommendations on the management of a lucerne stand with regards to grazing time and water availability will be made with the intention of achieving maximum production of both lucerne and grazing livestock.

This dissertation is written in six chapters, with the literature review followed by materials and methods, results and discussion. The general discussion then examines findings from this experiment in the wider context of lucerne in New Zealand.


2 REVIEW OF THE LITERATURE

2.1 Introduction

Lucerne (*Medicago sativa* L.), also known in North America as alfalfa, is a perennial flowering plant belonging to the Fabaceae family (Irwin *et al.*, 2001). The lifespan of the crop can exceed 20 years and is influenced by cultivar, climate and management. The crop originates from a temperate zone in the valley of Euphrates, with a pronounced arid continental climate that has cold winters and hot, dry summers (Iversen and Meijer, 1967). As a result, lucerne is adapted to an environment where moisture is only accessible from deep in the soil for a greater extent of the year. The deep tap root associated with the species allows water extraction from deeper soil layers, thus increased drought tolerance compared with more common temperate pasture species (Charlton and Stewart, 2006). The erect growth habit of lucerne makes it suitable for grazing by sheep, cattle and deer.

Lucerne has the ability to fix nitrogen as a result of a symbiotic relationship between the plant and the rhizobia residing in the root nodules (Ledgard and Steele, 1992). It was reported a lucerne crop could fix an average of 160 kg N/ha/year. The crop also has a superior water use efficiency (WUE) compared with grass-based pasture (Moot *et al.*, 2008). WUE can be defined as the ratio of total dry matter accumulation to the total water input in to the system. The average lucerne WUE over three commercial dryland sites during spring, summer and autumn was 14.2 kg DM/ha/mm water used, compared with 8.9 kg DM/ha/mm water used for ryegrass (Kearney *et al.*, 2010). Water is used more efficiently by lucerne due to its nitrogen fixation abilities, as the plant is seldom nitrogen deficient.

During summer lucerne produced 62% more forage than pasture in a study of North Island hill country by McGowan *et al.* (2003) (Figure 2.1). As a result of its superior production, lucerne is able to provide greater live weight gains for grazing livestock. Live weight gains of sheep grazing lucerne at Lincoln University were 33-42% higher than sheep grazing grass-based pastures (Mills *et al.*, 2008). Lambs grazing lucerne during summer at Lincoln University had an average live weight gain of 160 g/head/day, compared with only 65 g/head/day for lambs grazing ryegrass/white clover.
2.2 Production of lucerne

2.2.1 Lucerne growth and development
Lucerne growth refers to the accumulation of dry matter as a result of light interception and the partitioning of the products of photosynthesis (Moot et al., 2003). Development of the plant involves the stage of maturity within a regrowth cycle in reference to vegetative nodes, flower bud initiation and flower opening. Apices or growing points are located on the top of each stem and this is where the production of new nodes and attached leaves occurs. Following defoliation, regrowth takes place from basal buds on the crown of the lucerne plant. The initiation of basal buds is stimulated by the remobilization of stored carbohydrate and amino acid reserves in the tap root. This occurs about the time of flower initiation and in response to canopy removal by cutting or grazing. The removal of the green canopy allows more red light to the crown, which decreases the red:far red light ratio to stimulate bud development. During the regrowth phase light interception is initially low, due to the production of small leaves on the lower nodes. This phase is known as the lag phase and will be reduced under high temperatures due to more rapid leaf production and expansion. Following the lag phase, growth rates become linear and growth is determined by temperature and water availability. At this point bud initiation and flowering become
the main focus of the plant. When lucerne becomes reproductive, shoot dry matter accumulation is reduced in favour of increasing crown and tap root reserves.

Lucerne crops have been consistently higher yielding than other pasture species (Brown et al., 2006). Figure 2.2 showed that in a dryland experiment lucerne had a 65% average annual yield advantage (P<0.01). The primary reason for the superior growth of lucerne over other pasture mixes was its greater WUE compared with other species.

![Figure 2.2 Annual dry matter yields of six dryland pastures grown at Lincoln University. Cf = cocksfoot, Bal = balansa clover, Sub = subterranean clover, Cc = Caucasian clover, Wc = white clover, Rg = ryegrass, Luc = lucerne (from Brown et al., 2006).](image)

Lucerne was also the most responsive species to summer rainfall on commercial farms in Central Otago (Kearney et al., 2010). The greatest difference in WUE between lucerne and pasture was during summer when lucerne had an average WUE of 12.6 kg DM/ha/mm, compared with only 4.8 kg DM/ha/mm for pasture (Figure 2.3). These values were based on dry matter accumulation, rainfall and potential soil moisture deficit (PSMD) over the growing season and thus are lower than measured WUE values.
2.2.2 Seasonal growth and development

Dry matter production of lucerne exhibits a distinctive seasonal pattern (Brown, 2004). Spring lucerne yields were reported by Baars et al. (1975) to be most highly correlated with spring rainfall ($r=0.81$), summer yields with summer rainfall ($r=0.89$) and autumn yields also with summer rainfall ($r=0.91$). When water was non-limiting, it was suggested lucerne growth is closely related to temperature and radiation (Moot et al., 2008). At a North Island hill site McGowan et al. (2003) reported that ‘Rere’ lucerne yielded 3,949 kg DM/ha in spring (September-November), compared with 5,454 kg DM/ha in summer (December-February), 2,082 kg DM/ha in autumn (March-May) and 1,457 kg DM/ha in winter (June-August). These figures agree with other data, which stated 36% of lucerne production occurred in spring, 49% in summer and 15% in autumn (Baars et al., 1975). As temperature increases during September shoot growth rates increase. For example, Moot et al. (2003) showed that between September and January linear growth rate of lucerne increased from approximately 30 kg DM/ha/day to over 100 kg DM/ha/day. Maximum daily growth rates of up to 158 kg DM/ha/day were reported for the months of December and January (Brown, 2004). Negligible growth was reported for periods of 100-120 days beginning around the end of May/start of June in the colder regions of New Zealand.
(Douglas, 1986). The temperature induced difference in pasture growth rates occurred as a result of a shift in dry matter allocation from the roots to the shoots (Brown, 2004). During spring, stored carbohydrates were remobilized in the initiation of new basal buds after defoliation or are lost in respiration. Regardless of rotation length (28 or 42 days), root dry matter was reduced in spring and summer (Teixeira et al., 2008). In contrast, dry matter partitioning to roots increased during autumn, leading to reduced shoot growth in this period. This allows reserves to be replenished for overwintering and spring regrowth. Thus it has been advised that defoliation frequency is reduced in March-May to allow the accumulation of root reserves that are required to support the following spring regrowth (Moot et al., 2003).

The vegetative and reproductive development of lucerne also displays a seasonal trend (Brown, 2004). In spring, the rate of vegetative node appearance increased due to rising temperatures. ‘Kaituna’ lucerne exhibited a constant phyllochron of 37±5 °Cd in winter, spring and summer. Consequently, node appearance occurred every second day at a mean summer temperature of 17.5 °C. In autumn, the phyllochron increased up to 60 °Cd, reducing the rate of canopy expansion. The phyllochron values reported were similar to those found by Teixeira et al. (2007), of 34 °Cd/leaf in spring-summer and 40-65 °Cd/leaf in autumn-winter. The area of the largest primary leaf was 60% lower in spring than in summer as a result of sub-optimal temperatures for development during leaf formation in winter (Teixeira et al., 2007).

2.2.3 Winter dormancy
The ability of lucerne to survive through the winter period and remain productive the following season is referred to as winter hardiness (Brouwer et al., 1998). Winter hardiness involves the interaction of numerous morphological, physiological and environmental factors, as well as genetic variability within the species. Lucerne cultivars differ in their activeness throughout winter and are rated as such. Winter active cultivars have a greater abundance of soluble sugars and stress-related translation products, as well as differential accumulation of protein, DNA and RNA (Castonguay et al., 2006). Such plants can produce up to 20% of their annual growth during winter by limiting the freezing that occurs in extracellular spaces (Belanger et al., 2002). Extracellular freezing results in a vapour-pressure gradient between intra- and extracellular compartments that shifts water to the outside of the cell, thus lowering the freezing point of the cytosol. The germplasm of
more winter-active cultivars was concluded to have lower specific conductivity than winter dormant germplasm due to reduced leakage of electrolytes (such as K+) from the cells.

Dormancy ratings are ascribed to lucerne cultivars depending on their winter activity, with higher dormancy ratings indicative of greater winter activity. Winter activity is measured using the regrowth height of lucerne during winter. Figure 2.4 illustrates the higher growth rates of winter active cultivars during autumn, winter and early spring (South Australian Research and Development Institute (SARDI), 2012). These cultivars generally have lower persistence than winter dormant cultivars but higher WUE in early spring. Winter dormant cultivars have lower growth rates from autumn-early spring, are more adapted to handle cold and wet conditions and can generally persist for 10 years longer than winter active cultivars.

Figure 2.4 Growth rates of winter active (−) and winter dormant (- - - ) lucerne cultivars (from South Australian Research and Development Institute (SARDI), 2012).

2.2.4 Thermal time
Thermal time (Tt) (°Cd) is a commonly used method for determining the relationship between temperature and plant development between different stages of growth (Moot et al., 2000). Both Tt and base temperature (Tb, the threshold below which no development occurs) are species dependent and there are different models used in determining these relationships. At its simplest, Tt is calculated as the mean temperature minus Tb. The broken-stick method for lucerne involves using different rates of Tt accumulation (Teixeira et al., 2011). Tt is assumed to be zero for temperatures below a Tb of 1.0 °C. Tt then
accumulates at a rate of 0.7 °Cd°C⁻¹ until 15 °C, from where it gathers at a rate of 1.0 °Cd°C⁻¹ until the optimum temperature (T_{opt}) of 30 °C. Beyond this Tt decreases at a rate of 2.4 °Cd°C⁻¹, to a maximum of 40 °C.

Lucerne growth was found to be linear against thermal time and accumulated of 4.23 kg DM/°Cd for a defined period of 213 days at Lincoln University (Morris, 2011). This was a lower rate than other pasture treatments (e.g. cocksfoot/sub clover 5.73 kg DM/°Cd) but the response occurred over a longer period of time. Moisture stress led to reduced growth rates during summer, when lucerne grew at a rate of 1.0 kg DM/°Cd, which was lower than the cocksfoot/Caucasian clover mix (1.1 kg DM/°Cd) but higher than the ryegrass/white clover mix (0.8 kg DM/°Cd). Similar results from Lincoln University suggested lucerne grew at a rate of 2.4 kg DM/ha/°Cd for 1854 °Cd over the summer period (Tonmukayakul, 2009). Using this data an annual growth rate of approximately 3 kg DM/°Cd could be calculated.

The Tt required for flowering to be reached is influenced by photoperiod (Moot et al., 2003). As lucerne is a long-day plant, the period of Tt between defoliation and flowering increases as day length decreases. When the mean photoperiod decreased from 16 to 13.5 hours the Tt requirement for this period increased from 350 to 550 °Cd. In contrast, the Tt requirement for early-bud decreased by 67 °Cd for each hour change in photoperiod as it increased from 13.5 to 16.5 hours for ‘Kaituna’ lucerne (Moot et al., 2001).

Further to this, Tt requirements differed between seedling and regrowth lucerne crops (Teixeira et al., 2011). For seedling crops (those from sowing to first defoliation), the Tt taken to reach 50% buds visible stage was 1200 °Cd at a photoperiod of 10 hours and declined to 500 °Cd at a photoperiod of 16.5 hours. For regrowth crops the Tt requirement was much lower, beginning at 700 °Cd at a 10 hour photoperiod and declining to 270 °Cd at >14 hour photoperiod. Following the bud visible stage development was primarily driven by temperature, with a Tt requirement of 161 °Cd for seedling crops and 274 °Cd for regrowth crops.

### 2.2.5 Water use

The growth of lucerne in a dryland environment is largely dependent on its ability to extract water from the soil (Sim et al., 2012). The deep rooting ability of lucerne allows it
to survive under water limiting conditions where other plants would dry out. Lucerne yield is less sensitive to rainfall than a ryegrass/white clover pasture (Brown, 2004). The relative yield advantage of lucerne increased from 25-105% when rainfall decreased from 700-300 mm. In a 350-550 mm annual rainfall zone in the South Island it was found that lucerne had a 40% yield advantage over grass-based pasture (Douglas, 1986). This decreased to a 20% advantage when the annual rainfall increased to 600-800 mm. It was stated that relatively dry soil conditions induce a more extensive root system in lucerne (Jodari-Karimi et al., 1983). Non-irrigated plants produced 80% more root weight than irrigated plants.

2.2.5.1 Plant available water content

The plant available water content (PAWC) is significantly influenced by soil type, which in turn impacts on potential lucerne yield (Sim et al., 2012). Wakanui silt loam soils typically have a high PAWC. In contrast, Lismore stony silt loam soil has a low PAWC, thus plants cannot extract as much water from the soil. Seedling lucerne grown on a Wakanui silt loam used 86 mm of water from the soil, compared with only 45 mm used by lucerne grown on a Lismore stony silt loam (Figure 2.5). As a result of the low PAWC on the Lismore soil, lucerne compensated for less water by reducing canopy expansion rates. This led to a decline in the light interception available for photosynthesis and thus reduced growth rates. Seedling crops have lower water extraction than regrowth crops due to a smaller root mass (Brown, 2004). It was reported that the water extraction of a regrowth crop was 20% greater than that of a regrowth crop, thus the water extraction in Figure 2.5 was not to the full capacity of the soil. A lower limit of PAWC of 0.5 mm³/mm³ at a depth of 0.7-0.9 m was reported for a Wakanui silt loam at Lincoln University as a result of a sand layer. The layers of finer material underlying this layer would cause water to perch in the large pores of the sand and become readily available for plant extraction. A similar sand layer was reported below 2 m, explaining the higher PAWC of 0.15 mm³/mm³, than in overlying layers.
2.2.5.2 Water extraction

Soil water extraction is calculated using the total soil water content of the profile (PSWC) and the drained upper limit (DUL) (Brown et al., 2005). DUL is also referred to as field capacity (FC) and can be defined as “the state of the soil after rapid drainage has effectively ceased and the soil water content has become relatively stable” (McLaren and Cameron, 1996). The lower limit (LL) or permanent wilting point (PWP) of the soil occurs when the soil is completely dry and is defined as “the amount of water in the soil at which plants are permanently wilted”. When the LL is taken away from the DUL it gives the PAWC of the soil at a given time and depth. The DUL for the soil profile above 1 m can usually be determined from late July to early August in New Zealand when the soil has been fully re-wetted after winter and plant water uptake is minimal (Brown et al., 2005). To do this the volumetric water content (θ) of each soil layer is determined about five days after the last rainfall event to allow for any drainage to occur. For soil layers below 1 m depth seasonal recharge is less reliable, thus the DUL is taken as the highest stable θ for each layer. The extraction pattern of water from the soil is influenced by the moisture in the overlying layers of the soil (Brown et al., 2009). In their study, when water was readily available, such as under irrigation, little water was extracted below a depth of 1.3 m. In the

Figure 2.5 Upper (○) and lower (●) limits of water extraction for ‘Stamina 5’ seedling lucerne to 50% flowering on a Lismore stony silt loam (a) and a Wakanui silt loam (b) at Lincoln University (from Sim et al., 2012).
dryland treatment where water was limiting, lucerne continued to extract water down to a depth of 2.3 m. As a result it was suggested that the water demand from individual layers of the soil controlled the depth of water extraction. The water was preferentially used in the top layers and progressed downwards through the soil as the top layers dried out. It was reported that irrigated lucerne extracted 85% of its water from the top metre of soil, and only 10% and 5% from the second and third metres (Brown and Tanner, 1983). Lucerne that was exhibiting water stress obtained 42% of its total water from the first metre of soil, 45% from the second metre and 13% from below two metres. A further example of this occurred when one lucerne treatment experienced 296 mm more rainfall than another (Brown et al., 2009). As a result the rainfall was able to be extracted from the top layers of the soil during the early summer period and water extraction to 2.3 m did not occur until February. The lucerne that received less rainfall began extracting water to 2.3 m in November. Numerous literature sources supported the theory that lucerne extracts water from a greater depth than the measured 2.3 m (Brown, 2004; Brown et al., 2005; Moot et al., 2008; Brown et al., 2009). Firstly lucerne extracted 18 mm of water at a depth of 2.2-2.3 m, suggesting there may be further water below this depth. Assuming 18 mm of water could be extracted from each 100 mm layer below 2.3 m, it was expected lucerne would have used a total of 420 mm to a depth of 2.7 m. Daily water extraction increased from zero in July to 2.3 mm/day in December, then dropped back to 2 mm/day in January (Brown et al., 2005). At this point extraction had reached a depth of 1.9 m (Brown, 2004). From February to April water extraction continued to decline until it reached approximately 0.2 mm/day in May (Brown et al., 2005). During this time lucerne had 0.2-0.5 mm/day greater water extraction than red clover or chicory as it continued to extract water from greater depths, allowing it to have superior water use (WU). Water extraction of lucerne is also dependent on soil type (Moot et al., 2008). Figure 2.6 illustrates the water extraction pattern of an established lucerne stand grown on two soil types to a depth of 2.3 m. The Wakanui silt loam had greater water storage capacity than the Lismore very stony loam, thus the lucerne was able to extract a maximum of 20 mm more water than on the Lismore soil. On both soils water was extracted to a depth of 2.3 m; however only 131 mm of stored water was extracted on the Lismore soil compared with 328 mm on the Wakanui soil.
2.2.5.3 Water use efficiency

A theoretical maximum value for WUE was defined as the net photosynthesis of a pasture relative to the amount of water transpired, but can only be achieved when no soil evaporation or drainage occurs (Moot et al., 2008). A ryegrass pasture grown under non-limiting conditions was reported to have a typical annual WUE of 20 kg DM/ha/mm of potential evapotranspiration (PET). A dryland lucerne crop grown on a deep Wakanui silt loam soil had an annual WUE of 40 kg DM/ha/mm. The range in WUE values among crops has been ascribed to differences in the soil water holding capacity (WHC), the plants ability to extract water and its efficiency of water utilization in producing dry matter. For a dryland crop this is narrowed to a combination of the WHC of the soil and the depth at which the roots can extract water. The greater annual WUE for dryland lucerne was a result of the extraction of 328 mm of water to a depth of at least 2.3 m. The high water storage capacity of the Wakanui silt loam allowed this to occur. In a study at Lincoln University lucerne had an annual WUE of 20.6 kg DM/ha/mm, compared with 14.7 kg DM/ha/mm for a cocksfoot/sub clover pasture (Tonmukayakul, 2009). This was the result of greater lucerne yields (>14 t DM/ha/year) compared with the cocksfoot/sub clover pasture (9 t DM/ha/year). Further reasoning for the increased WUE observed in legumes compared with grasses is the higher herbage N content in legume species (Moot et al.,

**Figure 2.6** Water extraction (mm) for each 0.1 m soil layer from 0-2.3 m depth on a deep Wakanui silt loam (●) or a Lismore very stony loam (○) (from Moot et al., 2008).

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*Figure 2.6* Water extraction (mm) for each 0.1 m soil layer from 0-2.3 m depth on a deep Wakanui silt loam (●) or a Lismore very stony loam (○) (from Moot et al., 2008).
This allows the photosynthetic efficiency per unit of leaf area to be maximized, thus increasing the rate of photosynthesis per unit of water used. Douglas (1986) reported that lucerne was an inefficient user of water due to its low stomatal resistance to water transpiration, thus had higher rates of transpiration than perennial ryegrass. Lucerne had a transpiration rate of 6.98 g DW/leaf/ha, compared with 4.74 g DW/leaf/ha for ‘Ruanui’ ryegrass when both were grown under the same conditions (Forde et al., 1977).

2.2.5.4 Soil evaporation

Soil evaporation involves the diffusion of water vapour through the soil and is dependent on crop cover and soil wetness (Brown, 2004). Presence of a crop canopy reduces soil evaporation as it intercepts solar radiation, reducing the heat of the soil and wind speed at the soil surface. In a summer dry environment, rainfall during the February to April period is often considered ineffective (Moot et al., 2008). A combination of warm soil and low herbage cover leads to increased soil evaporation. It was reported that the first 10-20 mm of any rainfall event at this time is rapidly evaporated from the soil. Further to this, frequent defoliation of a crop may lead to periods of 10-20 days of incomplete ground cover, thus increasing evaporation of moisture from the soil (Brown, 2004).

2.2.5.5 Soil water deficit

Lucerne creates a greater soil water deficit (SWD) than other plants due to its greater water extracting ability (McCallum et al., 2001). Lucerne swards were reported to have a maximum SWD of 403 mm, which was 62 mm greater (P<0.05) than chicory or red clover (Brown et al., 2005). This is indicative of greater water extraction (Brown, 2004). Water deficits were stated to reduce lucerne yields due to the induction of water stress. Water stress can be defined as “the induction of cell turgor below a maximum potential” and occurs when the lucerne roots are unable to provide water to the plant at the rate it is being transpired from the tops. Yield reduction occurs as a result of a negative impact on stem density, height and leaf size (Brown and Tanner, 1983). The dry weight of irrigated plants was reported at 414 g/m² with a stem height of 64.4 cm, compared with 247 g/m² for water stressed plants with a stem height of 48.0 cm. Water stress thus reduced leaf area and internode length by 39 and 48% respectively, compared with irrigated plants. The lucerne stomata close during water stress to control water loss, at the expense of photosynthesis. The transpiration demand follows a diurnal cycle, thus under mild water stress stomatal closure will only occur during the middle of the day (Brown, 2004). As water stress
becomes greater lucerne is unable to maintain cell turgor, resulting in the stomata remaining closed for longer and this then increases the detrimental effects on yield.

2.2.6 Nitrogen and metabolisable energy
Lucerne herbage produces high levels of protein, with reported accumulated protein yields of around 2000 kg/ha/year (Douglas, 1986). It was reported that 25 kg N was fixed per tonne of dry matter for legumes (Peoples and Baldock, 2001). Values for lucerne shoot nitrogen fixation reported varied between 4 and 284 kg/ha/year, with an average of 108 kg N/ha/year. A protein yield of 2000 kg/ha/year would be equivalent to 320 kg N/ha/year. Recalculating this value, at an average reported yield of 13 t DM/ha/year (Douglas, 1986), 24.6 kg/t DM nitrogen was fixed, which is in line with the value reported above. The leaves and upper stem material of lucerne contain the highest quality material (Brown, 2004). The lower stems have a higher proportion of indigestible lignin, thus are of lower quality. As a lucerne plant matures the proportion of stem increases, resulting in a drop in overall quality. Grazing livestock selectively graze leaves and soft stem first so it is possible to maintain high production on mature lucerne provided the stock are shifted once they have eaten the highest quality fraction of the forage.

Brown and Moot (2004) reported the palatable CP content followed a regression equation equal to 0.26 + 0.19 * DM (Figure 2.7 (a)). When yields are greater than 2.4 t DM/ha any remaining dry matter can be considered unpalatable. A comparison between irrigated lucerne and chicory or red clover monocultures indicated that the utilized proportions of a lucerne sward provided 30% greater CP and ME to grazing livestock than the other two species. The annual average nitrogen content (%) of lucerne was concluded to be 4.0% six years after sowing and 3.8% seven years after sowing (Mills and Moot, 2010). This was similar to the nitrogen content in other grass/legume mixes, such as cocksfoot/subterranean (sub) clover, which had a higher nitrogen content in the legume component (4.2% and 4.3% six and seven years after sowing), but a lower nitrogen content in the grass component (3.4% and 3.5% six and seven years after sowing). As a result of the superior dry matter yield from lucerne, the nitrogen yield of this crop was 250 kg/ha higher than the other grass/legume mixes (Figure 2.8). It was reported that the lucerne herbage provided nitrogen yields of 510 kg N/ha/year, compared with 150 kg N/ha/year for the ryegrass/white clover sward. The higher nitrogen yield provides production advantages for
the lucerne in terms of protein intake of grazing livestock and increased WUE (Section 2.2.5.3).

Figure 2.7 (b) suggests the palatable ME content could be calculated as 11.9 * DM (Brown and Moot, 2004). It was reported that the annual average ME of lucerne seven years after sowing was 11.0 MJ/kg DM (Mills and Moot, 2010). This was lower than what was stated for other grass/legume mixes. Cocksfoot/sub clover had an annual ME content of 11.3 MJ/kg DM six and seven years after sowing. However, the lucerne sward accumulated an average 134 GJ ME/year, compared with an average of 88 GJ ME/year for the cocksfoot/subterranean clover mix.

Figure 2.7 Crude protein (a) and metabolisable energy content (b) of the palatable (●) and unpalatable (○) fractions of lucerne herbage in relation to total standing herbage accumulated during different regrowth cycles (from Brown and Moot 2004).
2.3 Grazing of lucerne

2.3.1 Rotational grazing
Successful lucerne management fits the grazing regime to the natural growth pattern of the crop (O'Connor, 1970). Rotational grazing is in line with the growth pattern of lucerne (Janson, 1974). A high proportion of the lucerne was able to grow uninterrupted for a longer period of time. A cut taken four weeks after rotational grazing was finished showed 30% greater regrowth than from a set-stocked stand. The speed of the rotation influences dry matter production and survival (Brownlee, 1973). O’Connor (1970) recommended a four paddock rotation over an eight week cycle was optimal for lucerne production. This was in contrast to Brownlee (1973), who proved an eight paddock rotation had a feed availability of 223 kg DM/head after two years rotational grazing in New South Wales, compared with 165 and 113 kg DM/head for the six and four paddock rotations. Further to this, at the end of the two year period survival of lucerne in the eight paddock rotation was 35%, compared with only 28% and 1% for the six and four paddock rotations. This was extremely low survival due to severe drought; however results are still representative of the increased lucerne survival when given a longer period of recovery. Lucerne grazed

Figure 2.8 Nitrogen yield (kg N/ha/year) of six dryland pastures grown at Lincoln University. Cf = cocksfoot, Bal = balansa clover, Sub = subterranean clover, Cc = Caucasian clover, Wc = white clover, Rg = ryegrass, Luc = lucerne (from Mills and Moot 2010).
every 28 days was reported to have a reduced annual shoot yield of 50% when compared with the 23 t DM/ha produced by lucerne that was grazed every 42 days (Teixeira et al., 2008). This reduction in yield occurred as a result of a reduction in the amount of photosynthetically active radiation (PAR) that was intercepted when crops were defoliated more frequently. Rotational grazing every 42 days allowed maximal light capture, thus canopy expansion and yield (Teixeira et al., 2007).

The length for which the stand may be grazed is influenced by the maturity of the plant (Douglas, 1986). It was concluded that when lucerne was in the mid-vegetative to early-bud stage it could be grazed over 14 days without newly emerging basal shoots becoming vulnerable to defoliation, while at the 1% flowering stage grazing for only 7 days was recommended. Increasing grazing time reduced stand production by 29% relative to a 4 day grazing period. The 14 day grazing period was also reported to provide the most regrowth over the following 36 day rest period. Reducing grazing time to only 2-4 days reduced the grazing pressure on less palatable weed species, thus reducing stand life. Crops that were grazed more frequently had a lower interception of PAR, thus reduced canopy expansion (Teixeira, 2006). Repeated defoliation at 28 days during spring and summer resulted in maximum LAI in only 20% of the regrowth cycles, compared with 65% in crops grazed more laxly.

2.3.2 Set stocking
Set stocking of lucerne for a prolonged period of time during periods of active growth was reported to reduce stand productivity and persistence (Janson, 1974). The herbage availability of a stand that had been set stocked for six weeks was 630 kg DM/ha, compared with 1180 kg DM/ha for a rotationally grazed stand. When livestock were set stocked they grazed down the lucerne relatively evenly, first consuming the apices and upper leaves, before eating down the stem. Eventually the lower stem material was rejected in favour of newly appearing growth developing from the base of the plant. Set stocking does not fit the growth pattern of lucerne as growth of the immature lucerne is consistently interrupted and new shoots are vulnerable to decapitation. Continuously grazed areas of lucerne were also reported to produce high weed yields the following season, with little lucerne produced the following spring (O'Connor, 1970). It was reported that set stocked lucerne at Ashley Dene (Canterbury) stoked at a rate of 40 SU/ha continued to grow at a faster rate than consumption following the introduction of stock in
the beginning of October until the end of October, to a peak of 1820 kg DM/ha, after which yield declined. When stock were removed in early December dry matter was only 270 kg/ha (Speedy, 2012).

2.4 Management of lucerne

2.4.1 Spring (September-November)
Spring management of lucerne should aim to maximize live weight gain of grazing livestock or maximize herbage yield and quality for forage conservation (Moot et al., 2003). Temperature, solar radiation and water are generally non-limiting for crop growth during this time and defoliation frequency should be based on crop growth. It is possible that in a six paddock rotation grazing may need to occur in one or more paddocks before they reach their maximum dry matter potential. If possible stands that are in need of renewal should be grazed first. This is in line with Janson (1974), who stated when grazing commences stock should begin on the most mature stand, which were generally ungrazed or early-grazed the previous autumn/winter. Defoliation at a height of 25-30 cm compromises between maximizing stem extension and meeting animal demand (Moot et al., 2003). The timing of the first spring grazing was reported to determine stand production for the remainder of the season (Janson, 1974). Delaying the beginning of grazing at Winchmore by two weeks until 6 September increased lucerne yield over the spring period by 24%. White and Lucas (1990) reported the first lucerne grazing should not occur until late October to eliminate any yield depression from late autumn grazing. This is not realistic in practice as lucerne stands are commonly required as soon as early September in dryland farming systems throughout New Zealand as a high quality feed source for lactating ewes and young stock. Grazing the lucerne prior to it reaching the ideal height resulted in reduced LAI due to a reduction in intercepted PAR (Teixeira, 2006). The duration of grazing should avoid damaging new stems while encouraging crop regrowth (Moot et al., 2003). The ideal rotation should aim to remove all herbage within 7-10 days, as grazing for any longer may damage newly developing basal buds. When grazing occurred for 12 days, over 70% of lucerne apices were removed (O'Connor, 1970).

2.4.2 Summer (December-February)
From early spring until the end of summer lucerne should be utilized for grazing to maximize live weight gains of grazing stock (Moot et al., 2003). The number of crop regrowth cycles during this time is dependent on the availability of moisture from seasonal
rainfall. A lucerne crop grown on a Wakanui silt loam with a PAWC of 350 mm yielded over 7 t DM/ha over three regrowth rotations. Lucerne grown on stony Lismore soil with a PAWC of 150 mm had a total annual yield of no greater than 7 t DM/ha, with the majority of growth occurring in spring. Section 2.2.5 indicated that water stress reduced the production of lucerne as a result of a negative impact on stem density, height and leaf size (Brown and Tanner, 1983). If this occurs in mid-summer crops should be hard grazed to prevent the loss of current production through senescence. Defoliation such as this will allow a water stressed crop to slowly accumulate nodes on the basal buds and enable a rapid rainfall response. As in spring, priority stock should be rotationally grazed for no longer than 7-10 days to ensure they are consuming only high quality feed. Remaining residual may be cleaned up by lower priority or dry stock. Stock should be moved between lucerne paddocks in a 4-5 paddock rotation to allow 35±4 day’s regrowth.

2.4.3 Autumn (March-May)
In autumn, lucerne management should focus on managing the stand for persistence and production the following year. Growth is reduced over this period due to declining temperature and photoperiod, which increases the dry matter partitioning to roots (Section 2.2.4). Lucerne should be allowed to reach at least 50% flowering in early autumn to maximize these root reserves. Grazing of autumn regrowth should be delayed until after a significant rainfall event to assist the plant in recovering reserves and developing a canopy to reduce the germination of winter weeds. Expansion of the lucerne canopy utilizes any rainfall at the expense of these weeds. Such rainfall may not occur in a dryland environment, thus the lucerne should be spelled earlier to maximize growth for the remainder of the season. Janson (1974) suggested if lucerne is required to be grazed during autumn, the sooner it can be grazed and closed up the better. This is because lucerne that was grazed in autumn produced 2210 kg DM/ha the following spring, while lucerne grazed in winter produced 11% less dry matter at this time. Lucerne that was ungrazed during autumn and winter yielded 2640 kg DM/ha the following spring. Lucerne growth generally ends as hard frosts begin in late autumn as the growing point at the top of the plant is damaged.

2.4.4 Winter (June-August)
Winter management of lucerne is related to weed control and ensuring crop regrowth can begin as early in spring as possible (Moot et al., 2003). A ‘clean-up’ graze of residual
lucerne herbage should occur during late June to early July to control over-wintering aphids (White and Lucas, 1990). Any yield depression from a late grazing such as this would be more than offset by increased spring yield as a result of reduced aphid populations. By October, the number of aphids per stem reportedly decreased from 87 to 29 as a result of June grazing; however by this stage any aphids present would have already caused considerable damage to the stand. Herbicide application should occur 7-10 days after grazing to prevent the development of annual weeds such as shepherd’s purse (*Capsella bursa-pastoris*) and storksbill (*Erodium cicutarium*) (Moot *et al.*, 2003). An unsprayed crop presented 31% more weeds than a sprayed crop. Applying herbicide as late as 31 July damaged developing lucerne buds, which was evident when growth did not begin until 14 days after the unsprayed crop.

Vegetative node accumulation during winter allows rapid stem elongation and early spring dry matter production. Thus, removing the growing point via grazing during late winter/early spring will reduce yield potential for the entire spring period. The relationship between node appearance and height over time is expressed in Figure 2.9. The number of nodes on a lucerne crop grown at Ashley Dene increased linearly from June, while height increased exponentially. Lucerne was found to require 37 °Cd/node. Low temperatures during the winter period means thermal time accumulation between nodes is slow, thus early bud removal will act negatively on node appearance.

The effect of early winter grazing on spring yields was reported to be strongly influenced by the winter activity of a lucerne cultivar (White and Lucas, 1990). When ‘Rere’ (winter active) and ‘Wairau’ (winter dormant) lucerne were grazed in June, the resulting spring production of the ‘Wairau’ was 3130 kg DM/ha, compared with 1670 kg DM/ha for ‘Rere’. The recovery of growth the following winter grazing of winter active cultivars depletes carbohydrate and nitrogen reserves almost completely, thus the low spring yield. In contrast, dormant cultivars retain high reserves throughout winter with consequently higher spring yields.
Figure 2.9 Spring node appearance (●) and stem height (◇) of a lucerne crop at Ashley Dene, Canterbury (from Moot et al., 2003).

2.5 Experiment

Based on this review of the literature there is little current information that compares modern cultivars used in New Zealand or assesses the impact of grazing on yield and water use. Thus, this dissertation reports on the dry matter yields across seven lucerne cultivars grown on a stony soil at the Lincoln University dryland research farm. The experiment has been running for three years at Ashley Dene and includes a set stocked and semi-set stocked component which will not be included in this dissertation. Results presented are for the 2011/2012 growing season.
2.6 Conclusions

- Lucerne has a superior production compared with common pasture species due to a higher WUE as a result of the interaction between greater water access, high leaf nitrogen and higher dry matter yields than other pasture species.

- The majority of lucerne growth occurs in spring (36%) and summer (49%), compared with autumn (15%).

- Growth, leaf appearance and flowering are strongly influenced by thermal time, and thermal time requirements differ depending on day length and crop maturity.

- Lucerne had superior water extraction, PAWC and WUE, with yield advantages as great as 105% over pasture in a dryland environment.

- Lucerne should be rotationally grazed rather than set stocked due to a closer match with plant growth. Crop regrowth was 30% greater on a rotationally grazed stand compared with a set stocked stand.

- Management of lucerne requires different approaches depending on season. The spring focus revolves around maximizing live weight gains and yield, while in summer growth is dependent on moisture availability. A clean-up graze should occur towards the end of autumn after the crop has been allowed to reach 50% flowering. Stands should be de-stocked over winter as minimal growth occurs during this time.
3 MATERIALS AND METHODS

3.1 Experimental site
This experiment is located in paddock H7 at Ashley Dene Research Farm, Home Block, Canterbury, New Zealand (43°65’ S, 172°32 E, 35 m a. s. l.). The soil type is a mix of Lowcliffe moderately deep and Lowcliffe stony soil (Appendix 4), both of which are poorly drained (McLenaghen and Webb, 2012). The depth of sandy gravels ranges from 0.6-1.1 metres. Below this the soil is stony to a depth of approximately 1.7 metres, at which point there is clay in the soil. The total moisture holding capacity is around 140 mm per metre of soil for the Lowcliffe moderately deep soil and approximately 70 mm per metre of soil for the Lowcliffe stony soil.

3.2 Experimental area
The experimental site was sown in ‘Grasslands Moata’ (Lolium multiflorum) in 2007/08. The site was grazed then ploughed, roto-crumbled, harrowed and rolled prior to sowing. In early November 2008 lucerne (Medicago sativa L.) was sown with three runs of an Øyjoord single cone seeder per plot. There were 28 plots within each paddock, each of 6.3 x 24.5 m.

The experiment used seven lucerne cultivars or breeding lines. These seedlots were labeled as ‘Kaituna’, ‘Rhino’, ‘Runner’, ‘CW85087’, ‘AgResearch (grazing tolerant)’, ‘AgResearch (high preference)’ and ‘Stamina’. The cultivars were chosen to give a range of winter/spring activity and grazing tolerances (Table 3.1). ‘Rhino’, ‘Runner’ and ‘AgResearch (high preference)’ are considered more winter dormant and ‘AgResearch (grazing tolerant)’, ‘CW85087’, ‘Stamina’ and ‘Kaituna’ are semi-winter active, thus are more active in late winter and early spring. ‘Kaituna’ is a standard New Zealand bred cultivar, ‘Rhino’ and ‘Runner’ are American cultivars and ‘Stamina’ and ‘CW85087’ are from Australia. Recently, PGG Wrightsons identified a labeling error on the seedlots received which affected two of the lines listed. They have confirmed the Cal West 85087 line is marketed as ‘Stamina 5’ and the seedlot labeled ‘Stamina’ was marketed as ‘Stamina GT6’. The two AgResearch breeding lines were included for their grazing attributes. PGG Wrightsons supplied the ‘Kaituna’, ‘Stamina 6’ and ‘Stamina 5’ lines as
pelleted seed with a Superstrike treatment. ‘Rhino’ and ‘Runner’ were supplied by Kiwi Seeds Co. and were inoculated with ALOSCA® prills. The grazing tolerant and high preference lines were supplied as bare seed by AgResearch and inoculated with peat inoculant.

Table 3.1 Dormancy rating of cultivars used in the experiment at Ashley Dene, Canterbury.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Dormancy rating</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Semi-winter active</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘Kaituna’</td>
<td>4-5</td>
<td>Specialty Seeds Ltd. (2012)</td>
</tr>
<tr>
<td>‘Stamina 5’</td>
<td>5</td>
<td>Specialty Seeds Ltd. (2012)</td>
</tr>
<tr>
<td>‘AgResearch (grazing tolerant)’</td>
<td>5</td>
<td>K. Widdup (Pers. comm., 2012)</td>
</tr>
<tr>
<td>‘Stamina 6’</td>
<td>6</td>
<td>University of Wisconsin (2012)</td>
</tr>
<tr>
<td><em>Winter dormant</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘AgResearch (high preference)’</td>
<td>2</td>
<td>K. Widdup (Pers. comm., 2012)</td>
</tr>
<tr>
<td>‘Rhino’</td>
<td>3</td>
<td>Specialty Seeds Ltd. (2012)</td>
</tr>
<tr>
<td>‘Runner’</td>
<td>3</td>
<td>Specialty Seeds Ltd. (2012)</td>
</tr>
</tbody>
</table>

(University of Wisconsin, 2012) (Specialty Seeds Ltd, 2012)

3.3 Experimental design

The entire experimental area covers 2.6 hectares (ha). Within this, there are six paddocks of 0.43 ha (48 x 89 m) which were used for a conventional paddock grazing rotation. One of the seven lucerne cultivars was sown in each of these plots and all were replicated four times, totaling 168 plots (Appendix 1). Prior to this experimental period the lucerne was grazed by sheep of various ages from 2 October 2009-26 April 2010 and from 9 September 2010-3 May 2011 (Speedy, 2012). Grazing for this experiment began on 27 September 2011 using ewes and lambs.

3.4 Soil fertility

In July 2010 and May 2011 soil tests were taken to a depth of 75 mm (Table 3.2) (McLaren and Cameron, 1996).
Table 3.2 Soil test results (2010/2011) for H7, Ashley Dene, Canterbury.

<table>
<thead>
<tr>
<th>Soil test results</th>
<th>Optimum</th>
<th>July 2010</th>
<th>May 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6-6.5</td>
<td>5.5</td>
<td>5.8</td>
</tr>
<tr>
<td>Olsen P</td>
<td>20-30</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>K (me/100 g)</td>
<td>6-12</td>
<td>0.75</td>
<td>0.48</td>
</tr>
<tr>
<td>Ca (me/100g)</td>
<td>0.5-12</td>
<td>7.1</td>
<td>6.9</td>
</tr>
<tr>
<td>Mg (me/100 g)</td>
<td>0.8-3</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>Na (me/100 g)</td>
<td>0.1-0.5</td>
<td>0.12</td>
<td>0.2</td>
</tr>
<tr>
<td>CEC (me/100 g)</td>
<td>20-25</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Total base saturation</td>
<td>55-75</td>
<td>55</td>
<td>59</td>
</tr>
<tr>
<td>Volume weight</td>
<td>0.6-1</td>
<td>0.93</td>
<td>0.84</td>
</tr>
<tr>
<td>Sulphate Sulphur (mg/kg)</td>
<td>10-20</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

3.5 Fertiliser

In November 2008 lime was applied at a rate of 2 t/ha and Super Sulphur at a rate of 125 kg/ha. Based on the results of the May 2011 soil tests, lime was applied at 2.8 t/ha and Sulphur Super 15 was applied at 500 kg/ha in September 2011.

3.6 Meteorological data

Mean monthly air temperature and total monthly rainfall data were collected from Broadfields meteorological station, approximately 14 kilometres north-east of the experimental site (43°62’S, 172°47’E). The data are presented in Figure 3.1, as well as the long term means for average monthly temperature and total monthly rainfall for the period 1981-2010 which were recorded at the same location. The temperature data for the experimental period were within the normal range. Rainfall during October 2011 was approximately 50 mm above average, while the April-May 2012 period received up to 50 mm less rainfall than normal.
Figure 3.1 Mean monthly air temperature ( ■ ) (a) and total monthly rainfall ( ■ ) (b) for the 2011/2012 growth season with long-term means ( — ) for the period 1981-2010. Data were obtained from Broadfields meteorological station (43°62'S, 172°47'E).
3.7 Thermal time

Thermal time (Tt, °Cd) was calculated using the broken-stick model (Jones et al., 1986). Using this method Tt is assumed to be zero for mean air temperatures below the base temperature (Tb) of 1 °C (Figure 3.2). From there, Tt accumulates linearly at a rate of 0.7 °Cd °C⁻¹ until 15 °C, and then at a rate of 1.0 °Cd °C⁻¹ until the optimum temperature (Topt) of 30 °C (Section 2.2.4).

![Figure 3.2 Daily thermal time accumulation (°Cd) in relation to temperature (from Teixeira et al., 2011).](image)

3.8 Soil water budget

3.8.1 Potential soil water deficit

The potential soil moisture deficit (PSMD) that developed between 1 July 2011 and 30 June 2012 is displayed in Figure 3.3. The PSMD was set at zero on 1 July 2011 and accumulated thereafter with:

**Equation 1**  \( \text{Today's PSMD} = \text{Yesterday's PSMD} + (\text{today's Penman PET} - \text{today's rainfall}) \)
The PSMD was not allowed to provide negative values. Rainfall and Penman potential evapotranspiration (PET) were obtained from Broadfields meteorological station near the experiment site. The PSMD increased from zero in winter to a maximum of 389 mm on 5 June 2012.

![Graph showing PSMD (mm) over time](image)

**Figure 3.3** Potential soil moisture deficit (PSMD, mm) between 01/07/2012 – 30/06/2012 (from Speedy, 2012).

### 3.8.2 Soil water content

The volumetric soil water content was measured for the duration of the experiment in each paddock at Ashley Dene. The top layer of the soil (0-0.2 m) was measured using Time Domain Reflectometry (TDR) and the remaining 20 layers (0.3-2.3 m) using a neutron probe (Troxler). This allowed the soil water content (SWC) to be determined and thus the plant available water calculated. The upper limit of the SWC was determined as the highest value over the experimental period at a given depth and the lower limit as the lowest value at each depth over this period. Total available water was calculated using Equation 2.

**Equation 2** \[ \text{Available water} = \text{drained upper limit} – \text{lower limit} \]
3.8.3 Water use
The water use (WU) was calculated using equations to determine water use efficiency (WUE) of the lucerne (Sim et al., 2012).

Equation 3 \[ WU = P_R - (SWC_E - SWC_S) \]
where \( P_R \) is the sum of the rainfall during the experimental period, \( SWC_E \) is soil water content at the end and \( SWC_S \) is soil water content at the start of the measurement period and represent the change in actual soil water content of the soil profile as measured above.

The Penman potential evapotranspiration (\( \text{PET} \)) on each day of the experimental period (\( \text{PET}_{\text{daily}} \)) was then used to determine daily water use (\( WU_{\text{daily}} \)).

Equation 4 \[ WU_{\text{daily}} = \left( \frac{WU}{\text{PET}} \right) \times \text{PET}_{\text{daily}} \]
Canopy cover (\( R/R_0 \)) was used (given leaf area index (LAI) and thermal time data) to calculate soil evaporation (\( E_S \)) from the top 0.4 m layer of the soil.

Equation 5 \[ E_S = WU \times (1 - \frac{R}{R_0}) \]
Where \( R \) is intercepted radiation and \( R_0 \) is incident radiation

3.9 Lucerne quality
Samples of lucerne were taken periodically during the experimental period for analysis of nutritive quality. Nitrogen and ME content were determined by near infrared spectroscopy (NIRS) at the Analytical Laboratory Unit at Lincoln University. Nitrogen content was calibrated using the Kjeldahl method. Metabolisable energy content of the herbage was calibrated from in-vitro organic matter digestibility.

3.10 Livestock and grazing management
The livestock used for this experiment were all obtained from the Lincoln University Coopworth flock. On Tuesday 27 September 2011, 34 ewes and 60 lambs aged from 1-3 weeks were assigned to the experiment at a stocking rate of 15 SU/ha (Table 3.3). A stocking rate is defined as the number of animals carried on a defined area of land and is expressed as stock units (SU)/ha (Fleming, 2003). One basic stock unit is equivalent to one breeding ewe that weighs 55 kg, bears one lamb a year and consumes 550 kg feed/year.
The ewes had been grazing pasture prior to lambing. Stock were shifted every 6-8 days, depending on how long it took them to achieve the desired grazing residual. This grazing residual was determined by the maturity of the lucerne, but it was intended that a high proportion, if not all the leaf matter and vegetative stem were consumed. The stock were removed after weaning on 5 December 2011 after two complete rotations (12 separate shifts). The stocking rate was temporarily increased to 23 SU/ha from 12 October to 23 October 2011 when feed supply exceeded feed demand.

After weaning on 6 December 2011, 84 weaned lambs were returned to the experimental area. The same grazing rotation was continued with an initial stocking rate of 16 SU/ha. On 15 December 2011 the stocking rate was reduced to 9 SU/ha due to reduced lucerne growth rates. By 11 January 2012 the remaining lambs had completed one rotation and were removed. All lambs were weighed at the beginning and end of the grazing period and those of a sufficient live weight (36 kg when empty) were slaughtered.

On 11 January 2012, 60 new lambs were brought onto the experiment. The lambs had been previously grazing other lucerne stands at Ashley Dene. The lambs were stocked at 10 SU/ha and rotationally grazed. This rotation was completed on 7 February 2012 and the lambs were removed, weighed (when empty) and slaughtered.

All stock were removed from the experiment between 7 February and 29 March 2012. At this point 29 ewe hoggets were brought in at 5 SU/ha. The ewe hoggets were rotationally grazed until 10 May 2012. On 20 June 2012 100 ewes were brought in at 16 SU/ha for a fast rotation to clean up the remaining lucerne. They were removed on 26 June 2012. This marked the end of the experimental period.

The grazing areas were defined by a combination of permanent netting fencing and electric netting (‘flexinet’). To assist in identifying treatments, tape was tied to the fences at the edge of each plot. Water was supplied to the stock in small plastic troughs in each paddock.
Table 3.3 Summary of grazing periods for each rotationally grazed stock class during the 2011/2012 growth season in H7, Ashley Dene, Canterbury. Ewes and lambs are denoted as ‘E and L’. Ewe hoggets denoted by ‘Ewe hgts’. Lambs 1 and 2 are different mobs.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Paddock</th>
<th>Stock</th>
<th>No. of stock</th>
<th>Date on</th>
<th>Date off</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>E and L</td>
<td>34</td>
<td>27/09</td>
<td>04/10/2011</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>E and L</td>
<td>34</td>
<td>04/10</td>
<td>10/10/2011</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>E and L</td>
<td>34</td>
<td>10/10</td>
<td>12/10/2011</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>E and L</td>
<td>49</td>
<td>12/10</td>
<td>14/10/2011</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>E and L</td>
<td>49</td>
<td>14/10</td>
<td>18/10/2011</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>E and L</td>
<td>49</td>
<td>18/10</td>
<td>20/10/2011</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>E and L</td>
<td>49</td>
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<td>23/10/2011</td>
</tr>
<tr>
<td>1</td>
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<td>E and L</td>
<td>34</td>
<td>25/10</td>
<td>02/11/2011</td>
</tr>
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<td>1</td>
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<td>34</td>
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<td>07/11/2011</td>
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<tr>
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<td>2</td>
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<td>7/11</td>
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</tr>
<tr>
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<td>6</td>
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<td>6</td>
<td>6</td>
<td>Ewes</td>
<td>100</td>
<td>26/06</td>
<td>27/06/2012</td>
</tr>
</tbody>
</table>
Plate 1 View of ewe hoggets grazing lucerne in H7, Ashley Dene, Canterbury. Taken 27/04/2012.

3.11 Weed control

The primary weeds that were an issue in the experiment were nodding thistle (*Carduus nutans*) and horehound (*Marrubium vulgare*). Both these weeds were removed by hand grubbing. The lucerne was sprayed on 10 August 2011 with Gramoxone (active ingredient paraquat) at 2.4 L per 300 L of water/ha and Atranex (active ingredient atrazine) at 1.1 kg per 300 L of water/ha to control other broadleaf weeds such as dandelion, storksbill and clover.
3.12 Measurements

3.12.1 Dry matter measurements
Sward height was measured pre and post-grazing for each plot using an automated sward stick (Plate 2). Within each plot 20 measurements were taken in a diagonal line between opposite corners of the plot. Start and end readings of the clicker on the stick were recorded for each cultivar. These were determined by measuring the height from the shaft of the stick to the base of the sward. The difference between the distance travelled by the slide tube and the total length of travel to the ground is the height of the sward. The average sward height (cm) was calculated for each plot using Equation 6.

\[
\text{Equation 6 } \left( \frac{\text{Number of clicks}}{\text{Number of readings}} \right)/2
\]

The height measurements were calibrated for dry matter by taking a series of quadrat cuts from the lucerne (Appendix 5). A 0.2 m² quadrat was used to determine the relationship between height and dry matter. The quadrat was placed in a location selected to be representative of the entire plot. It was positioned horizontal to the drill rows to ensure only whole crowns were included. Any shoots attached to the crowns within the quadrat were included in the cut. Before the cut was taken the height was measured using the automated sward stick. The shoots were cut using a pair of hand shears above crown height so only regrowth material was included. Samples were stored in individual paper bags in a cool store, at a temperature of 4 °C before being processed. Dead matter from the previous rotation was removed and discarded from each sample, which was then sorted into lucerne, weed and dead material. The samples were then dried in a forced air draft oven at 65 °C for a minimum of 48 hours to a constant weight. Samples were weighed using a Mettler Toledo PB1502 and Mettler PJ3000 electronic scales. The values obtained from the dry matter cuts and the height measurements were used in Equation 7. Determining the relationship between height and dry matter at various times of the year allows farmers to estimate the amount of accumulated dry matter based on the height of their lucerne swards.

\[
\text{Equation 7 } \text{DM yield} = \text{slope} \times \text{height}
\]
Plate 2 Automated sward stick used for measuring sward height.
**Plate 3** View of pre-grazing sward height in plot number 127 (‘Kaituna’) in H7, Ashley Dene, Canterbury on 9 November 2012. Growth is comparable to that in November 2011.

**Plate 4** View of post-grazing sward height in plot number 1 (‘Kaituna’) in H7, Ashley Dene, Canterbury on 9 November 2012. Growth is comparable to that in November 2011.
3.12.2 Live weight measurements
All stock used in the experiment were weighed using a Gallagher Smart Scale 600 system attached to a Prattley weight crate. Prior to weighing all stock were fasted for approximately 18 hours (overnight), with the exception of ewes and suckling lambs at the beginning of the experiment.

3.13 Statistical analysis
All statistical analyses were conducted using Genstat 14 (version 14.1.0.5943, VSN International Ltd, Hemel Hempstead. UK). Data for individual cultivars and paddocks were subjected to a one-way analysis of variance (ANOVA) with cultivar or paddock as factors. For the analysis of cultivar there were 22 reps of the seven cultivars (d.f. = 153). For the analysis of paddock cultivar was used as replicate, thus there were seven replicates of the six paddocks (d.f. = 41). Fisher’s protected LSD was used to identify the differences among cultivars and paddocks where the ANOVA identified a significant effect (P<0.05).

The thermal time, WUE and height against dry matter data were analyzed by fitting linear regressions. Where there were missing values they were replaced with the treatment mean to balance designs.
4 RESULTS

4.1 Animal production

During lactation the ewes grazing the lucerne gained an average of 34 g/head/day, with 37 kg LW/ha gained by lactating ewes over the entire experimental period. During the same period the lambs grazing the lucerne gained an average of 248 g/head/day, with 437 kg LW/ha put on by the lambs prior to weaning.

Post-weaning when only lambs were used to graze the lucerne, they gained an average of 294 g/head/day, with a total of 264 kg LW/ha gained by the lambs in the post-weaning stage. During summer the live weight gain of the lambs was reduced to 101 g/head/day and they gained a total of 66 kg LW/ha over the summer period.

The ewe hoggets that were used to graze the lucerne in autumn gained an average of 183 g/head/day and a total of 90 kg LW/ha over the grazing period (Table 3.3).

More detail on the live weight gains of the stock used in this experiment were reported by Speedy (2012).

4.2 Dry matter production

4.2.1 Dry matter production of individual cultivars

The total annual yield differed (P<0.01) among the seven cultivars. The yield from ‘Stamina 5’ was 14% higher than the 11.4 t DM/ha/yr produced by ‘Runner’. ‘Stamina 5’, ‘Kaituna’, ‘Stamina 6’ and ‘AgResearch (high preference)’ produced an average of 12.9±0.17 t DM/ha/yr. The yield differences among cultivars within each rotation are illustrated in Figure 4.1.
Figure 4.1 Dry matter yield (kg/ha) of ‘Kaituna’ (■), ‘Stamina 6’ (▨), ‘Stamina 5’ (□), ‘AgResearch (grazing tolerant)’ (▧), ‘AgResearch (high preference)’ (▤), ‘Rhino’ (◼) and ‘Runner’ (▩) lucerne plots in each rotation (Rotation 1: 27/09 – 02/11/2011; Rotation 2: 02/11 – 09/12/2011; Rotation 3: 05/12/2011 – 16/01/2012; Rotation 4: 13/01 – 07/02/2012; Rotation 5: 29/03 – 10/05/2012; Rotation 6: 20/06 – 27/06/2012) in H7, Ashley Dene, Canterbury. Error bars are the standard error of the mean (SEM).

The first grazing rotation began in Paddock 1 on 27/09/11 and ended in Paddock 6 on 25/10/11. The mean yield across cultivars for this rotation differed. On average, ‘Stamina 5’ yielded 3.2 t DM/ha, which was 36% greater (P<0.01) than the 2.4 t DM/ha produced by ‘Runner’. ‘Kaituna’ also yielded 3.2 t DM/ha and ‘Stamina 6’ yielded 3.1 t DM/ha.

In Rotation 2 (which ended on 30/11/11) ‘AgResearch (high preference)’ yielded 3.6 t DM/ha, which was 23% higher (P<0.01) than the lowest yield of 2.9 t DM/ha from ‘Runner’. ‘Stamina 6’ produced 3.3 t DM/ha, while ‘Kaituna’ produced 3.2 t DM/ha.

The cultivar that yielded the highest in Rotation 3 (ended 08/01/12) was ‘Stamina 5’, which produced 3.2 t DM/ha (P<0.01). This was 15% higher than the 2.8 t DM/ha from ‘Runner’. ‘Kaituna’ also produced 3.2 t DM/ha and ‘Stamina 6’ yielded 3.1 t DM/ha.
Rotation 4 began on 13/01/12 and ended on 06/02/12. ‘Rhino’, ‘Stamina 6’, ‘Stamina 5’ and ‘Kaituna’ were the cultivars with the highest (P<0.01) yields of 2.0±0.02 t DM/ha. The lowest yield was 1.8 t DM/ha from ‘AgResearch (grazing tolerant)’.

The fifth rotation ended on 04/05/12. ‘Stamina 5’ and ‘Kaituna’ yielded an average of 1.5 t DM/ha, which was 11% more (P<0.01) than the average yield of 1.4 t DM/ha produced by ‘Runner’, ‘Rhino’ and ‘AgResearch (high preference)’.

Rotation 6 was considered a ‘clean-up’ graze and took place between 20/06/2012 and 27/06/2012. Dry matter during this period was estimated at 300 kg/ha for each cultivar.

Dry matter yield also differed among cultivars within each season (Figure 4.2). For the purposes of this analysis spring refers to the period between 01/07 and 30/11/2011 as it is assumed moisture stress did not occur during this period and covers the grazing of ewes and lambs. Summer was the period of grazing by weaned lambs between 01/12/2011 and 29/02/2012. Autumn/winter was the period between 01/03 and 30/06/2012 which covers the ewe hogget and ewe grazing. In spring ‘AgResearch (high preference)’ yielded 6675 kg DM/ha, which was 25% higher than the 5324 kg DM/ha produced by ‘Runner’. In summer ‘Stamina 5’ yielded 5239 kg DM/ha which was 31% more than was produced by ‘AgResearch (grazing tolerant)’ (3998 kg DM/ha). ‘Stamina 5’ was also the highest yielding in autumn but the difference between the lowest yielding cultivar (‘AgResearch (high preference)’) was reduced to 10%.
Figure 4.2 Total lucerne yields (kg DM/ha) for individual cultivars in spring (1 July 2011 – 30 November 2011) (■), summer (1 December 2011 – 29 February 2012) (□) and autumn (1 March 2012 – 30 June 2012) (▩) in H7, Ashley Dene, Canterbury. Error bar is the standard error of the mean (SEM).

4.2.2 Dry matter production of individual paddocks
The grazing management of the six paddock rotation over the duration of the 2011/2012 growth season is shown in Figure 4.3. The thermal time accumulated from the last grazing in the 2010/2011 season to the first grazing in the 2011/2012 season was 650 °Cd.

When grazing in Paddock 1 began in Rotation 1 the dry matter was 1.4 t DM/ha and when the ewes and lambs were removed a residual of 0.3 t DM/ha remained. When the first graze of Paddock 6 occurred in Rotation 1 the dry matter had reached 4.3 t DM/ha and at the end a residual of 2.0 t DM/ha remained. The rainfall was highest during this period, at 105 mm over a 30 day period.

In Rotations 2 and 3 there was less of a difference between the starting dry matter in Paddocks 1 and 6. In Rotation 2 there was a cover of 2.9 t DM/ha when the ewes and lambs entered Paddock 1 and 3.8 t DM/ha when they entered Paddock 6. In Rotation 3 there was 2.4 t DM/ha when the lambs entered Paddock 1 and 2.8 t DM/ha when they
entered Paddock 4. The cover increased to 3.8 t DM/ha when they entered Paddock 6. The residuals varied from 0.9-1.8 t DM/ha in Rotation 2 and 1.0-1.4 t DM/ha in Rotation 3.

In Rotation 4 cover began at 2.6 t DM/ha in Paddock 1 and decreased to 1.6 t DM/ha in Paddock 6 due to low and ineffective rainfall in January. The difference between the pre-grazing cover and post-grazing residual was smaller in Rotation 4 than the earlier rotations. When the lambs left Paddock 1 the residual was 1.2 t DM/ha and when they left Paddock 6 the residual was 0.9 t DM/ha.

There was minimal difference in the pre-grazing covers across all paddocks in Rotation 5, with an average of 1.4 t DM/ha and an average residual of 0.5 t DM/ha.

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**Figure 4.3** Standing lucerne dry matter (kg/ha) for Paddocks 1-6 over six rotations during the 2011/2012 growth season in H7, Ashley Dene, Canterbury. Numbers in black are the post-grazing residuals for each paddock and coloured numbers refer to the pre-grazing dry matter. The blue bars represent monthly rainfall (data taken from Broadfields meteorological station (43°62'S, 172°47'E)).
Total annual yield differed (P<0.01) among the six paddocks used to rotationally graze the animals in this experiment (Figure 4.4). In most cases the total annual yield was inversely related to the order of their first grazing in spring. For example, Paddock 6 (15.1 t DM/ha/year) yielded 39% more than Paddock 1 (10.9 t DM/ha/year). Paddock 6 was grazed last in the first rotation, while Paddock 1 was the first one grazed. Paddocks 5 and 3 had an annual yield of 13.1±0.20 t DM/ha/year.

**Figure 4.4** Total accumulated dry matter (kg/ha) over time for Paddock 1 (●), Paddock 2 (○), Paddock 3 (▼), Paddock 4 (△), Paddock 5 (■) and Paddock 6 (□) under rotational grazing from 27 September 2011 – 27 June 2012 in H7, Ashley Dene, Canterbury. Error bars are the standard error of the mean (SEM).

### 4.3 Thermal time

The mean growth rate of all seven lucerne cultivars over the entire season was 4.9 kg DM/ha/°Cd (Figure 4.3). Regression lines were fitted to the data and individual t-tests determined there was no difference (P<0.05) in the growth rate between each cultivar. There was a period of linear growth during spring, where the lucerne grew at 9.9 kg DM/ha/°Cd.
Using a linear regression on the thermal time data allowed it to be extrapolated back to determine the point at which growth started for each cultivar. ‘Kaituna’, ‘Stamina 6’ ‘AgResearch (grazing tolerant)’ and ‘Stamina 5’ began growth at 140 °Cd after 1 July 2011, ‘AgResearch (high preference)’ started growing at 154 °Cd, ‘Rhino’ started growing at 169 °Cd and ‘Runner’ was the last to begin growth at 195 °Cd. T-tests were used to determine the differences in the starting growth date. No differences were detected but this was influenced by the required extrapolation as there was no yield data prior to 470 °Cd. Regression lines were only fitted until 1100 °Cd as beyond this point linear growth ceased due to moisture stress.
4.4 Soil water budget

4.4.1 Available water
The DUL and LL of the soil were used to calculate the available water in the soil over the experimental period. The total available water over the season was determined by adding up the water available in each 0.1 m soil layer. There was 240 mm of water available in Paddock 1 (Figure 4.6 (a)) and 202 mm in Paddock 6 (Figure 4.6 (b)). This differed throughout the soil profile. In the top 0.2 m of soil in Paddock 1 there was a total of 51 mm of water available to the lucerne. From 0.8 m to 1.7 m the available water varied between 8.5-10.5 mm/0.1 m soil. In the lowest measured level of the soil (2.3 m) there was only 3 mm of water available. In Paddock 6 there was 31 mm of available water in the top 20 cm of soil, between 4.8-11.7 mm/0.1 m soil from 0.3-1.5 m, 8.3-13.9 mm/0.1 m soil between 1.6-2.2 m and 6.3 mm of water available in the bottom layer at 2.3 m depth.
Figure 4.6 Water extraction pattern of ‘Kaituna’ lucerne roots in the soil profile to a depth of 2.3 m, where (●) is the upper limit and (○) is the lower limit (mm) for plant available water in Paddock 1 (a) and Paddock 6 (b) in H7, Ashley Dene, Canterbury.
4.4.2 Soil water content

Figure 4.7 illustrates the impact of rainfall on SWC and DM yield. The total soil water content remained stable from September-November at around 410 mm in Paddocks 1 and 6 (Figure 4.7 (b)). At this point the soil reached its DUL. Two rainfall events of over 40 mm occurred in mid-October and appeared not to have drained, which would have resulted in super saturated soil and implicates a perched water table. The SWC declined to 230 mm over the next three months at a rate of 2.0 mm/day. In the March-May period only 95 mm of rain fell, keeping the SWC at around 220 mm, but 75 mm of rainfall in June allowed the SWC to rise again to an average of 270 mm.

Dry matter yields of all cultivars increased in a linear fashion until late December (Figure 4.7 (a)). At this point the dry matter accumulation of all cultivars slows from an average of 86 kg DM/ha/day to an average of 54 kg DM/ha/day, which is when moisture stress became apparent from early November to mid-January. From mid-January to the end of the growth season in late June dry matter accumulation slowed further to a rate of 12 kg DM/ha/day. During this time SWC was at its lowest, with an average of 233 mm across Paddocks 1 and 6 from January-June. Lines between the data points are not fitted regression lines.
Figure 4.7 Total accumulated dry matter (kg/ha) (a) for ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (▲), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne plots from 27 September 2011 – 27 June 2012 and soil water content (b) of Paddock 1 (—) and Paddock 6 (---) (mm), monthly rainfall (mm) (■) and thermal time accumulation (°Cd) in H7, Ashley Dene, Canterbury. Rainfall data are taken from Broadfields meteorological station (43°62’S, 172°47’E). Shaded area represents the period where no water was available for growth and dashed (---) line in (a) represents estimated growth rates based on SWC. Error bars are the standard error of the mean (SEM).
4.4.3 Water use efficiency

Using the cumulative water use and lucerne yields from the plots containing a neutron probe, the WUE was able to be calculated for ‘Kaituna’ (Figure 4.8). The yields obtained from the plots containing a neutron probe in Paddocks 1 and 6 exhibited a WUE of 34.7 kg DM/mm water. T-test on the WUE of each paddock was not significantly different. Therefore, a single regression line was fitted to the data. There is systematic error surrounding the regression line due to the higher WUE values for Paddock 6 when water use is low and the flattening off of WUE after 350 mm of water had been used.

**Figure 4.8** Water use efficiency (kg DM/mm water used) for ‘Kaituna’ lucerne grown in Paddock 1 (●) and Paddock 6 (□) during the 2011/2012 growth season in H7, Ashley Dene, Canterbury. Equation for regression slope: 
\[ y = 976 + 34.7x \quad R^2 = 0.90. \] Error bar is the coefficient.
4.5 Lucerne quality

4.5.1 Nitrogen

‘Runner’ consistently had a higher nitrogen content (P<0.05) than the other six cultivars (Figure 4.9). For all cultivars the nitrogen content decreased between December and January, to an average of 2.7±0.06%. Nitrogen content increased between January and April, when the N% in ‘Runner’ was 3.4%, compared with a 2.7±0.06% average for ‘AgResearch (high preference)’ and ‘Stamina 6’.

![Figure 4.9](image)

**Figure 4.9** Nitrogen content (%) of ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (△), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne at four harvest dates in the 2011/2012 growth season in H7, Ashley Dene, Canterbury. * indicates a significant difference (P<0.05) between cultivars. Error bars are the standard error of the mean (SEM).

The total nitrogen yield was calculated by multiplying the nitrogen content by the yield for each cultivar. Values for 11 November 2011 and 23 June 2012 were calculated using the relationship between palatable and unpalatable lucerne components published in Brown.
and Moot (2004). Equation 8 was used to calculate the total crude protein content (g/g DM) of the palatable fraction of the sward. The dry matter value used was 2400 kg DM/ha as it was reported that the first 2.4 t DM/ha of a lucerne stand was palatable material.

**Equation 8** \( \text{Palatable CP} = 0.26 + 0.19 \times \exp(-9^{-5} \times 2400) \)

Equation 9 was used to determine the unpalatable crude protein content of the sward, where 2400 kg DM/ha was taken away from the total dry matter as the unpalatable fraction was considered any dry matter above this yield. This value was added to the value calculated for the palatable crude protein content to give the total crude protein content, which was divided by 6.25 to give the total nitrogen yield.

**Equation 9** \( 0.11 \times (DM - 2400) \)

Total nitrogen yield was greatest for ‘Kaituna’, at 562 kg N/ha (Figure 4.10). The nitrogen yield of ‘Kaituna’ increased at a rate of 1.7 kg N/ha/day until 23 June, when it reached its total annual yield. The increase in nitrogen yield slowed towards the end of the growth period as yield accumulation slowed down. ‘Rhino’ consistently had the lowest nitrogen yield and increased at a rate of 1.5 kg N/ha/day until its total annual yield of 503 kg N/ha was reached.
Figure 4.10 Total nitrogen yield (kg N/ha) of ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (▲), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne at four harvest dates in the 2011/2012 growth season in H7, Ashley Dene, Canterbury. * indicates a significant difference (P<0.05) between cultivars, arrows indicate calculated values based on the relationship published in Brown and Moot (2004). Error bars are the standard error of the mean (SEM).

4.5.2 Metabolisable energy
ME was highest in ‘Runner’ at all four harvest dates (Figure 4.11). In November ‘Runner’, ‘Stamina 6’, ‘Kaituna’ and ‘AgResearch (high preference)’ had an average ME content of 10.4±0.06 MJ ME/kg DM, while ‘Rhino’, ‘Stamina 5’ and ‘AgResearch (grazing tolerant)’ had an average ME content of 10.0±0.06 MJ ME/kg DM. There was no difference among the ME of all cultivars in December (10.7±0.09 MJ ME/kg DM) or January (10.2±0.09 MJ ME/kg DM). Between November and April the ME content of ‘Runner’ increased from 10.5 MJ/kg DM to 11.1 MJ/kg DM. ‘Stamina 6’ had a significantly lower (P<0.01) ME in April of 9.7 MJ ME/kg DM.
Figure 4.11 Metabolisable energy (ME) (MJ ME/kg DM) of ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (▲), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne at four harvest dates in the 2011/2012 growth season in H7, Ashley Dene, Canterbury. * indicates a significant difference (P<0.05) between cultivars. Error bars are the standard error of the mean (SEM).

The total ME yield was calculated by multiplying the ME content by the yield for each cultivar (Figure 4.12). Values for 11 November 2011 and 23 June 2012 were calculated using the relationship between palatable and unpalatable lucerne components published in Brown and Moot (2004). Equation 10 was used to calculate the total ME yield (GJ/kg DM) of the palatable fraction of the sward. The multiplier used was 2400 kg DM/ha as it was reported that the first 2.4 t DM/ha of a lucerne stand was palatable material.

\[
\text{Equation 10} \quad \text{Palatable ME} = 11.9 \times 2400
\]

Equation 11 was then used to determine the unpalatable ME content of the sward, where 2400 kg DM/ha was taken away from the total dry matter as the unpalatable fraction was
considered any dry matter above this yield. This value was added to the value calculated for the palatable ME content to give the total ME yield.

Equation 11  \[ \text{Unpalatable ME} = 7.9 \times (\text{DM} - 2400) \]

Total ME yield was greatest in ‘Stamina 5’ on 11 November, at 35 GJ ME/kg DM. The ME yield of ‘Stamina 5’ increased at a rate of 0.49 GJ ME/kg DM/day until 23 June, when it reached a total annual yield of 146 GJ ME/kg DM. The increase in ME yield slowed towards the end of the growth period as yield accumulation slowed down. ‘Rhino’ consistently had the lowest ME yield and increased at a rate of 0.46 GJ ME/kg DM/day until its total annual yield of 133 GJ ME/kg DM was reached.

\[ \begin{array}{c|c|c|c|c|c|c}
\text{Date} & \text{11 Nov} & \text{24 Nov} & \text{12 Dec} & \text{13 Jan} & \text{26 Apr} & \text{23 Jun} \\
\hline
\text{Total ME (GJ ME/ha)} & \text{0} & \text{50} & \text{100} & \text{150} & \text{200} & \text{250} \\
\end{array} \]

* indicates a significant difference (P<0.05) between cultivars, arrows indicate calculated values based on the relationship published in Brown and Moot (2004). Error bars are the standard error of the mean (SEM).

\[ \begin{array}{c|c|c|c|c|c|c}
\text{Date} & \text{11 Nov} & \text{24 Nov} & \text{12 Dec} & \text{13 Jan} & \text{26 Apr} & \text{23 Jun} \\
\end{array} \]

\[ \begin{array}{c|c|c|c|c|c|c}
\text{Total ME (GJ ME/ha)} & \text{0} & \text{50} & \text{100} & \text{150} & \text{200} & \text{250} \\
\end{array} \]

Figure 4.12 Total metabolisable energy (ME) (GJ ME/ha) of ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (△), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□) and ‘Runner’ (◆) lucerne at four harvest dates in the 2011/2012 growth season in H7, Ashley Dene, Canterbury. * indicates a significant difference (P<0.05) between cultivars, arrows indicate calculated values based on the relationship published in Brown and Moot (2004). Error bars are the standard error of the mean (SEM).
5 DISCUSSION

5.1 Animal production

Lactating ewes were reported to have an average daily live weight gain of 34 g/head/day and unweaned lambs averaged 248 g/head/day. Lambs grazing lucerne over the summer period gained 101 g/head/day. Stocker (2011) reported live weight gains of lactating ewes for the same experiment to be 150 g greater than what was observed in the 2011/2012 growth season. The results from this experiment were also 74% lower than reported elsewhere (Douglas et al., 1995). The difference in live weight gains of unweaned lambs at this time was less severe, with lambs in this experiment only averaging 15 g/head/day less than what was reported by Douglas et al. (1995) and 13 g/head/day greater than reported by Stocker (2011). The daily live weight gains of lambs illustrated during the summer in this experiment were slightly below those reported by Mills et al. (2008) who reported that lambs averaged 160 g/head/day during this period. The live weight gains of the lambs during summer in this experiment was greater than the average 65 g/head/day gained by lambs consuming a ryegrass/white clover based pasture in an adjacent paddock (Mills et al., 2008).

The experiment had a total annual live weight production of 894 kg/ha. This was 90% lower than the total live weight of 1702 kg/ha/year over the 2010/2011 growth season on the same experimental site reported by Stocker (2011). Numerous possibilities were investigated for the reasoning of this. The flocks used had the same genetic basis, thus genetic differences could be discounted. A standard animal drenching protocol is administered at Ashley Dene, thus it can be assumed that parasite burdens were not an issue.

The lower live weight gains in this year of the experiment could have been a result of the quality of the lucerne herbage. The average ME content was 10.4 MJ ME/kg DM across all cultivars, with ‘Runner’ experiencing the highest ME content at the final harvest of 11.1 MJ ME/kg DM (Figure 4.11). Mills and Moot (2010) reported an average ME lucerne content of ~11 MJ ME/kg DM in a dryland environment at Lincoln University. A lactating ewe in mid-late lactation and her lamb require a daily ME intake of ≥12.5 MJ ME/day (Nicol and Brookes, 2007), thus ewes would have been required to consume a minimum of 1.2 kg DM/day for ME requirements to be met. Ewes were offered 9.25 kg DM/ewe/day
during the first and second rotation. It was reported that ewes have the potential to consume 4% of their live weight (Court et al., 2010), so assuming an average live weight of 65 kg across all the ewes, then neither dry matter nor ME intake were limiting and would not have caused reduced live weights. It was reported that excess nitrogen in the diet of lactating ewes may lead to reduced live weight gains of suckling lambs (Malik et al., 1999). When ewes were fed a base diet containing 23 g N/kg DM, then supplemented with ammonium bicarbonate containing 15 g N they had an increased fat:protein ratio. Among other physiological changes, the milk yield of the ewes was reduced by 20%, resulting in a reduction of lamb live weight gains of 67 g/day. It cannot be confirmed if this occurred in the current study, thus the experiment is being repeated for the 2012/2013 growth season to determine the basis of live weight reductions.

5.2 Dry matter production

5.2.1 Dry matter production as influenced by rotation

In the first rotation ‘Kaituna’ and ‘Stamina 5’ yielded 3.2 t DM/ha (Figure 4.1) and Paddock 6 yielded 4.3 t DM/ha (Figure 4.4). Rotation 1 began on 27 September 2011 in mid-spring and Rotation 2 ended in late spring. Over the entire spring period ‘AgResearch (high preference)’ was the highest yielding cultivar and total spring yields ranged between 5.3-6.6 t DM/ha. During this time lucerne yields are most highly associated with spring rainfall (Baars et al., 1975). Moisture proved not to be limiting during this period (Figure 4.7 (b)), thus yields were more closely related to temperature and radiation (Moot et al., 2008). The dry matter yields experienced in this experiment were approximately 2 t/ha higher than spring yields reported by McGowan et al. (2003), although similar to Baars et al. (1975), who stated that 36% of lucerne production occurred during spring. These differences are likely to be a result of differences in location, as the results from McGowan et al. (2003) were achieved on North Island hill country with an average spring rainfall of 100 mm, compared with the 190 mm of rain that fell during spring in this experiment.

Growth rates in this experiment increased in a linear fashion at 86 kg DM/ha/day until late December (Figure 4.7 (a)). Elsewhere, linear growth rates of lucerne from September-January of over 100 kg DM/ha/day have been reported (Moot et al., 2003; Tonmukayakul, 2009). This could have been a result of stones present in the soil in this experiment, as less soil was available for water extraction.
Rotation 3 began on 5 December 2011 in early summer and Rotation 4 finished in late summer. Over this period ‘Stamina 5’ was the highest yielding cultivar (5.2 t DM/ha) (Figure 4.2) and Paddock 6 was the highest yielding paddock (3.3 t DM/ha) (Figure 4.4). Over the summer period (December-February) the highest rainfall event that occurred was only 34 mm, resulting in the SWC declining at a rate of 2 mm/day. In January/February there was a total rainfall of 72 mm. For rainfall to be effective during the summer period it appeared there needed to be at least 30 mm (Figure 4.7 (b)). At the end of February/beginning of March there was 31 mm of rain, which lifted the SWC of Paddocks 1 and 6 by 20 mm. Rainfall did not have any effect on yield in summer because by the time the two significant rainfall events occurred (68 mm at the end of March and 70 mm at the end of June) temperature appears to have declined to a point where growth was reduced (~5 °C). During the summer period, yields reflect summer rainfall (Baars et al., 1975; Kearney et al., 2010). Moot et al. (2008) reported that rainfall during February to April is often ineffective as the SWC has dropped considerably. These authors stated that the first 20 mm of any rainfall event is often evaporated from the soil, although from this experiment it can be concluded that rainfall was ineffective when less than 30 mm. Average lucerne yields of 5.5 t DM/ha were reported for a dryland North Island site (McGowan et al., 2003), which was 15% higher than the average yield achieved over that period in this experiment. The total rainfall recorded for this site over January/February was 215 mm. The reduced yields as a result of lower rainfall suggests that summer yield and summer rainfall are highly correlated. Water stress acts negatively on lucerne yields by reducing stem density, height and leaf size (Brown and Tanner, 1983).

Rotation 5 started on 29 March (mid-Autumn) and finished on 10 May. ‘Stamina 5’ and ‘Kaituna’ yielded 1.8 t DM/ha over this period (Figure 4.2) and Paddocks 1, 4 and 5 yielded 1.5 t DM/ha (Figure 4.4). Growth rates over Rotation 5 and 6 were no greater than 5 kg DM/ha/day, with negligible yields over this period. The correlation between autumn yields and summer rainfall was reported to have an r value of 0.91 (Baars et al., 1975). As previously mentioned, summer rainfall in this experiment was below average (130 mm in this experiment, compared with 200 mm reported by Mills et al. (2008) at Lincoln University), thus these yields were considerably lower than reported elsewhere. McGowan et al. (2003) found lucerne yields in the North Island in autumn to average 2.1 t DM/ha, while Tonmukayakul (2009) reported lucerne growth rates at Lincoln University from 24 March-30 June of <10 kg DM/ha/day. Rainfall (>70 mm in one event) in June allowed
SWC to increase but with no impact on yield as growth had near stopped for the winter period (Figure 4.7).

5.2.2 Dry matter production as influenced by paddock

Paddock 1 consistently yielded less than Paddock 6 for the majority of the growth season (Figure 4.3). There was a difference in total accumulated yield of 4.1 t/ha (Figure 4.4). In the first rotation Paddock 6 was grazed 28 days later than Paddock 1, thus Paddock 1 accumulated a further 2.9 t DM/ha. As a result, Paddock 1 continued to yield higher than Paddock 6 until mid-summer, at which point the soil moisture availability of each paddock appears to have determined the dry matter production. In Rotation 4 (mid-January) Paddock 1 yielded 58% more than Paddock 6. The SWC of both paddocks peaked in October (465 mm in Paddock 1, 433 mm in Paddock 6). From there it declined steadily at a rate of 2 mm/day until the end of January, when it remained relatively stable until the end of May, at an average of 230 mm between both paddocks.

When the herbage in Paddock 1 was grazed earlier than Paddock 6, it appeared that soil water was conserved in Paddock 1 while Paddock 6 used the available water for dry matter production. This allowed the water content of Paddock 1 to consistently remain above that of Paddock 6 (Figure 4.7 (b)). It was reported that when lucerne leaf is removed, it creates a fallow where soil moisture is conserved (Brown, 2004).

5.2.2.1 Differences due to PAWC

The PAWC of Paddock 1 was 40 mm greater than that of Paddock 6, resulting in greater dry matter yields from Paddock 1. There was no difference in the WUE of ‘Kaituna’ lucerne between Paddocks 1 and 6 (34.7 kg DM/mm water used) (Figure 4.8). By multiplying the difference in PAWC between both paddocks by the WUE it can be stated that the differences in PAWC created a 1.5 t DM/ha yield difference between Paddocks 1 and 6. Thus if the PAWC was the same in Paddock 1 and Paddock 6 it can be assumed that there would have been a 5.6 t DM/ha yield difference. Lucerne reportedly compensates for lower PAWC by reducing the rate of canopy expansion (Brown, 2004). As a result, light interception available for photosynthesis declines and growth rates are reduced.
5.2.2.2 Differences due to timing of grazing

Of the 4.1 t/ha yield difference between Paddock 1 and Paddock 6, Section 5.2.2.1 attributed 1.5 t DM/ha of the difference to differences in PAWC. The remaining 2.6 t DM/ha that was unexplained by soil water occurred due to the timing of grazing. In Rotation 1 there was a difference of 2.9 t DM/ha accumulated between the first and last grazed paddocks (Figure 4.3). The difference was then 0.9 t DM/ha in Rotation 2 and 1.2 t DM/ha in Rotation 3. Janson (1974) stated that the timing of the first grazing would determine stand production for the remainder of the season. A lucerne stand that was first grazed two weeks after another stand was reported to have a 24% yield increase. Grazing the lucerne before it had reached its ideal height resulted in a reduced LAI as a result of a reduction in the intercepted PAR (Teixeira, 2006). This lead to lower canopy expansion, thus an impact on yield (Teixeira et al., 2007). It has been stated that the first lucerne grazing should not occur until October (White and Lucas, 1990). This is not a realistic recommendation as lucerne is commonly required in dryland systems throughout the country in spring to provide feed to lactating ewes. By grazing the first paddock before its maximum yield a feed wedge ahead of the animals can be created. In contrast, delaying grazing in the first paddock until the optimum yield is achieved will increase the yields in all other paddocks but the quality of the dry matter produced would decline as the stem content increases.

The dry matter consumed in Paddock 1 varied from 1.9 t DM/ha in Rotation 2 to 0.9 t DM/ha in Rotation 5, with 65% of the total dry matter production utilized in Paddock 1 over the 2011/2012 growth season (Figure 4.3). The dry matter consumed in Paddock 6 varied from 2.3 t DM/ha in Rotation 1 to 0.9 t DM/ha in Rotation 5, with 60% of the total dry matter utilized in Paddock 6 over the 2011/2012 growth season. By multiplying the dry matter consumed in each rotation by 11.9 (value for palatable ME obtained from Brown and Moot (2004)), it was determined that 80 GJ ME/ha was consumed from Paddock 1 and 110 GJ ME/ha was consumed from Paddock 6 (Figure 4.12). Paddock 1 produced a total nitrogen yield of 361 kg N/ha (Figure 4.10), 224 kg N/ha of which was consumed. Paddock 6 produced a total nitrogen yield of 497 kg N/ha, 310 kg N/ha of which was consumed. As a result, it can be concluded that grazing Paddock 1 on 27 September was early enough to prevent a decline in the quality of the herbage in Paddock 6. Had grazing been delayed any further the consumption from Paddock 6 would have exceeded the palatable yield of 2.4 t DM/ha and quality would have been affected.
residual from Paddock 6 was 2.0 t DM/ha in the first rotation and 1.8 t DM/ha in the second rotation. Such residuals should be avoided in a commercial situation as the feed is wasted. This could be avoided in a grazing context by dropping Paddock 6 out of the rotation and cutting the herbage for conservation. If this occurred the stock would have been returned to Paddock 1 sooner and further issues with such high production from Paddock 6 would have been avoided. Another option rather than cutting the herbage is to add more stock in to the system to lower the residuals.

### 5.2.2.3 Water use efficiency

The WUE of Paddocks 1 and 6 was 34.7 kg DM/mm water used (Figure 4.8). Systematic error was present surrounding the WUE regression line in the present experiment, thus was likely to have influenced the high WUE value. Above 320 mm, water use increased while yield remained stable. This could have been a result of water appearing to be used but leaving the soil either via soil evaporation (as a result of low yields) or drainage. Moot et al. (2008) stated a WUE for a dryland lucerne crop grown on a deep Wakanui silt loam soil of 40 kg DM/ha/mm, which is higher than observed in this experiment. The WUE found in this experiment was considerably greater than the WUE of 15 kg DM/ha/mm water for a ryegrass monoculture (Moot et al., 2008). This was a result of higher nitrogen content in the lucerne (Section 5.4).

### 5.2.2.4 Water extraction

The decrease in SWC and subsequent increase in dry matter yields observed in Figure 4.7 are evidence of water being extracted from the soil. The difference between the DUL and LL of water extraction at 2.3 m for both Paddocks 1 and 6 (Figure 4.6) was significant enough for it to be assumed water was being extracted below this depth or drainage was occurring. There are numerous reports of water extraction by lucerne below 2.3 m in other experiments (Jodari-Karimi et al., 1983; McCallum et al., 2001; Brown et al., 2003; Brown, 2004; Brown et al., 2005; Moot et al., 2008; Brown et al., 2009); however it appeared this did not occur in this experiment. The linear growth rate in Figure 4.7 (a) was interpolated until the point where water was no longer available, then dry matter production was assumed to be constant during the period when water was not available (dashed line). After the 67 mm rainfall event in March it was assumed that growth resumed at the same linear growth rate as before (86 kg DM/ha/day). Similarly, it was reported that no growth occurred in a cocksfoot pasture when the critical limiting deficit
(78 mm) was exceeded and growth did not begin again until a significant rainfall event (Mills et al., 2006). Thus it is apparent that when water was no longer available in this experiment the lucerne stopped growing, rather than extracting water from below 2.3 m. This further indicates that the difference between the DUL and LL was primarily due to water draining from the soil profile. Based on the known period of water stress in this experiment, the potential yield loss due to insufficient water was estimated to be 6 t DM/ha. This additional dry matter production could have been achieved if irrigation was used.

5.2.2.5 Soil type

The differences in available water at varying depths (Figure 4.6) suggested different soil types present in the soil profile. The top 0.2 m of soil in both Paddock 1 and Paddock 6 consisted of silt material that had a higher PAWC (25.7 mm/0.1 m soil in Paddock 1 and 15.3 mm/0.1 m soil in Paddock 6). Below this depth in Paddock 1 there appeared to be stony soil, with the PAWC decreasing from 18.6 mm/0.1 m soil at 0.2 m to 8 mm/0.1 m soil at 1.0 m. From here the soil consisted of mainly gravel with a low PAWC and a total of 90 mm of available water from 1.0-2.3 m. The profile appeared to be considerably different in Paddock 6, with a clear gravel pan evident from 0.4-1.3 m that had a total PAWC of 60 mm between these depths. From here it appears there is an increase in the clay content of the soil, with a total PAWC from 1.4-2.3 m of 100 mm. The Lowcliffe soils present in H7 at Ashley Den were reported to have less than 0.2 m of stone-free material over-lying a very stony horizon (McLenaghan and Webb, 2012), which was consistent with the water extraction patterns observed in this experiment. Dense gravel pans occur at varying depths and thicknesses in the soil, beginning at 0.5 m from the soil surface with a thickness of 0.5 m. The deeper Lowcliffe soils have dense subsoils that differ with the sandiness of the soil but are able to be penetrated by roots. The advantage of a deep rooting species such as lucerne is greatest on soils with deep layers of fine material, thus a high PAWC (Brown et al., 2003).

5.2.3 Dry matter production as influenced by cultivar

Distinct differences were apparent in dry matter production of all cultivars (Figure 4.1). ‘Kaituna’ and ‘Stamina 5’ had the highest total accumulated yields of 13 t DM/ha. Differences in cultivar yields were due to differences in winter activity and thermal time requirements. ‘Kaituna’ has a dormancy rating of 5 and ‘Stamina 5’ has a dormancy rating
of 5, meaning these cultivars are more active in late winter-early spring than cultivars with a lower dormancy rating. ‘Runner’ had the lowest total yield (11.4 t DM/ha) and has a dormancy rating of 3, thus is considered winter dormant. As a result of the differences in growth between winter active and winter dormant cultivars (Section 2.2.3) it would be recommended that ‘Kaituna’, ‘Stamina 5’ or ‘Stamina 6’ be sown for greater production in early spring and autumn. However, if persistence of the stand is desired then a more winter dormant cultivar such as ‘AgResearch (high preference)’ could be sown (Section 2.2.3). In terms of the environment at Ashley Dene the more winter active cultivars are suitable as the climate is generally mild, with an average winter temperature of 6.9 °C.

By early November in Rotation 2 the winter dormant cultivars had begun growing and ‘AgResearch (high preference)’ (dormancy rating 2) had the highest yield of 3.6 t DM/ha. During summer ‘Kaituna’, ‘Stamina 6’ and ‘Stamina 5’ produced the greatest yields. The average growth rate of these three cultivars from December-February was 56 kg DM/ha/day, which was lower than the 90 kg DM/ha/day reported for ‘Kaituna’ lucerne (Brown et al., 2003).

The annual yield of ‘Kaituna’ was lower than cited in other literature (Section 2.2.2). It is likely this is a result of an interaction between PAWC of the soil and rainfall during the 2011/2012 growth season.

5.3 Thermal time

All cultivars grew at an average rate of 4.9 kg DM/ha/°Cd over the entire 2011/2012 growth period (Figure 4.5). Growth was linear during spring, at a rate of 9.9 kg DM/°Cd. The growth rate over the whole season was higher than the 3 kg DM/°Cd reported for the same length of time by Tonmukayakul (2009). This difference could be described by the variation in base temperatures used. The growth rate of 3 kg DM/°Cd was calculated using a base temperature of 0 °C, compared with the broken-stick method used in this experiment. It was reported that lucerne grew at 4.9 kg DM/°Cd during spring, which was higher than a ryegrass white clover pasture in the same experiment which grew at <4.1 kg DM/°Cd. Morris (2011) found that lucerne grew at 4.2 kg DM/°Cd, compared with 3.1 kg DM/°Cd for a cocksfoot/white clover pasture. As before, the study by Morris (2011) did not use the broken stick method for calculating thermal time that was used in this experiment, thus differences in growth rates are likely to be a result of this.
The thermal time accumulation prior to the first grazing was 649 °Cd. There has been no previous research to determine the appropriate thermal time accumulation prior to the first spring grazing. Further studies to quantify this value would allow a recommendation to farmers based on their average air temperatures when they are able to start grazing.

5.4 Nitrogen status

‘Runner’ consistently had the highest nitrogen content (Figure 4.9), but ‘Stamina 5’ had the highest total accumulated nitrogen yield of 562 kg N/ha (Figure 4.10). This was higher than the total nitrogen yields of 462 and 471 kg N/ha in two dryland experiments at Lincoln University (Tonmukayakul, 2009; Morris, 2011). These values were higher than the average nitrogen yield discussed in Section 2.2.6. Nitrogen content influences WUE by affecting the photosynthetic efficiency per unit leaf area (Morris, 2011) (Section 2.2.5.3). Plants with lower levels of nitrogen had reduced protein content and activity, influencing the photosynthetic capacity of the leaf (Peri et al., 2002).

The proportion of lucerne stem and leaf can be identified across the period of growth (Brown and Moot, 2004). It was calculated that the first 2.4 t DM/ha of a lucerne stand was palatable leaf material, while any remaining dry matter could be considered unpalatable stem material. In the first three rotations all seven cultivars produced 100% palatable material of less than 2400 kg DM/ha in each rotation and left residuals of 0.2-1.7 t DM/ha of palatable herbage. When moisture became limiting in January the quality of lucerne declined as the proportion of unpalatable material increased. This is supported by Brown and Moot (2004), who reported the percentage of palatable lucerne decreased over time. The unpalatable proportion of herbage remained constant at 0.11 g/g DM, but the palatable proportion of lucerne exhibited an exponential decrease from 0.35-0.27 g/g DM as total dry matter increased from 0.7-4.3 t DM/ha. Thus lucerne stands should be grazed before they exceed 3.0 t DM/ha to ensure herbage quality does not decline to a point where animal performance is affected.

A simple regression was used to provide a multiplier that can determine the dry matter yield of a stand from the height of the sward (Appendix 5). During spring the multiplier is higher as the dry matter yields are greater, with 120 used in early spring. This decreased to around 60 during summer and autumn.
6 GENERAL DISCUSSION AND CONCLUSIONS

6.1 General discussion

Lucerne produced large quantities of high quality feed in spring, as supported by the results of this study. Production was efficient in regards of WUE and large quantities of nitrogen and ME were produced for consumption by ewes and lambs.

Based on the results of this experiment, lucerne should be utilized on farms to benefit from its increased dry matter production in periods of feed deficit during spring and summer. Lucerne should be rotationally grazed throughout the growth season using an approximately 42 day rotation. Grazing should commence at the start of the season when the first stand reaches a dry matter yield of approximately 1.5-2.0 t DM/ha. The stand should be grazed to a residual of 0.3-0.6 t DM/ha, as occurred in Paddock 1 and 2 in the first rotation of this experiment. There is a dilemma between quality and quantity of lucerne in terms of the first grazing of the season. In a grazing context farmers should not wait until October or 10% flowering has been achieved for the first grazing as recommended by White and Hodgson (1990). Based on these results, grazing the first stand before it has reached the ideal height may sacrifice yield slightly. However, this is essential to ensure the quality of the paddock in a six paddock rotation does not decline. Ewes and lambs should be stocked on the lucerne at 15-20 SU/ha (based on an average ewe live weight of 65 kg) for the spring period, and can be set stocked when lucerne growth exceeds feed demand (Stocker, 2011).

During summer, ideally, stands should be grazed at a dry matter yield of 2.5-3.0 t DM/ha and grazed to a residual of 0.5-1.0 t DM/ha at 10-15 SU/ha. Livestock should not consume more than 2.4 t DM/ha, as after this point the unpalatable stem content of the herbage increased. However stock should be offered an allowance above this, as not all that is offered is consumed.

Lucerne growth rates declined in autumn, thus stands should be grazed at around 1.4 t DM/ha to residuals of 0.4 t DM/ha and grazed at a reduced stocking rate of 5-10 SU/ha. If required, a clean-up graze should occur in mid-late autumn before all lucerne stands are shut up for the winter. Rotational grazing allows a fallow to be created to conserve soil moisture. Removal of the leaves of lucerne reduces the rate of evapotranspiration, so
particularly in deeper soils there is less moisture lost after the lucerne stand is grazed, allowing growth to continue at the end of the season.

Based on the results of this study ‘Kaituna’, ‘Stamina 5’ or ‘Stamina 6’ should be sown due to their superior yields. These cultivars are more winter active than the other cultivars used, thus have greater production during early spring and autumn. However, persistence of winter active cultivars is often not as long-term as winter dormant cultivars. Recent studies suggest these cultivars have been persisting for periods of approximately seven years. There was no difference in the nitrogen or ME content of these cultivars, with an average nitrogen content of 3% and an average ME content of 10.4 MJ ME/kg DM.

Results of this study suggested live weight gains were below what would be expected for the ewes and lambs grazing the lucerne. Numerous probable causes were investigated; however nothing definite could be concluded as the basis for this occurring. Ensuring livestock grazing lucerne are adequately drenched, provided with a fibre source if required and dry matter yields are sufficient then the live weight gains of grazing livestock should not be an issue.

Overall, the areas of lucerne in dryland environments throughout New Zealand should be increased for superior performance compared with standard pasture species such as ryegrass and white clover. The stands in this experiment were three years old and no issues were apparent with weed invasion or persistence of the lucerne.

Future research regarding the dry matter production of lucerne should focus on a number of areas, including:

- thermal time accumulation prior to the first grazing of the season, and
- simple methodologies for predicting dry matter yield, growth rates and soil water status for use on farm.
6.2 Conclusions

- ‘Kaituna’, ‘Stamina 5’ and ‘Stamina 6’ should be used as their early season production allowed them to produce annual yields of 13.2-13.3 t DM/ha. Overall, the production of ‘Kaituna’ was similar to ‘Stamina 5’ and ‘Stamina 6’.

- 48% of annual production occurred in spring when temperature and moisture were not limiting; 38% of production occurred summer as SWC became limiting and 13% of production occurred in autumn as temperature declined towards winter.

- Grazing need not be delayed in early spring, as doing so may reduce the quality of the last stand in the rotation. Utilization of the herbage was 65% for first paddock in the rotation (that was grazed at a lower height) and 60% for the last grazed stand.

- Growing lucerne on deep alluvial soils with high PAWC will reduce the impact of insufficient water extraction on dry matter yields.

- All cultivars had an average nitrogen content of 3.3% and an average ME content of 10.4 MJ ME/kg DM, both of which were adequate for sufficient animal production.

- Stands should be rotationally grazed to allow the creation of a fallow and soil moisture to be conserved during the rotation.
Acknowledgements

Finally, I would like to give a huge thanks to Professor Derrick Moot for the opportunity to study under you in my final year – you have been a great inspiration and the knowledge and passion you have for lucerne have made you a great supervisor. Thank you for your constant support and guidance, not only this year but throughout my degree – and for teaching me that the world could not be without lucerne!

Dr. Anna Mills – you have been of more help than you know and I couldn’t have done this without you. You have the patience of a saint and skills to match and I want to thank you for all of your incredible and much appreciated help – this time I promise it’s the last thing!

I would like to thank Mr. Malcolm Smith for his endless hard work in ensuring this experiment continues to run smoothly. Your commitment to the field work and data collection, as well as your willingness to always answer my ‘quick questions’ has made this year a lot easier.

To Mum, Dad, Will and my sisters – thank you for your never-ending love and support, just knowing you’re there is awesome.

And lastly to my fellow honours students, for always being around to bounce ideas off and have a laugh with or a rant when it all seems to get a bit too much – we finally made it!
References


### Appendix 1

Experiment plan for H7, Ashley Dene, Canterbury. The cultivar name represents the plot in which it is sown.

<table>
<thead>
<tr>
<th>Shelter Belt</th>
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<th>Kaituna</th>
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| Ashley Dene Road |
| Runner | Rhino | Stamina 5 | Stamina 6 | Runner | AgR (hi pref) |
| AgR (hi pref) | Runner | Runner | AgR (graz tol) | AgR (graz tol) | Kaituna | |
| Stamina 6 | AgR (graz tol) | Stamina 5 | Stamina 5 | Stamina 5 | Rhino | |
| Rhino | AgR (hi pref) | Stamina 6 | Rhino | Kaituna | Stamina 6 | |
| Stamina 5 | Kaituna | Rhino | Runner | AgR (hi pref) | AgR (graz tol) | |
| Kaituna | Stamina 6 | Kaituna | AgR (hi pref) | Rhino | Stamina 5 | |
| AgR (graz tol) | Stamina 5 | AgR (hi pref) | Kaituna | Stamina 6 | Runner | |
| AgR (hi pref) | Kaituna | Kaituna | AgR (graz tol) | AgR (graz tol) | Stamina 5 | |
| AgR (graz tol) | Rhino | AgR (hi pref) | Stamina 6 | Rhino | AgR (graz tol) | |
| Stamina 5 | Runner | Stamina 5 | Rhino | AgR (hi pref) | AgR (hi pref) | |
| Stamina 6 | Stamina 6 | Runner | Runner | Stamina 5 | Kaituna | |
| Runner | Stamina 5 | AgR (graz tol) | Kaituna | Stamina 6 | Rhino | |
| Rhino | AgR (graz tol) | Stamina 6 | AgR (hi pref) | Kaituna | Runner | |
| Kaituna | AgR (hi pref) | Rhino | Stamina 5 | Runner | Stamina 6 | |
Appendix 2 Experiment plan for H7, Ashley Dene, Canterbury. Numbers represent individual plot numbers.
Appendix 3 Experiment plan showing main paddocks and paddock rotation for H7, Ashley Dene, Canterbury.
Appendix 4 Soil map of Ashley Dene, Canterbury (red box outlines H7).
Appendix 5 Change in the relationship between height and dry matter over the 2011/2012 growth season for ‘Kaituna’ (●), ‘Stamina 6’ (○), ‘Stamina 5’ (▼), ‘AgResearch (grazing tolerant)’ (△), ‘AgResearch (high preference)’ (■), ‘Rhino’ (□), ‘Runner’ (◆) and values published by (Moot and Smith, 2011) (●) for H7, Ashley Dene, Canterbury.