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**The feeding value of a perennial lupin-cocksfoot pasture compared  
with lucerne for sheep**

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A dissertation  
submitted in partial fulfilment  
of the requirements for the Degree of  
Bachelor of Agricultural Science with Honours  
at  
Lincoln University  
by  
Matthew J. Hight

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Lincoln University

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Abstract of a dissertation submitted in partial fulfilment of the requirements  
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**The feeding value of a perennial lupin-cocksfoot pasture compared with  
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The aim of this study was to determine the feeding value of perennial lupin-cocksfoot pasture compared with lucerne for sheep. Lupin-cocksfoot and lucerne pastures sown on the 5<sup>th</sup> of December 2013 were rotationally stocked with Merino lambs over autumn (11 March – 19 May) and Coopworth hoggets over spring (5 August – 20 October) in 2014 at Lincoln University, Canterbury. The Merino lambs grew faster (32 g/day) on the lucerne in autumn because the lambs consumed more high quality leaf material in this pasture than in the lupin-cocksfoot pasture. The nutritive analyses of total herbage on offer in the lucerne and lupin-cocksfoot pastures indicated that dry matter digestibility (DMD), crude protein and metabolisable energy (ME) contents were similar in autumn. However, the DMD, crude protein and ME contents varied greatly between the separated fractions, but the nutritive value of leaves was similar for lupin and lucerne. In spring, the Coopworth hoggets grazing on lucerne had a higher growth rate (365 vs. 262 g/day), stocking rate (30.8 vs. 19.7 sheep/ha) and liveweight gain per hectare (333 vs. 177 kg/ha) than on the lupin-cocksfoot pasture. These differences were associated with greater DM

yield (2520 vs. 2100 kg DM/ha), pasture allowance (3.2 vs. 2.4 kg DM/head/day) and apparent DM intake (2.4 vs. 1.8 kg DM/head/day) for lucerne than lupin-cocksfoot. The nutritive analyses in spring were consistent with the results from autumn. Sheep showed a grazing preference for the highly digestible fractions than lower quality fractions of both swards. Lupin forage is known to contain low concentrations of alkaloids making them sour-tasting to sheep. However, the sheep in this study appeared to adapt to the taste of the lupins and they consumed lupin leaf in the first few days after they were put into a paddock of lupin-cocksfoot. Therefore, this study has shown that perennial lupins are a viable forage option for where other conventional forage legumes such as lucerne cannot be grown.

**Keywords:** *Dactylis glomerata*, dryland, high country, liveweight gain, *Lupinus polyphyllus*, *Medicago sativa*, Merino, nutritive value, rotational grazing

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## 1 Introduction

New Zealand's high country is characterised by acid (low pH) soils with low phosphorus (P) and sulphur (S) fertility. Furthermore, concentrations of exchangeable aluminium (Al) in these acidic soils often reach levels that are toxic to most legume species. High country pastures in New Zealand have traditionally incorporated legumes to improve the nitrogen (N) fertility and feed quality of pastoral systems for grazing livestock. However, the growth and persistence of the conventional forage legumes such as white clover (*Trifolium repens*) and lucerne (*Medicago sativa*) are often limited by acid, low fertility soils (Scott *et al.*, 1995). In terms of soil fertility, low N availability to plants is often the main nutritional limitation to pasture production in the high country (Lambert *et al.*, 1982). Hence, the successful introduction and persistence of legumes is essential for improving forage production in the high country. Soil pH and P levels, are regarded as the major soil fertility factors most limiting to legume (and therefore pasture) growth in high country pastures (Edmeades *et al.*, 1984). Therefore, a suitable legume for New Zealand's high country pastoral system must be able to thrive in acidic soils with low fertility and low or nil fertiliser inputs.

The perennial 'Russell' lupin (*Lupinus polyphyllus*) is a legume that is capable of surviving and thriving in sub-optimal soil conditions in the high country of NZ. It is a herbaceous perennial legume that is similar to lucerne in that it has a tap-root, grows from a crown and is dormant in winter (Scott, 1989). Agronomic studies in the high country have shown that 'Russell' lupin has the ability to survive and persist in acidic, low fertility soils. Scott *et al.* (1995) indicated that 'Russell' lupin was a persistent legume species that could be used on loose-textured soils that receive low inputs of superphosphate, in moderate to high rainfall areas, or seepage and streamside areas of dry zones of the high country in the South Island. Therefore, assuming 'Russell' lupin has a high forage nutritive value and recovers well after grazing, then its potential

as a persistent legume option in extensive grasslands should translate into improved sheep production on high country farms.

Despite the agronomic evidence supporting the persistence of 'Russell' lupin in the high country, there is much less information around its feeding value for grazing livestock. Kitessa (1992) reported that the leaves and flowers of 'Russell' lupin maintained their nutritive value throughout spring and summer (October to January), whereas the nutritive value of stem, and petioles of lupins decreased with increased plant maturity. Kitessa (1992) also showed that sheep began to eat the lupins within the first day of grazing; however, the liveweight gains of the sheep grazing on the lupins were not measured. In addition, lupin foliage contains low levels of alkaloids, which give lupins a bitter taste, but sheep adapt to them (Scott, 1989).

Until recently the only experiment investigating sheep performance on 'Russell' lupin was by Scott *et al.* (1994). In that study, liveweight of Merino wethers were reported for lupins compared with red (*Trifolium pratense*) and alsike (*Trifolium hybridum*) clovers under set-stocking from November to April at Tekapo in the South Island high country. The wethers grew faster on the red clover and alsike clover than on the lupins, suggesting that 'Russell' lupins had a lower feeding value other more conventional legumes.

In response to the lack of information around the performance of sheep grazing on perennial lupins, Black *et al.* (2014) recently investigated the performance of Merino ewes and lambs grazing on a mature stand of 'Russell' lupins over 3 years on Sawdon Station, a farm near Lake Tekapo. The herbage mass, composition and nutritive values of the lupins were also quantified over two growing seasons. The lupin stand was set stocked for about a month in spring during lambing (October to November) and then rotationally grazed until May/June, at about 10-14 ewes/ha. The authors concluded that lambs on the lupins grew almost as fast as lambs in one of the main ewe flocks grazing on lucerne and other conventional legume-based pastures on the farm. Scanning and lambing percentages and wool weights of the ewes on the lupins were also

similar to the ewes on lucerne. The leaves of the lupins were consistently high in dry matter digestibility (DMD) of 81% and N (3%-5%), while the nutritive values of petioles and stems of lupins declined as the season progressed. Those results were consistent with the nutritive value results of Kitessa (1992). While the herbage results of the lupins in that study helped to explain the sheep performance on the lupin stand, the yield, quality and stocking rates of the lucerne pastures (ca. 200 ha) were not quantified. This limited the extent to which the authors could explain any differences in sheep production between the two pastures.

In addition to feeding value, the ability of lupins to survive and regrow after grazing is essential if this plant is to be used as a low cost forage option in the high country. Lupins do not survive under prolonged continuous set stocking, although plants can be periodically grazed to ground level provided they are allowed to recover, and lax grazing at low to moderate stocking rates is probably preferable (Scott, 1989; Scott and Covacevich, 1987). The results of the grazing trial at Sawdon Station and Kitessa (1992) suggest that lupins can still produce leaves from their basal buds on the crown after the plant has reached physiological maturity and in the presence of old and new stems. This allows for either hard grazing or mowing post-grazing to remove stem residual to improve regrowth quality, without damaging the growing point a sacrificing regrowth yield. However, there has been no investigation as to the response of 'Russell' lupins to different rotational grazing regimes and its ability to quickly regenerate before the next grazing.

After reviewing all the available literature in New Zealand on perennial 'Russell' lupin, it is clear that there is a knowledge gap concerning the feeding value of 'Russell' lupin and whether it is capable of withstanding rotational grazing. More specifically, there is very little quantitative information on sheep intake of lupins, acceptability of lupins by sheep, nutritive value of plant components and corresponding lightweight gains of sheep grazing on lupins compared with lucerne. Regrowth following grazing and season growth rates of lupins compared with lucerne also have not been adequately quantified. Therefore, the aim of this study was to determine the

feed value of perennial lupins and their ability to be rotationally grazed compared with lucerne.

To do this, the study used a newly established lupin-cocksfoot pasture and lucerne pasture in H12 at Lincoln University. The specific questions of study were:

1. How well do sheep perform on perennial lupins compared with lucerne?
2. What is the nutritive value of perennial lupin compared to industry best lucerne?
3. What is the grazing behaviour and acceptability of perennial lupins to sheep compared with lucerne?
4. Can perennial lupin be rotationally grazed and what is the regrowth like after frequent rotational grazing compared with lucerne?

## 2 Literature review

### 2.1 Lupins in NZ

There are three perennial *Lupinus* species in New Zealand: *L. polyphyllus*, *L. arboreus* and *L. perennis*. All three are native to North America and *L. polyphyllus* was introduced to eastern Europe in the late 1700s to early 1800s and now is relatively widespread.

*L. polyphyllus*, the older straggly blue-flowered form of the horticultural 'Russell' lupin most probably has been in New Zealand for some time with some stands that pre-date the multi-coloured form. The multi-coloured form is a hybrid selected by George 'Russell' in the UK; *L. polyphyllus* forms the majority of its parental genetic material with small contributions from *L. arboreus* and *L. nootkatnensis* (Gladstones, 1970). It was introduced to New Zealand as a garden horticultural species. The success of *L. polyphyllus* on the bare, well-drained roadsides, wet areas, acidic, low P, high Al soils and eroding subalpine soils in the high country of New Zealand's South Island indicated its potential as a forage species on high country farms. *L. polyphyllus* is referred to by its common name perennial 'Russell' lupin throughout this dissertation.

*L. arboreus* (yellow tree lupin) is commonly found on lower altitude riverbeds and coastal sand dunes. Generally regarded as a weed and unacceptable to stock, and also has been found to change the nature of braided river floodplains. However it has been recognised for its soil improving ability in relation to coastal sand forestry plantations.

*L. perennis* was introduced as a forage species for seed production and re-export, however no evaluation has been carried out in regards to its forage potential. There seems to be little difference between *L. perennis* and *L. polyphyllus*.

Two annual species of *Lupinus* have been used as forage species in New Zealand - *L. angustifolius* (blue lupin; as bitter and white flowered sweet forms), and *L. luteus* (yellow lupin) (Claridge and Hadfield, 1972). Blue lupin peaked as lamb fattening feed (best grazed before

flowering) in the 1940's and 1950's (Greenall, 1956; McPherson, 1940), but was eventually replaced by the use of lucerne. It should be noted that the annual 'blue lupin' should not be confused with the 'blue' cultivar of perennial lupin which was compared to 'Russell' in this study.

## **2.2 'Russell' lupin**

'Russell' lupin is a tap-rooted, winter dormant, perennial lupin which grows from a crown and dies back to a stout crown each winter. During vegetative growth stems remain inconspicuous with leaves containing 9-16 pointed palmate leaflets of 5-15 cm long on 15-40 cm petioles raised from the crown. Once reproductive, stems can reach a height of 1.5 m. The seed pods produced are 2.5-5.0 cm long containing approximately 9 seeds, that are brown to black in colour with a glossy sheen (Horn and Hill, 1982; Horn *et al.*, 1987).



Plate 2.1 A whole 'Russell' lupin taken from the 8-year-old crop at Sawdon Station, 21 May 2012.

### 2.3 Growth and development

'Russell' lupin is a strongly apical dominant with plant response determined by the apical growing point at the tip of each stem. Continued vegetative growth or repeat flowering is strongly

dependent on the absence of any previous flowering stem - even if partly dead. Therefore, when grazing 'Russell' lupin as a forage on farm it would be recommended to continue grazing the crop until the stem is mostly eaten, or mow post-grazing to encourage vegetative growth and a possible second flowering. However, forcing stock to graze low-quality material may have an adverse effect on animal performance, therefore, mechanical topping may be preferred. Growth of new leaves and stems occurs from basal buds on the crown (Plate 2.1).

'Russell' lupin flowering is indeterminate and not considered to be influenced by day length and vernalisation; however this has not been quantified. In general, flowering occurs in November and December, but under any conditions suitable for growth 'Russell' lupin will try to flower in any season.

At physiological maturity the pods shatter and the seeds are dispersed. This process is strongly dependent on temperature (temperature above 25°C causes the pods to shatter) and will vary depending on the maturity of pods within a spike and between plants.

#### **2.4 Adaptations to grow in sub-optimal soils**

Lucerne is the legume of choice for dryland farms, however it is unable to grow and persist in acid soils with low fertility and is highly intolerant of aluminium toxicity (Moir and Moot, 2010) whereas 'Russell' lupin not only survives, but thrives in these conditions.

The ability of 'Russell' lupin to tolerate soil acidity and associated high levels of soluble Al (Davis, 1981a; Scott, 1989; Scott and Covacevich, 1987; Scott *et al.*, 1995) makes it a potential forage plant in areas where only low fertiliser inputs are used. The main features of lupins, with respect to productivity under adverse soil conditions, are:

1. Tolerant of low soil P levels and capable of utilising soil P which is unavailable to most other plants (Borie, 1990; Davis, 1981a). Borie (1990) listed four probable root adaptations of lupins growing on P-deficient soils: (i) root excretion of acid substances, (ii)

deep roots and other geometry of rootlets, (iii) exudation of root phosphatases, and (iv) formation of mycorrhizal associations. Lambers *et al.* (2013), acknowledged that lupins were able to mobilise unavailable P, but offered no explanation for the ability of 'Russell' lupin.

2. The potential to mobilise unavailable P in excess of their own requirement (Borie, 1990). This may increase P availability to companion species and further increase the productivity of low input pastures.
3. Large root system improves soil structure and aids erosion control on loose-textured soils by increasing the soil organic matter content, which forms and stabilises aggregates (Rowland *et al.*, 1986) and encourages N cycling (Scott *et al.*, 1995).

Table 2.1 shows the ability of lupin to persist under poor soil fertility conditions. 'Russell' lupin became and remained dominant at the lower fertiliser levels, but not without fertiliser. The application of 50 kg/ha/year S fortified superphosphate was the most relevant treatment for discussing the potential role of lupin. There was no obvious effect of the grazing intensity on the abundance of lupin during the first decade, but it decreased subsequently under moderate, and more particularly high set stocking rate treatments.

Table 2.1 Change in species dominance over six periods across 25 years in response to five rates of (superphosphate, kg/ha/year 1 = nil, 2 = 50, 3 = 100, 4 = 250, 5 = 500 + irrigation) and grazing management (H = high stocking rate, M = moderate, L = low, and s = set stocking and m = mob stocking). A = alsike clover, C = chewings fescue, D = cocksfoot, H = *Hieracium*, K = caucasian clover, L = lupin, O = tall oat grass, W = white clover, and Z = fescue tussock (Scott, 2008)

Grazing	Year 2 - 4					Year 5 - 8					Year 9 - 12					Year 13 - 16					Year 17 - 20					Year 21 - 24									
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5					
Hs	L	A	A	L	A	H	A	A	H	W	H	L	K	K	C	H	K	K	K	C	H	K	K	K	C	H	K	K	K	C					
Hm	L	L	L	L	W	L	L	L	L	D	H	L	L	L	K	L	K	K	L	K	L	K	K	K	K	L	K	K	K	K					
Ms	L	L	A	L	A	H	L	L	A	W	H	L	L	K	C	H	L	L	K	C	H	L	L	K	C	H	L	L	K	C					
Mm	L	L	L	L	A	H	L	L	L	D	H	L	L	L	D	H	L	L	L	C	H	K	K	K	K	H	O	O	K	C					
Ls	L	L	L	L	A	H	L	L	L	D	H	L	L	L	C	H	L	L	L	C	H	L	L	L	C	Z	K	K	K	K	Z	O	O	K	C
Lm	L	L	A	L	A	H	L	L	L	L	H	L	L	L	L	Z	L	L	L	C	Z	O	O	O	K	Z	O	O	O	C					

It has been reported by a number of studies that ‘Russell’ lupin has the ability to survive and thrive under minimal fertiliser inputs in the high country (Davis, 1981a; Nordmeyer and Davis, 1977; White, 1995). White (1995) found that it would persist under low soil P conditions provided S was not deficient. It was found that ‘Russell’ lupin produces more biomass than clovers (*Trifolium* spp.) on soils lacking in P (Davis, 1981a) and that it has a greater tolerance of acidity and exchangeable Al than most other legumes (Davis, 1981b; Nordmeyer and Davis, 1977; Scott *et al.*, 1995; White, 1995). Therefore, ‘Russell’ lupin could potentially complement or even replace clovers at high country sites where marginal soils cannot be sufficiently and economically developed for the production of conventional pasture legumes such as lucerne and white clover (Scott and Covacevich, 1987; Scott *et al.*, 1989).

## 2.5 Dry matter production

The majority of high country trials which investigated ‘Russell’ lupin did so without quantifying its annual and seasonal patterns of DM production. Scott (2000) reported from the Mt John trial near Tekapo in the Canterbury high country that yields of 5-7 t DM/ha/year with low-to-moderate

fertiliser inputs (0-100 kg superphosphate per year) provided conditions under which 'Russell' lupin was abundant.

Tesfaye (1989) reported annual and seasonal DM yield of 'Russell' lupins. He indicated that spring regrowth yield was higher than autumn regrowth; 70% of spring regrowth plants produced 175-375 g DM per plant while 80 % of autumn regrowth plants produced 103-63 g DM per plant. The maximum DM yield per plant was 750 g, which was mainly from spring regrowth. However his study was not aimed at determining changes in yield of 'Russell' lupins.

An experiment by Kitessa (1992) investigated the changes in DM yield until maturity of spring growth of 'Russell' lupins and determined the stage of maximum DM yield and maximum nutrient yield to identify the optimum stage to harvest or graze the plant. Plots were sown in December 1987, and individual plants were cut, dried and weighed every three weeks from 5<sup>th</sup> of October 1989 to 18<sup>th</sup> of January 1990 (Figure 2.1). The plants reached maximum biomass yield (g DM/plant) at the dry pod stage (160 g DM/plant). However, 75% of this had been produced by the full bloom stage on 16<sup>th</sup> of November. The largest yield increase was during October when plant size increased from 42-100 g DM/ plant. The second largest increase was from 28<sup>th</sup> of December to 18<sup>th</sup> of January when plant weight increased from 120-160 g DM/plant, which was a result of the onset of flowering and development of stem material (Figure 2.2).

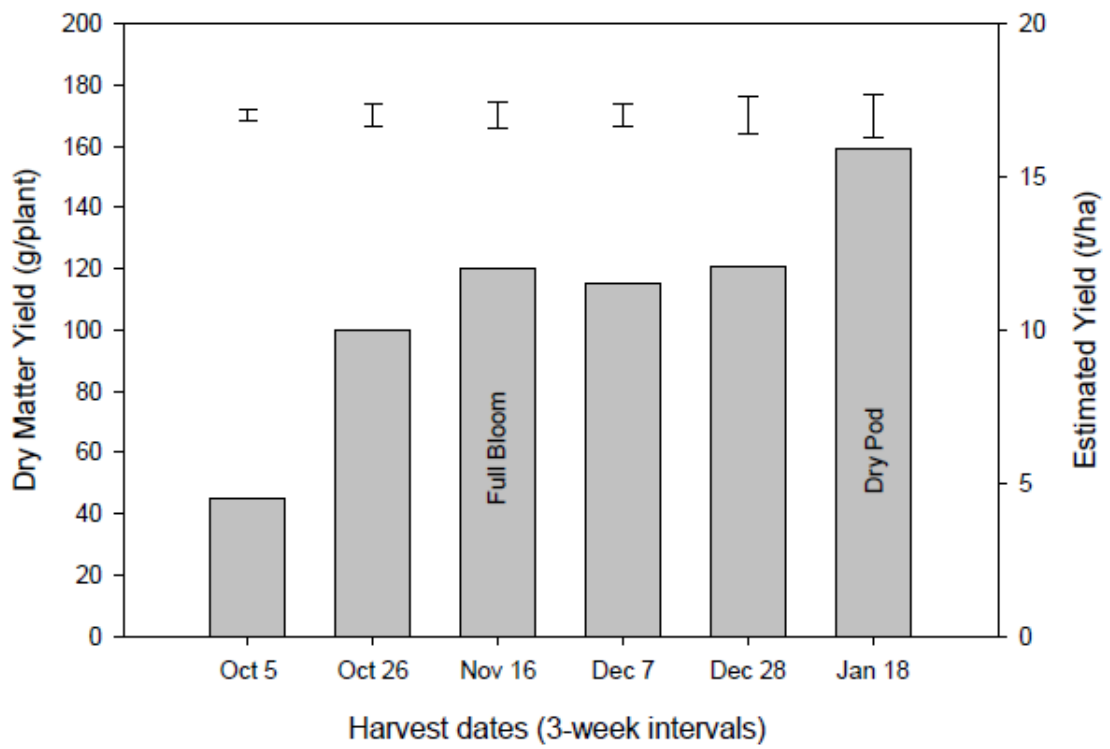


Figure 2.1 Dry matter of individual 'Russell' lupin plants at different growth stages during 5<sup>th</sup> of October 1989 to 18<sup>th</sup> of January 1990 at Lincoln University, Canterbury. Estimated yield based on plant population of 10 plants/m<sup>2</sup> (Kitessa, 1992)

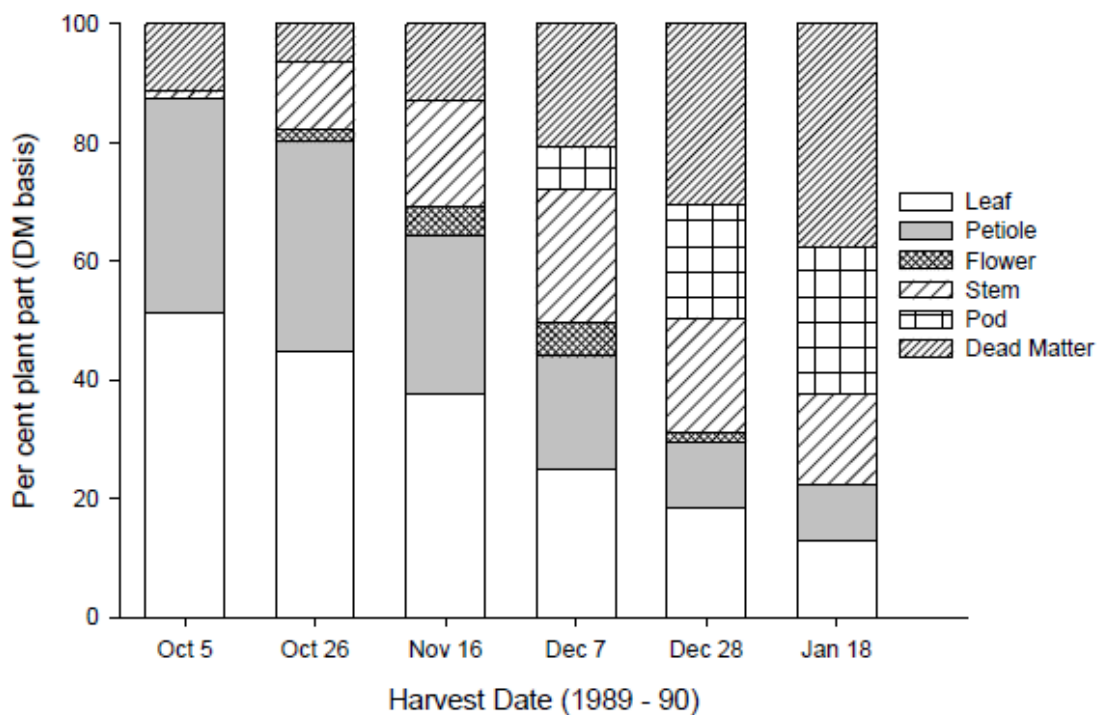


Figure 2.2 The distribution of plant parts in the total dry matter yield per plant of 'Russell' lupin at 3 week intervals from 5<sup>th</sup> of October 1989 to 18<sup>th</sup> of January 1990 at Lincoln University, Canterbury (Kitessa, 1992).

In percentage terms, the contribution of petiole and leaf to the total DM declined with maturity while that of stem increased up to pod formation (4<sup>th</sup> cut) and then declined slightly (Figure 2.2). The proportion of pod and dead matter increased consistently with maturity, and reached 25% and 39% of total DM yield respectively. This would suggest that DM accumulated between full bloom and dry pod had a low grazing preference.

Wilson (2013) reported that 'Russell' lupin total aboveground biomass as well as botanical composition both change throughout the growing season (Figure 2.3). On 11<sup>th</sup> of October, the average biomass was 2700 kg DM/ha consisting mostly of lupin leaf, petiole and dead stem material, in biomass had reached 6700 kg DM/ha and 7200 kg DM/ha in December. The majority of this increase was from green stem. The contribution of green stem, flower and dead material to the lupin biomass remained constant through to February; however, leaf and

petiole amount decreased. After this there was a small (500 kg DM/ha, of leaf and petiole) recovery by the lupins but also an increase of 2000 kg DM/ha of dead material, most of which was stem.

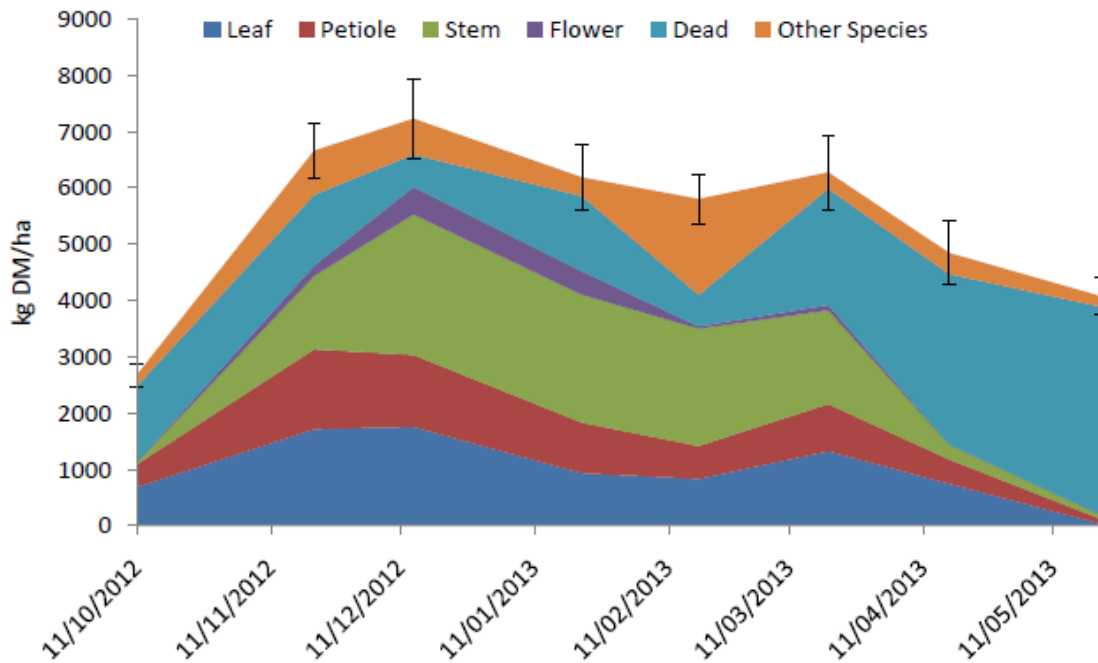


Figure 2.3 Seasonal pattern of above ground biomass and botanical composition of a crop of 'Russell' lupins for 11<sup>th</sup> of October 2012 to 22<sup>nd</sup> of May 2013 at Sawdon Station, near Tekapo in Canterbury. Bars are SEM for total biomass (Wilson, 2013).

## 2.6 Nutritive value

There is limited information available on the nutritional value of 'Russell' lupins. The major data sources are from Masters research by Soressa Kitessa (Kitessa, 1992), and Honours research by Kate Wilson (Wilson, 2013).

Kitessa (1992) reported that the leaves and flowers of 'Russell' lupin maintained their quality (12.2-12.8 MJ ME/kg DM) throughout all harvest periods, whereas the quality of stem and petiole decreased with increased plant maturity from 13.2-3.8 MJ ME/kg DM and 10.1-5.8 MJ ME/kg DM, respectively (Table 2.2).

Table 2.2 Within-harvest comparison of the mean metabolisable energy of different plant parts of 'Russell' lupin at various growth stages from the 5<sup>th</sup> of October 1989 to 18<sup>th</sup> of January 1990 at Lincoln University, Canterbury (adapted from Kitessa, 1992).

Harvest Date	Plant Part						1 L.S.D.	2 CV
	Stem	Petiole	Leaf	Flower	Pod	Dead Matter		
	MJ ME/kg DM							
Oct 5	13.2	10.1	12.2	-	-	2.6	0.05	0.04
Oct 26	11.5	9.1	12.8	11.4	-	4.2	0.07	0.05
Nov 16	7.1	7.1	12.4	12.2	-	7.5	0.04	0.11
Dec 7	5.0	6.9	12.5	12.2	11.8	5.2	0.07	0.05
Dec 28	4.4	6.9	12.6	11.9	8.1	4.0	0.06	0.05
Jan 18	3.8	5.8	12.2	-	6.5	4.5	0.17	0.15

<sup>1</sup> L.S.D. = Least significant difference at  $P < 0.05$ . <sup>2</sup> CV = Coefficient of variation (%)

Kitessa (1992) reported that N concentration in the 'Russell' lupins declined with maturity and fell from 4.2 to 2.4%, which mostly occurred over the first 3 weeks and at the final harvest it still contained DM with 15% crude protein. The *in vitro* digestibility also declined slowly, but remained above 55% over the whole sampling period. Leaf and pods had high N concentration and dry matter digestibility (DMD) and low neutral detergent fibre (NDF) concentrations, while stems showed the opposite.

A recent study by Black *et al.* (2014) agreed that N content was highest in lupin leaves, green seed pods and flowers and lowest in the stems, petioles and dead fractions (Figure 2.4). Leaf N decreased over the growth season from 5.4% to 3.8%, which was a similar decrease to that reported by Kitessa (1992). There was also a decrease in petiole N and stem N from 3.1% to 1.5% and 4.3% to 0.7% respectively (Black *et al.*, 2014). The DMD of leaves, petioles and stems was 80% in October, and leaf DMD stayed at 80% over the rest of the growth season, while petioles

and flowers plus seed pods decreased to 60%-70%, stems to 45%-55%, and dead material was 30%-56% (Figure 2.5)

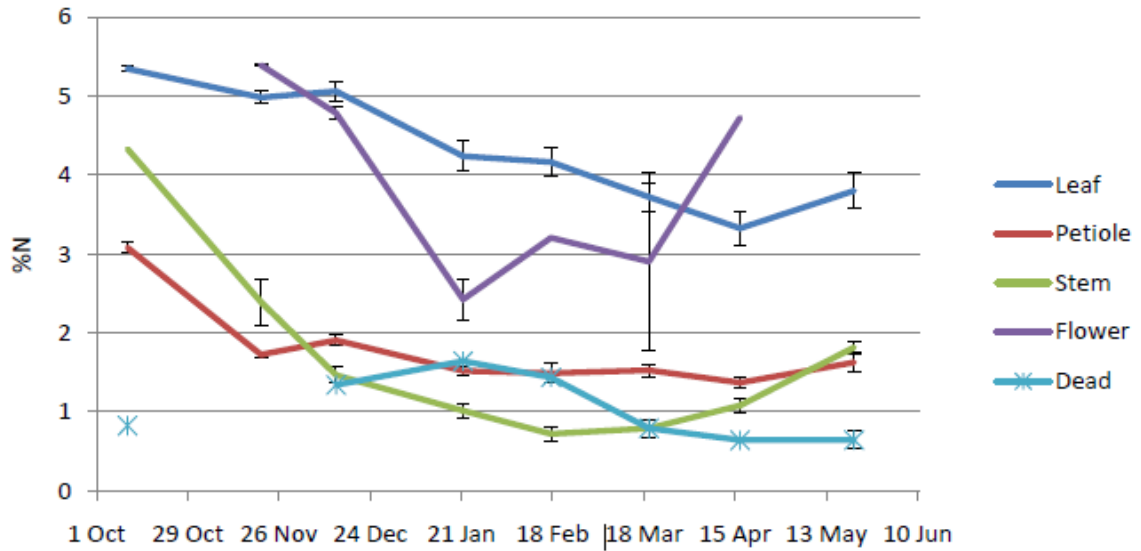


Figure 2.4 Nitrogen concentrations in the main fractions of 'Russell' lupin herbage collected between 11<sup>th</sup> of October 2012 and 22<sup>nd</sup> of May 2013 from Sawdon Station, Lake Tekapo in Canterbury (Wilson, 2013).

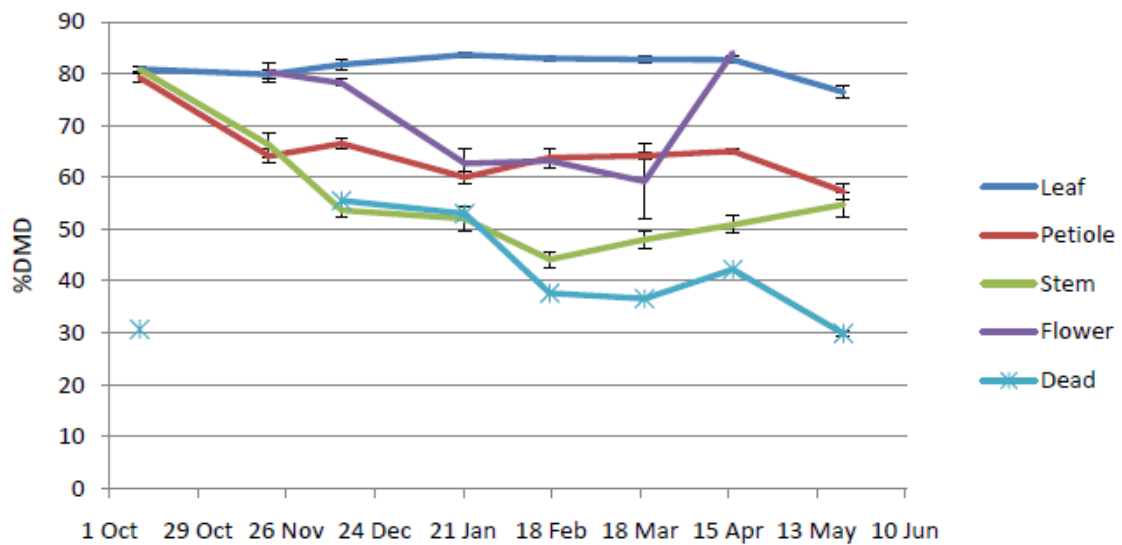


Figure 2.5 Dry matter digestibility (DMD) of the main fractions of ‘Russell’ lupin herbage collected between 11<sup>th</sup> of October 2012 and 22<sup>nd</sup> of May 2013 from Sawdon Station, Lake Tekapo in Canterbury (Wilson, 2013).

Peak digestible DM (DDM) yields of ‘Russell’ lupins, at 90 g/plant, occurred at full bloom and dry pod (Kitessa, 1992). The first peak DDM yield had less DDM from dead matter and a greater proportion of DDM from components with >80% DM digestibility. It was concluded that ‘Russell’ lupin produces high quality digestible DM with high N concentration and maintain these qualities over a long time.

## 2.7 Merino acceptability and grazing behaviour on ‘Russell’ lupins

It is known in general agriculture that animals and their ruminant micro-organisms need time for adaption to a new feed type. The present ‘Russell’ lupin is not highly acceptable to stock due to the bitterness caused by the alkaloid content. It has a high novelty to stock when at low densities, but when initially forced to feed at high plant densities by fencing and mob stocking, they seem to adapt to it.

Scott (1989) stated that the unacceptability of lupin to sheep over summer was undoubtedly due to high levels of alkaloids in the leaves, but was unsupported, neither did the study compare acceptance within a season in relation to stage of growth. It was possible that there was a substantial increase of stem and dead material over summer as reported by Wilson (2013) that had a negative impact on grazing preference. Under more frequent or intensive grazing, fresh regrowth may be able to maintain feeding value.

Gymptsho (1987) suggested that from 5570 kg DM/ha produced by 'Russell' lupins, 4530 kg DM/ha was 'browsable'. This assumption was based on an arbitrary definition that fine stem and leaf would be browsable as the study did not involve grazing by sheep. Kitessa (1992) indicated that leaf material remained the most acceptable of all yield components regardless of growth stage (Table 2.2). Within four days of sheep being introduced to the lupin plots on 27<sup>th</sup> of October, 99% of leaf material had been removed (Figure 2.6). Field observations indicated that flowers are the most preferred component of lupin yield, followed by leaves. This is inconsistent with Kitessa (1992) who reported that flowers were not grazed until nearly all the leaf material has been removed. All other components are not heavily grazed until the majority of leaf material has been removed. However there is little evidence to show that this grazing preference between leaf and flowers is based on quality (Table 2.2). Black *et al.* (2014) reported that DMD of leaves remained over 80% for the whole growth season whereas the DMD of flowers decreased to 60%-70%, which may explain the grazing behaviour reported by Kitessa (1992).

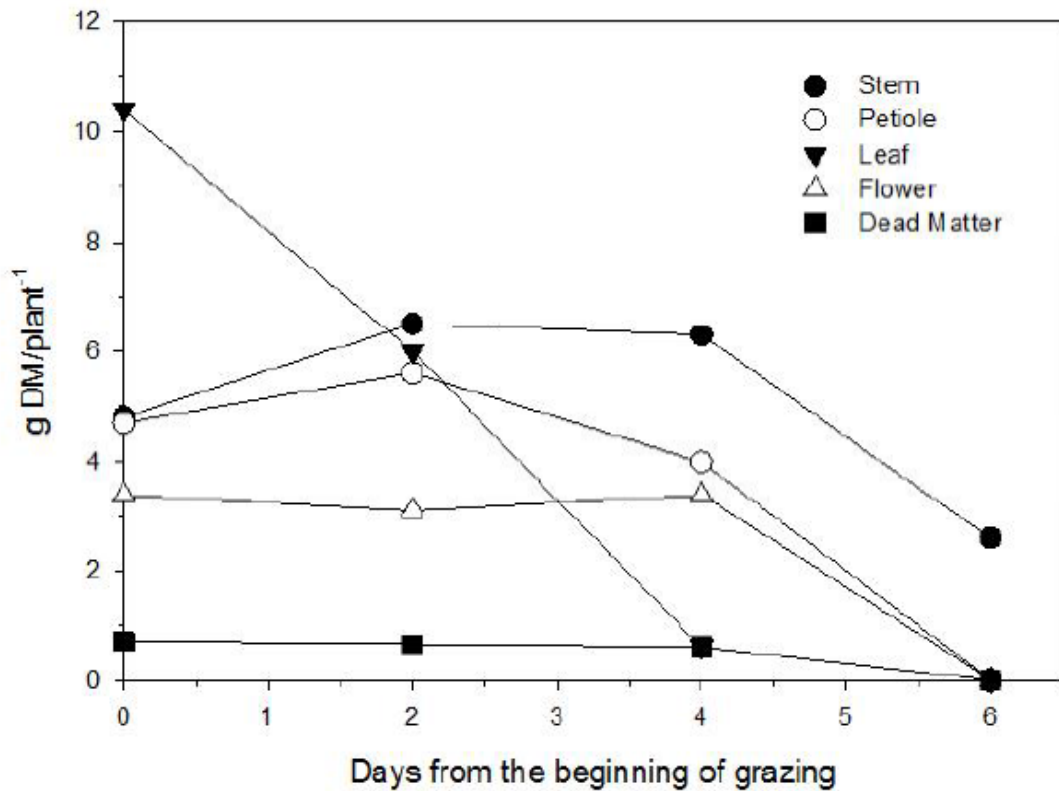


Figure 2.6 The pattern of disappearance of individual yield components of 'Russell' lupin plants over successive days of grazing from the 27<sup>th</sup> of November to the 3<sup>rd</sup> of December 1990 at Lincoln University, Canterbury (Adapted from (Kitessa, 1992).

Scott and Covacevich (1987) indicated that young flower buds are often the first part to be eaten from the plant. During spring, the observation was made that all parts of the plant are eaten, but then leaves are progressively grazed less. There was also evidence to suggest that sheep performance might decline once the flowers, leaves and immature green pod of the lupin have been consumed (Table 2.2). Wilson (2013) reported that a pre-grazing biomass of 7600 kg DM/ha looked similar to the post-grazing biomass of 4600 kg DM/ha, however the amount of leaf, petiole and flower were greater in the pre-grazing paddock. This indicates that the sheep were accepting these fractions and rejecting most of the green and dead stem.

Kitessa (1992) found that at the green pod stage sheep had removed all the weeds and started eating the lupins within the first day of grazing. The DM residual was slightly less on plots

grazed by accustomed sheep than on those grazed by unaccustomed sheep (Figure 2.7). Nevertheless, there were no differences ( $P>0.05$ ). At this stage the rate of DM disappearance was faster ( $P<0.01$ ) than at the full bloom stage. At the full bloom stage leaves were the most preferred parts. They composed 77% and 66% of total DM disappeared after the first two and four days of grazing, respectively which was more than twice the proportion of leaves in total DM on offer.

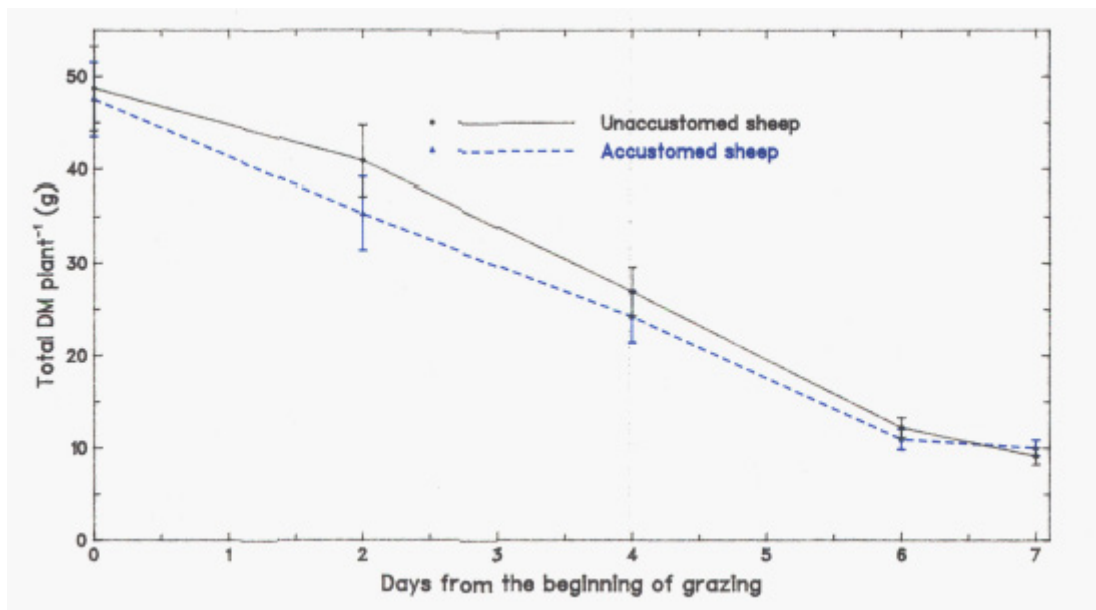


Figure 2.7 Comparison of defoliation over successive days of grazing ‘Russell’ lupin plants by accustomed and unaccustomed sheep at green pod stage (Kitessa, 1992).

When a ‘Russell’ lupin pasture was grazed by sheep at full bloom, the residual herbage was 270 kg DM/ha, which was considerably lower than the 960 and 1290 kg DM/ha left after the green and dry pod grazings, respectively (Table 2.3). Grazing preference was reduced by the increasing proportions of stem, pod and dead matter which decreased whole-plant quality. Grazing at full bloom stage provided a balance between herbage quality and quantity, and added flexibility in autumn. Lupin regrowth in autumn could also be used as feed for flushing ewes (Kitessa, 1992).

Table 2.3 Effect of spring/summer grazing on autumn regrowth of 'Russell' lupins at Lincoln University, Canterbury (Kitessa, 1992).

Growth stage at spring/ summer grazing	Autumn regrowth yield		
	Residual (kg/ha)	Regrowth (kg/ha)	Utilisation (%)
Full Bloom (27/11/90)	270	6690	89
Green pod (17/12/90)	960	2818	80
Dry pod (21/01/90)	1920	362	75

Kitessa (1992), stated that the results conclusively indicate that plant parts which were the major contributors to total N and *in vitro* digestible DM yield, namely leaves and petioles, were also the parts readily accepted by sheep; at all growth stages both components had around 100% utilisation.

### 2.7.1 Feed utilisation

Kitessa (1992) reported that as a 'Russell' lupin plant matured the feed utilisation by sheep decreased (Table 2.3). At full bloom the feed utilisation was 89% which decreased to 80% and 75% for growth stages green pod and dry pod respectively. This indicates that grazing at full bloom is likely to provide the optimal feed quality against feed quantity and give enough time for the plant to recover for an autumn grazing. However, to increase the nutritive value of 'Russell' lupins and liveweight gain of sheep on lupins, it may be better to graze the plant at an earlier stage of regrowth than some nominal state of reproductive maturity.

### 2.8 Regrowth after grazing

Lupin does not survive continuous set stocking, although plants can be periodically grazed to ground level, provided they are allowed to recover. Lax grazing at low to moderate stocking rates is probably preferable (Scott, 1989; Scott and Covacevich, 1987).

Wilson (2013) suggested that lupins can still produce new leaves from their basal buds on the crown after the plant has reached physiological maturity and in the presence of old and new stems. This was evident from that the small (500 kg DM/ha) regrowth during the month the lupin paddocks were spelled. It was observed that the regrowth of new leaf material was mostly from basal buds on the lupin plant rather than from any nodes that remain on the residual stems. This allows for either hard grazing or mowing post grazing to remove stem residual to improve regrowth quality, without damaging the growing point and sacrificing regrowth yield.

Kitessa (1992) reported that when a 'Russell' lupin stand was grazed at the full bloom stage (27/11/90) stock grazed to a residual of 270 kg DM/ha and the subsequent regrowth was 6690 kg DM/ha (Table 2.3). In comparison when grazed at the green pod (17/12/90) and dry pod (21/01/91) growth stage the grazing residual was 960 and 1920 kg DM/ha respectively with regrowth of 2818 and 362 kg DM/ha respectively. Although the amount of residual herbage mass remaining for regrowth was the smallest for lupins grazed at full bloom, the highest autumn regrowth was obtained from these lupins. Therefore, it was the time of grazing rather than the amount of residual herbage mass left that determined the amount of autumn regrowth obtained from 'Russell' lupin. Kitessa (1992) suggested that this probably related to the accumulation of nutrient reserves in the root system. The residual herbage mass did effect the quality of the regrowth, the combination of early grazing time at full bloom and the subsequent low grazing residual result in a favourable regrowth of high quality for an autumn grazing (flushing ewes). He concluded that, although annual DM yield was higher for lupins grazed at dry pod, grazing at full bloom increases the scope of incorporation of 'Russell' lupins in the New Zealand farming system.

Black *et al.* (2014) reported that a rotationally grazed 'Russell' lupin pasture at Sawdon Station when spelled for a month after weaning (February) had an average regrowth of 0.4 and 0.3 t DM/ha for 2013 and 2014 respectively. This small regrowth is likely due to the lack of time for the plants to recover before autumn grazing. Full bloom harvestable regrowth yield after

grazing in late November was 4872 kg DM/ha, which was three times greater than the regrowth of plants grazed at the dry pod stage in January (1597 kg DM/ha) (Kitessa, 1992). Vegetative growth was limited following grazing at the dry pod stage in late summer, as plants had little time to recover before autumn grazing.

'Russell' lupin develops a tap root similar to lucerne and also regrows from basal buds. 'Russell' lupin basal buds are located on the crown of the plant (Plate 2.1). These growing points are somewhat above ground, so grazing should preferably be down to, but not below 2-4 cm (Scott, 2012). Lucerne regrowth, after defoliation by grazing or cutting, also occurs from new basal buds located on the crown of the plant (Thomas, 2003). In lucerne, basal bud initiation and early growth are driven by remobilisation of carbohydrate and amino acid reserves from stores in the crown and tap root (Avice *et al.*, 1996). This would suggest that a similar grazing management practice could be applied to 'Russell' lupin management from lucerne grazing management as their mechanisms for regrowth are similar.

Kitessa (1992) allowed the 'Russell' lupin crop to reach certain stages of maturity to maximise DM yield before grazing (Figure 2.1). However, this was at the expense of crop quality as the quantity of stem and dead material greatly increased (Figure 2.2). Therefore the question can be asked, can 'Russell' lupin be grazed during the vegetative phase while quality is high and will the following regrowth be sufficient enough to support a rotational grazing system?

## **2.9 Merino performance on 'Russell' lupins**

Until recently there was only one study that had investigated the performance of Merinos on 'Russell' lupin. It is well known that 'Russell' lupins can grow in the harsh condition of the high country but whether they can support good animal performance needs to be investigated further. Scott *et al.* (1994), at Tekapo, found that Merino wethers set stocked on perennial ('Russell') lupins from November to March had a mean liveweight gain of 58 g/day compared with 110 and

77 g/day for red and aslike clovers, respectively. Kitessa (1992) grazed 'Russell' lupins with sheep, but did not measure animal performance.

A recent experiment by Black *et al.* (2014) at Sawdon Station, Tekapo, found that lambs had gained 150 g/day between tailing and weaning for a lupin pasture compared with 217 g/day on a lucerne pasture in 2011/2012 (Figure 2.8). Lamb growth rates were 121 and 166 g/day for lupin pasture and 152 and 194 g/day for the lucerne pasture in 2012/2013 and 2013/2014 respectively (Table 2.5). Lamb growth rates were consistently 30%-50% lower than the growth rates on the control pasture. Ewe liveweight during lambing tended to decrease in the Merinos grazing the lupins, 121 and 64 g/day decrease in 2012 and 2013 respectively. The ewes grazing the control pasture also lost liveweight in 2012 (30 g/day), however gained liveweight in 2013 (Table 2.5). The decrease in ewe liveweight and lower gain than the control ewes was attributed to potentially the lack of leaf material at this time on the lupin pasture. The lambing percent of the Merino ewes grazing the lupins seemed to be greater than the ewes grazing the conventional pasture (Table 2.4). This was possibly explained not by the nutritional quality of the lupins but by the tall shelter for new-born lambs that the lupin plants provided.

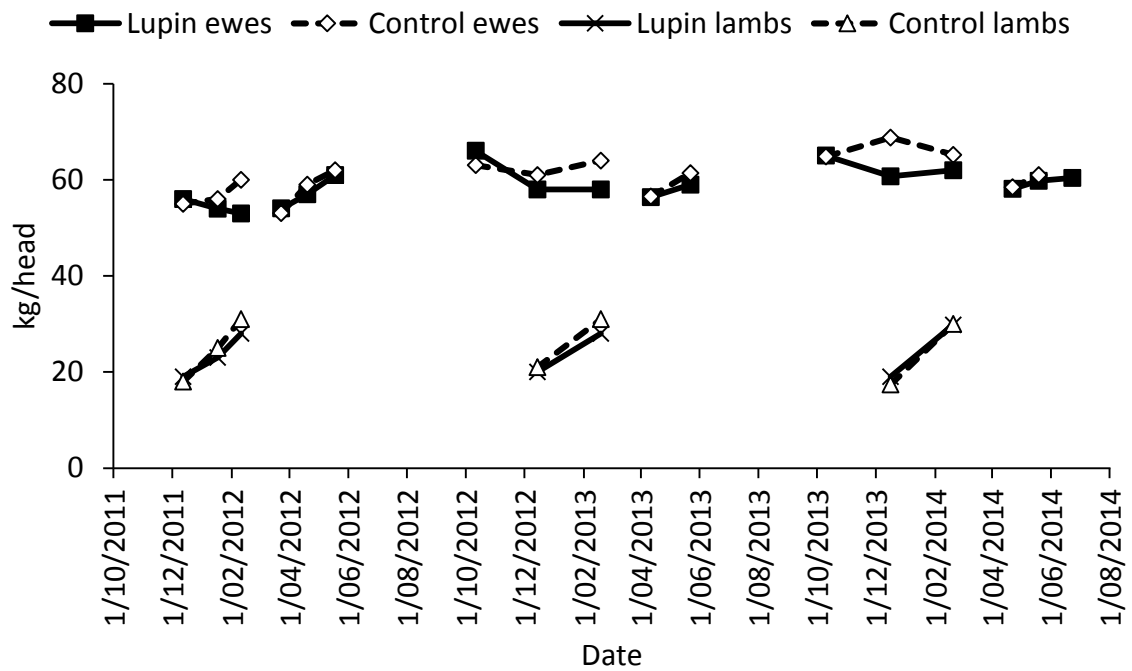


Figure 2.8 Live weights of Merino ewes and lambs on ‘Russell’ lupins compared with conventional pastures (control) from December 2011 to June 2014 at Sawdon Station, Lake Tekapo in Canterbury (Black *et al.*, 2014).

Table 2.4 Lambing percentages of Merinos on ‘Russell’ lupins compared with conventional pastures (control) for 2012 and 2013 at Sawdon Station, Lake Tekapo in Canterbury (adapted from Black *et al.*, 2014).

Year	Lambing %	
	Lupin	Control
2012	103	93
2013	120	117

Table 2.5 Liveweight gains of Merino ewes and lambs on ‘Russell’ lupins compared with conventional lucerne pastures (control) from December 2011 to May 2014 at Sawdon Station, Lake Tekapo in Canterbury (adapted from Black *et al.*, 2014).

Date	Ewes		Lambs	
	Lupin	Control	Lupin	Control
	Liveweight gain (g/day)			
12 Dec - 10 Feb 2012	-50	83	150	217
23 Mar - 18 May	125	161		
11 Oct - 14 Dec	-121	-30		
14 Dec - 18 Feb 2013	0	45	121	152
11 Apr - 22 May	64	120		
11 Oct - 16 Dec	-64	59		
16 Dec - 19 Feb 2014	19	-54	166	194
24 Apr - 19 May	63	96		

Black *et al.* (2014) reported three key results: 1) perennial lupins were used successfully as a forage crop for lambing, lactation and flushing ewes before and during mating, with acceptable lambing percentages, lamb weights and wool growth; 2) lupin growth started in September and provided significant amounts of forage during lambing and lactation; and 3) the leaves of the lupins were high in crude protein and digestibility during the entire grazing season. The authors concluded that after 3 years of measurement, it was shown that Merinos on lupins will perform almost as well as Merinos on lucerne and other improved pastures.

## 2.10 Measuring the feeding value of legumes?

Forage feeding value (FV) is defined as the animal production response to grazing forage under conditions where availability of the forage does not restrict animal performance (Barry, 2013). It is generally expressed as liveweight gain (LWG) in growing animals or milk yield in lactating animals, often when they are grazing diets of only one forage. Components of FV are voluntary feed intake (VFI), apparent digestibility and efficiency of utilisation of digested nutrients. When comparing FV between forages, it is generally accepted that a high ratio of readily fermentable carbohydrate (CHO) to structural CHO will lead to more rapid degradation in the rumen, faster rumen clearance and higher VFI and FV.

Currently there is no published data investigating the feed value of 'Russell' lupins. Scott *et al.* (1994) compared liveweight gain of Merino wethers on lupins, aslike and red clovers but did not measure feed intake. Kitessa (1992) measured FVI by disappearance and apparent utilisation; however sheep liveweight gain was not measured. Further research needs to be undertaken into the apparent digestibility of 'Russell' lupins and the efficiency of utilisation of digested nutrients.

## 2.11 Alkaloids

Lupin leaf has been shown to have high nutritive value (Kitessa, 1992; Wilson, 2013), however it has been suggested that secondary alkaloid compounds are somehow impacting on grazing preference (Scott, 1989). Much of the alkaloid content of annual lupins was removed early in the 20<sup>th</sup> century, and modern hybrids contain low levels of alkaloids (Gladstones, 1970). However, low levels of alkaloids are still present in lupins and serve an important purpose.

Lupins contain alkaloids that belong to the quinolizidine group (Wink, 1983; Wink and Witte, 1984; Wink, 1987). Their chemical structure is responsible for the bitterness associated with such compounds. Quinolizidine alkaloids (QA) are synthesised in the chloroplasts (Wink *et al.*, 1982). The alkaloids are produced in the leaves and are translocated throughout the plant via

the phloem (Wink *et al.*, 1982). In mature plants, the QA tend to accumulate in the seeds, pods, stems and roots (Gladstones, 1970; Wink, 1987).

The use of alkaloids as a defence mechanism and resultant plant survival; is certainly a plausible explanation for their presence. As a result of their presence, grazing animals may experience bitterness whereas insects are repelled by bitterness of alkaloids, even when present at low levels.

## **2.12 Animal health**

For a number of decades in New Zealand stock have been exposed to perennial lupins in different situations and it is clear that there are no animal health issues relating to perennial 'Russell' lupin. *Lupinosis* is a mycotocicosis caused by the ingestion of toxins produced by the fungus *Phomopsis leptostromiformis* (Edgar *et al.*, 1986), which commonly colonises dead lupin tissue (Gardiner and Petterson, 1972). This issue is mostly related to annual 'blue' lupin and is not known to occur in 'Russell' lupin.

### 2.13 Conclusions

- Perennial 'Russell' lupin has the ability to survive and thrive on marginal, acidic, low fertility soils in the South Island high country. They are a suitable forage species for loose-textured soils that receive low amounts of sulphur superphosphate in the moderate to high rainfall areas.
- The seasonal dry matter production of 'Russell' lupin has recently been quantified. With annual production providing sufficient amounts of forage for Merino ewes and lambs during the critical period from lambing in October to Weaning in February, and for the ewes during flushing from March to May at Sawdon Station, Lake Tekapo in Canterbury.
- Although animal liveweight gain of sheep grazing 'Russell' lupins has been measured, there is limited knowledge on animal performance of sheep grazing perennial lupin pastures. Therefore, further research is required to determine the expected animal performance of sheep grazing 'Russell' lupin.
- The grazing management of 'Russell' lupin in studies to date have mostly allowed the crop to reach a certain maturity level before grazing, this has been at the expense of crop quality. There has been little research investigating the potential ability of 'Russell' lupin to be rotationally grazed.

### **3 Materials and methods**

#### **3.1 Experimental site**

The experiment was located at the Horticultural Research Area (H12), Lincoln University (43°38'54" S 172°27'24" E) in Canterbury at an altitude of 9 m. The soil was a Templeton silt loam (New Zealand Classification: Typic Immature Pallic Soil (Hewitt 1998); USDA: Udic Haplustept soil (Soil Survey Staff 1998)). The climate is maritime temperate and sub-humid, characterised by cool, moist winters, and warm, dry summers. The predominant wind is a cool north-east sea breeze, but the site is also exposed to cold, moist south-west gales and a warm, dry north-west föhn wind. The mean annual temperature is 11.7°C, mean annual rainfall is 600 mm and mean annual evapotranspiration is 1020 mm.

A grass-clover pasture (ca. 2 ha), which had been used for grassland experiments from 2008-2012, was ploughed and sown into forage oats in March 2013 to reduce any background effects of the previous experiments. The oats were harvested in October 2013 and the area was irrigated and tilled through November in preparation for sowing.

#### **3.2 Experimental design**

The area (90 x 174 m) was divided along its longer axis into three blocks (replicates) each containing two 29 x 90 m (ca. 0.26 ha) plots. One plot in each block was selected at random to receive the lupin-cocksfoot and the other plot for lucerne. Raceways were located along the north, west and south boundaries of the experiment and the west raceway connected the six plots to a small corral.

#### **3.3 Plant varieties**

The lupin seed was supplied via Rosevear & Co. Ltd, Ashburton, from a commercial grower. The two lupin varieties used here are loosely referred to as 'blue' and 'Russell' as these were the common names supplied by the seed supplier. The 'blue' perennial lupin used here is not to be

confused with the annual 'blue lupin' (*L. angustifolius*) which is the more commonly planted forage lupin. The 'Russell' lupin seed used here was mostly derived from collections of roadside populations in New Zealand of the multi-coloured horticultural lupin hybrid *L. polyphyllus* x *L. arboreous* and is likely to include genetic material from other lupin species as well (Edward, 2003).

The cocksfoot cultivar used here was 'Grasslands Kara', bred in New Zealand and supplied via Agricom. Grasslands 'Kara' is described as having an upright growth habit, a mid-season heading date and improved winter growth and disease resistance than other cocksfoot cultivars in New Zealand.

The variety of lucerne used was 'Force 4', bred in Europe and supplied by Seed Force Ltd, Christchurch. 'Force 4' has a dormancy of four on the international dormancy scale of 1-10 (1 = highly winter dormant, 10 = highly winter active), therefore it has moderate winter dormancy. The majority of lucerne cultivars sown in New Zealand have a winter dormancy rating of four or five. The lucerne seed supplied was coated and inoculated.

### **3.4 Pasture establishment**

The lupin seed was scarified and inoculated with Group G rhizobia inoculant (Becker Underwood, Australia) on the day before sowing. This rhizobia is currently recommended for annual blue lupins and perennial 'blue' and 'Russell' lupins in New Zealand. However, recent research has indicated that the inoculation may not have been necessary (Ryan-Salter *et al.*, 2014). No additional seed treatment was applied to the lucerne and cocksfoot.

The plots were sown on 5 December 2013 using a Flexiseeder precision drill 2.1 m wide and fitted with coulters spaced 150 mm apart. The lupin sowing rate was 30 kg/ha with 10 kg/ha of 'Grasslands Kara' cocksfoot. 'Blue' lupin was sown in an 8 x 80 m strip in the middle of the plot and 'Russell' lupin was sown in the rest of the plot. The lucerne was sown at a rate of 15 kg/ha.

Soil test results from 14 March 2014 indicated pH 6.0 and Olsen P 10. There was no fertiliser applied at sowing.

Table 3.1 Soil analysis of the experiment site (H12) on 14 March 2014 at Lincoln University, Canterbury (0 - 7.5 cm depth).

pH	Olsen P (QTU)	K (QTU)	Ca (QTU)	Mg (QTU)	Na (QTU)
6.0	10	7	10	17	6

Following sowing the plots were irrigated (ca. 60 mm) through January and February and individually fenced in March. Each plot was divided into five 18 x 29 m paddocks by erecting four three-wire temporary electric fences across the plots.

### 3.5 Grazing Management

The livestock used for the autumn grazing rotation of this experiment were Merino lambs obtained from Sawdon Station, near Tekapo in Canterbury and were ewe lamb replacements. Grazing began with 50 lambs across the six plots with stock numbers per paddock adjusted as required based on pre-grazing herbage mass to keep stocking rate constant. There were five core lambs specific to each plot that grazed that particular plot for the entire autumn grazing rotation. Measurements from these lambs were used to compare growth rates. The first autumn rotation commenced on 11<sup>th</sup> March 2014 and stock were removed for winter on 19<sup>th</sup> May 2014. Each plot was grazed with five paddocks per plot and 7-11 days per paddock depending on pre-grazing pasture mass, and moved to a new paddock once pasture grazed to 3-4 cm in height. Following grazing paddocks were mown (3-4 cm height) if residual was uneven across the paddock and in an attempt to remove the fathen (*Chenopodium album*) (Plate 3.1). Lucerne was sprayed with 'Spinaker' on 8 July 2014 for control of broadleaf weeds and Gallant a week later for annual grasses.



Plate 3.1 Fathen in the lupin-cocksfoot plots during the first autumn grazing rotation (26 March 2014).

In spring, sheep were put onto lupin-cocksfoot pastures on the 5<sup>th</sup> August and were shifted every 7 days however, sheep were not put onto lucerne pastures until the beginning of the 2<sup>nd</sup> spring rotation on the 15<sup>th</sup> of September. Sheep grazing lupin-cocksfoot pasture continued to be shifted every 7 days but the sheep grazing lucerne pastures had 4 days in the 1<sup>st</sup> paddock, 6 in the second, 7 in the third, 8 in the fourth and 10 in the fifth because there was no feed wedge established for the lucerne pasture. However the overall length of the 2<sup>nd</sup> grazing rotation was the same for both pastures.

## **3.6 Measurements**

### **3.6.1 Herbage mass**

The amount of herbage dry matter (DM) in the pasture was obtained before and after grazing. Each time the groups were shifted, one random 0.5 m<sup>2</sup> quadrat of herbage for each pre-grazing and post-grazing paddock was cut to ca. 1 cm above ground level. The herbage sample was weighed before and after drying at 65°C in a forced-draft oven for 24-48 hours to determine its mass and DM content.

The average height of the pasture was measured each time the groups were shifted and at 14 day intervals through the winter period with 20 random readings per paddock, using an automated sward stick (Jenquip, Feilding, New Zealand). When the animals were first brought onto the trial on the 11<sup>th</sup> March 2014, pasture heights were only measured in the pre-grazing paddocks. The groups were shifted to their second paddock on the 18<sup>th</sup> of March, pasture heights were only taken in those paddocks and the paddocks that had just been grazed, after which all paddocks were measured for pasture height at each group shift.

If a paddock was mown post-grazing, the average height of the pasture was measured immediately following mowing.

### **3.6.2 Herbage accumulation**

Herbage accumulation was calculated for each paddock as the change in herbage mass since the previous measurement. Total herbage accumulation was summed from sowing (5<sup>th</sup> December 2013) up until when each paddock was grazed during the last rotation from 15 September to 20 October 2014.

### **3.6.3 Botanical Composition**

Pre-grazing and post-grazing herbage samples taken from the quadrats were separated into botanical components and dried to determine the botanical composition of the pasture. From

pre- and post-grazing sample values obtained, animal grazing selection could be determined for each paddock when it was grazed. A more detailed measurement of herbage defoliation was made when one of the five paddocks (paddock 2) per plot was grazed from 19<sup>th</sup> September – 25<sup>th</sup> September 2014 for the lucerne plots and from 22<sup>nd</sup> September – 29 September 2014 for the lupin plots. This was done by taking quadrat cuts and determining herbage mass and botanical composition on the day sheep were moved into the paddock followed by every 2-3 days until the sheep were taken out. This set of measurements allowed the relative defoliation of total herbage and of each component of the swards to be determined.

#### **3.6.4 Stock liveweight**

All lambs were weighed to the nearest 0.1 kg immediately before they were shifted to a new paddock. The liveweight data from the core lambs (five/plot) were used to determine the average daily liveweight gain for the plot. This value was applied to the number of all animals on the plot to determine the liveweight gain per hectare.

#### **3.7 Nutritive value analyses**

The samples of lupin and lucerne were retained and ground (Cyclone mill with a 1 mm sieve) for nutritive analysis at the Riddolls Analytical Laboratory at Lincoln University. Each sample was scanned by near infrared reflectance spectroscopy (NIRS) to determine crude protein and DMD. Analysis of organic matter was given which was used with DMD to calculate metabolisable energy (ME).

#### **3.8 Meteorological data**

Mean monthly air temperature and total monthly rainfall data were collected from Broadfields meteorological station located approximately 2 km north of the experimental site (43°62' S, 172°47' E).

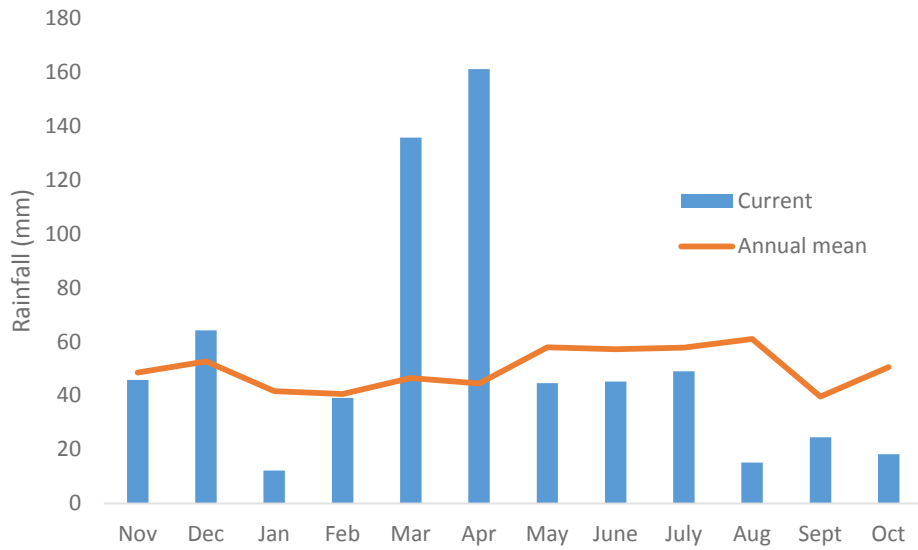


Figure 3.1 Accumulated rainfall between 1<sup>st</sup> of November 2013 and 31<sup>st</sup> of October 2014 and 30 year annual mean rainfall from Broadfields meteorological station, Lincoln, Canterbury.

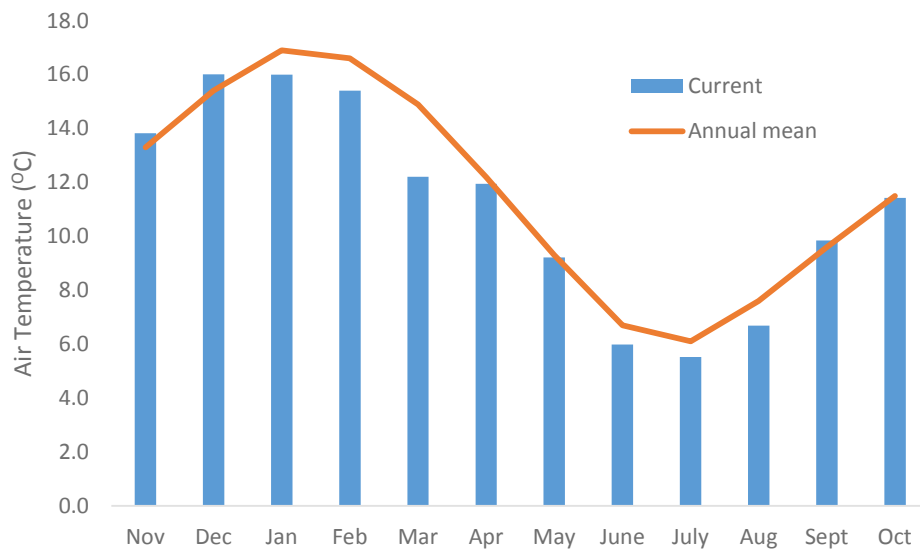


Figure 3.2 Mean air temperature between 1<sup>st</sup> of November 2013 and 31<sup>st</sup> of October 2014 and 30 year annual mean air temperature from Broadfields meteorological station, Lincoln, Canterbury.

### **3.9 Statistical Analysis**

All analyses were conducted with Genstat 16 Ed. (VSN International, 2014). The experiment was analysed for significant ( $\alpha=0.05$ ) effects on the variables from lupin-cocksfoot and lucerne pastures using the general analysis of variance model. For comparison of the means, all standard error of differences (SED) have been calculated at the  $P<0.05$  level.

## 4 Results

### 4.1 Animal performance

In autumn, the growth rate of the Merino lambs was higher ( $P<0.05$ ) on the lucerne (60 g/day) compared with the lupin-cocksfoot pasture (28 g/day) (Table 4.1). There were no differences between the two pastures in stocking rate and liveweight gain per hectare.

In spring, the growth rate of the Coopworth hoggets grazing on lupin-cocksfoot from 5<sup>th</sup> of August to 15<sup>th</sup> of September was 174 g/day at 15.4 sheep/ha, resulting in 110 kg/ha of liveweight gain (Table 4.1). From 15<sup>th</sup> of September, when the other hoggets started to graze the lucerne, to 20<sup>th</sup> of October, the growth rate of the hoggets on the lucerne (365 g/day) was higher ( $P<0.01$ ) than on lupin-cocksfoot (262 g/day) pastures. Also, lucerne was able to carry a higher ( $P<0.001$ ) stocking rate which resulted in more ( $P<0.01$ ) liveweight gain per hectare than on the lupin-cocksfoot pasture. Figure 4.1 shows the difference in growth rates between the Merinos and Coopworths grazing on the lucerne and lupin-cocksfoot pastures.

Table 4.1 Growth rate (GR), stocking rate (SR) and liveweight gain per hectare (LWG) of Merino lambs during autumn (11 March – 19 May 2014) and Coopworth hoggets during spring (5 August – 20 October 2014) on lupin-cocksfoot (Cf) compared with lucerne pastures at Lincoln University, Canterbury.

Pasture	GR (g/day)	SR (sheep/ha)	LWG (kg/ha)
Autumn (11 March to 19 May)			
Lucerne	60	26.7	110
Lupin-Cf	28	31.3	60
SED	3.9	1.24	12.2
P	<0.05	NS	NS
Early Spring (5 August to 15 September)			
Lupin-Cf	174	15.4	110
Mid Spring (15 September to 20 October)			
Lucerne	365	30.8	333
Lupin-Cf	262	19.7	177
SED	16.7	0.3	13
P	<0.01	<0.001	<0.01

NS = not significantly different

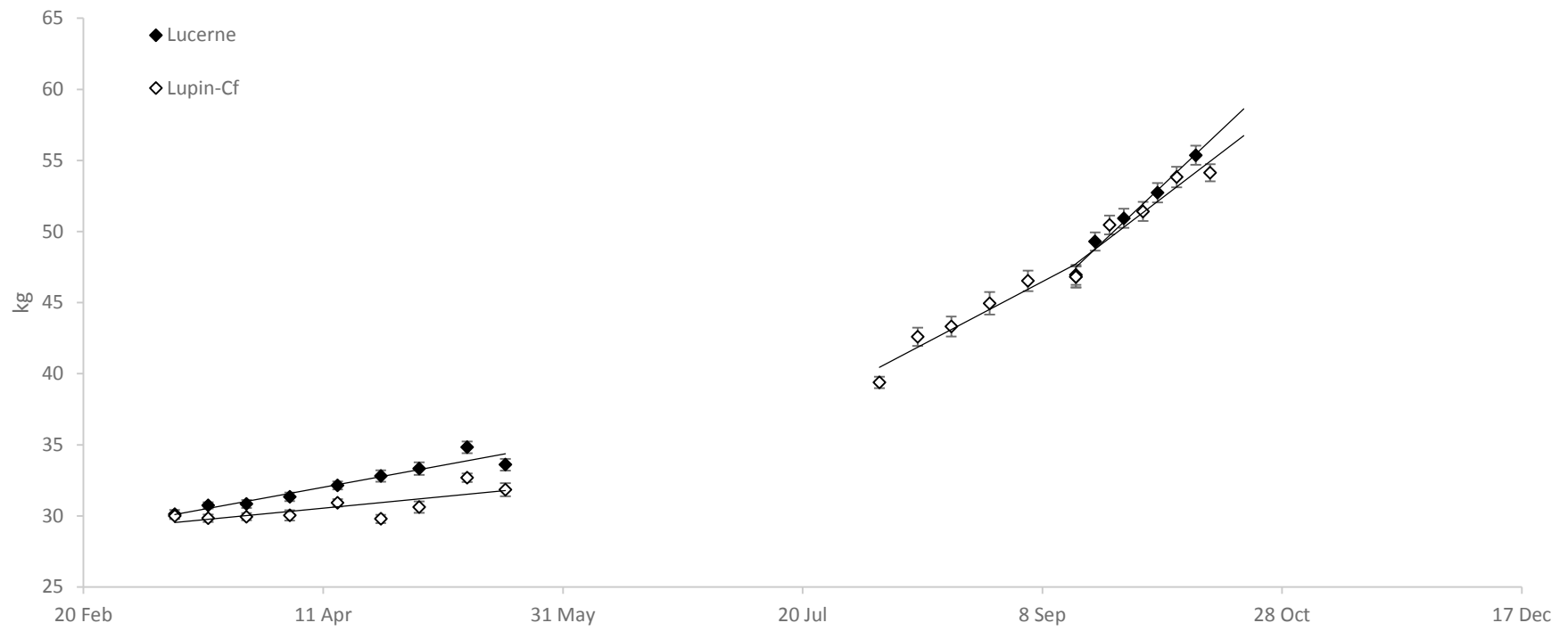


Figure 4.1 Average liveweight gain of Merino lambs during autumn (11 March – 19 May 2014) and Coopworth hoggets during spring (5 Aug – 20 Oct 2014) when grazed on lupin-cocksfoot (Cf) compared with lucerne pastures at Lincoln University, Canterbury.

Over the autumn grazing period the Merino lambs were given a similar pasture allowance on the lupin-cocksfoot and lucerne pastures (Table 4.2). The apparent DM intake by the lambs was also similar. The Coopworth hoggets in early spring on lupin-cocksfoot pastures had a pasture allowance of 2.5 kg DM/head/day and intake of 1.4 kg DM/head/day. However, the mid spring pasture allowance was higher ( $P=0.052$ ) for lucerne (3.2 kg DM/head/day) compared with lupin-cocksfoot (2.4 kg DM/head/day) pastures. This resulted in greater ( $P<0.01$ ) apparent DM intake by the Coopworth hoggets on the lucerne than on the lupin-cocksfoot.

Table 4.2 Average pasture allowance and apparent intake by young sheep grazing on lucerne and lupin-cocksfoot (Cf) pastures over autumn (11 March – 19 May 2014) and spring (5 August – 20 October 2014) at Lincoln University, Canterbury.

Species	Allowance (kg DM/head/day)	Intake (kg DM/head/day)
Autumn (11 March to 19 May)		
Lucerne	1.8	1.0
Lupin-Cf	1.8	0.7
SED	0.15	0.73
P	NS	NS
Early Spring (5 August – 15 September)		
Lupin-Cf	2.5	1.4
Mid Spring (15 September – 20 October)		
Lucerne	3.2	2.4
Lupin-Cf	2.4	1.8
SED	0.23	0.22
P	P=0.052	<0.01

NS = not significantly different

#### 4.2 Nutritive value

The DMD, crude protein and ME contents of total pre-grazing herbage were similar between lucerne and lupin-cocksfoot pastures during autumn and spring (Table 4.3). Lucerne leaf and petiole had a higher ( $P<0.01$ ) DMD than lupin leaf in autumn (Table 4.4). The DMD of lucerne leaf and petiole was 77.0% compared with 67.4% of lupin leaf, and there was no difference between

the crude protein content and ME of lupin leaf and lucerne leaf and petiole. However, during mid-spring the crude protein contents of lupin leaf of 27.1% was higher ( $P<0.01$ ) than 25.3% for lucerne leaf and petiole (Table 4.4). DMD and ME during spring were similar between lupin leaf and lucerne leaf and petiole.

Table 4.3 Dry matter digestibility (DMD), crude protein and metabolisable energy (ME) contents of total pre-grazing herbage of lucerne and lupin-cocksfoot (Cf) pastures during autumn (11 March – 19 May 2014) and spring (5 August – 20 October 2014) at Lincoln University, Canterbury.

Pasture	DMD (%)	Crude protein (%)	ME (MJ kg/DM)
Autumn (11 March to 19 May)			
Lucerne	69.4	19.7	10.5
Lupin-Cf	67.3	15.2	10.2
SED	4.25	2.5	0.30
P	NS	NS	NS
Early Spring (5 August to 15 September)			
Lupin-Cf	72.1	14.6	11.1
Mid Spring (15 September to 20 October)			
Lucerne	71.2	19.3	10.9
Lupin-Cf	71.8	17.7	10.9
SED	0.84	0.54	0.11
P	NS	NS	NS

NS = not significantly different

Table 4.4 Dry matter digestibility (DMD), crude protein and metabolisable energy (ME) contents of lupin leaf and lucerne leaf plus petiole on offer to sheep grazing during autumn (11 March – 19 May 2014) and spring (5 August – 20 October 2014) at Lincoln University, Canterbury.

Pasture	DMD (%)	Crude protein (%)	ME (MJ kg/DM)
Autumn (11 March to 19 May)			
Lucerne leaf + petiole	77.0	25.8	11.5
Lupin leaf	67.4	24.2	11.7
SED	1.32	1.49	0.31
P	<0.01	NS	NS
Early Spring (5 August to 15 September)			
Lupin leaf	78.5	24.4	12.0
Mid Spring (15 September to 20 October)			
Lucerne leaf + petiole	75.0	25.3	11.4
Lupin leaf	79.3	27.1	12.0
SED	2.08	0.19	0.23
P	NS	<0.05	NS

NS = not significantly different

The DMD, crude protein and ME contents of cocksfoot in the lupin-cocksfoot pasture were all higher ( $P<0.01$ ) in early and mid-spring than in autumn (Table 4.5). Cocksfoot had a DMD of 67.4%, 82.4% and 78.3%, crude protein content of 16.3%, 18.0% and 19.4%, and a ME of 10.2, 12.7 and 11.9 MJ/kg DM for autumn, early and mid-spring grazing periods, respectively. The crude protein and ME contents of lupin petiole were higher ( $P<0.01$ ) during early and mid-spring than in autumn, with a crude protein of 10.8%, 18.8% and 14.7%, and an ME of 10.2, 12.6 and

12.3 MJ/kg DM for autumn, early and mid-spring, respectively. The nutritive values of pre- and post-grazing samples of lupin-cocksfoot were similar between autumn, early and mid-spring.

Lucerne stem had higher ( $P<0.05$ ) DMD and ME contents in spring than in autumn (Table 4.6). Lucerne stem had a DMD of 55.9% and 69.9%, and an ME of 8.8 and 10.8 MJ/kg DM for autumn and spring, respectively. The crude protein content of 15.3% for post-grazing samples of lucerne in spring was higher ( $P<0.01$ ) than 12.3% obtained from post-grazing samples of lucerne during the autumn grazing rotation.

Table 4.5 Dry matter digestibility (DMD), crude protein and metabolisable energy (ME) contents of botanical components pre-grazing and total herbage pre- and post-grazing of lupin-cocksfoot pasture during autumn (11 March – 19 May 2014) and spring (5 August – 20 October 2014) at Lincoln University, Canterbury.

Pasture component	DMD (%)	Protein (%)	ME (MJ/kg DM)
Autumn (11 March to 19 May)			
Cocksfoot	67.4	16.3	10.2
Lupin leaf	67.4	24.2	11.7
Lupin petiole	65.1	10.8	10.2
Lupin pod	68.9	18.8	10.7
Lupin stem	57.2	13.2	8.9
Pre-grazing total	67.3	15.2	10.22
Post-grazing total	63.1	13.4	9.3
Early Spring (5 August to 15 September)			
Cocksfoot	82.4	18.0	12.7
Lupin leaf	78.5	24.4	12.0
Lupin petiole	81.8	18.8	12.6
Weed	76.9	15.6	11.4
Dead	36.8	9.3	5.8
Pre-grazing total	72.1	14.6	11.1
Post-grazing total	61.6	11.9	9.5
Mid Spring (15 September – 20 October)			
Cocksfoot	78.3	19.4	11.9
Lupin leaf	79.3	27.1	12.0
Lupin petiole	79.8	14.7	12.3
Weed	76.6	16.8	11.4
Dead	38.0	8.6	6.0
Pre-grazing total	71.8	17.7	10.9
Post-grazing total	64.5	13.1	9.8

Note: no weed or dead samples were analysed in autumn, and there were no pods or stems in spring

Table 4.6 Dry matter digestibility (DMD), crude protein and metabolisable energy (ME) contents of botanical components pre-grazing and total herbage pre- and post-grazing of lucerne pasture during autumn (11 March – 19 May 2014) and spring (15 September – 20 October 2014) at Lincoln University, Canterbury.

Pasture component	DMD (%)	Crude protein (%)	ME (MJ/kg DM)
Autumn (11 March – 19 May)			
Lucerne leaf + petiole	77.0	25.8	11.5
Lucerne stem	55.9	13.0	8.8
Pre-grazing total	69.4	19.7	10.5
Post-grazing total	54.4	12.3	8.6
Spring (15 September – 20 October)			
Lucerne leaf + petiole	75.0	25.3	11.4
Lucerne stem	69.9	16.8	10.8
Weed	71.0	15.5	10.7
Dead	45.9	10.0	7.4
Pre-grazing total	71.2	19.3	10.9
Post-grazing total	59.6	15.3	9.3

Note: no weeds and dead material were analysed for autumn

### 4.3 Pre- and post-grazing herbage mass

The pre-grazing pasture mass for the first grazing (11 March) since sowing was 2500 kg DM/ha for the lupin-cocksfoot pasture compared with 1700 kg DM/ha for the lucerne pasture (Figure 4.2).

The maximum pre-grazing pasture mass for the first rotation was obtained in paddock 1 on the 4<sup>th</sup> of April for both lupin-cocksfoot (3770 kg DM/ha) and lucerne (3420 kg DM/ha) pastures. The

average pre-grazing pasture mass of the last paddock grazed during the final autumn rotation (paddock 5) on the 11<sup>th</sup> of May was 1250 kg DM/ha for both lupin-cocksfoot and lucerne pastures.

On the 5<sup>th</sup> of August the pre-grazing pasture mass of the lupin-cocksfoot was 1900 kg DM/ha compared with 1500 kg DM/ha for lucerne (Figure 4.2). Therefore sheep were put onto the lupin-cocksfoot pasture but not the lucerne on 5<sup>th</sup> of August. The pre-grazing pasture mass of lupin-cocksfoot decreased until 28 August after which it began to increase. On the 15<sup>th</sup> of September, at the beginning of the second spring rotation, sheep were put onto the lucerne, starting in paddock 1, which had a cover of 3000 kg DM/ha. The pre-grazing pasture mass of lucerne then increased to a maximum of 4000 kg DM/ha at the end of the spring rotation, whereas the pre-grazing mass of the lupin-cocksfoot pasture ranged between 1600 and 2000 kg DM/ha during its second spring rotation.

The post-grazing herbage mass followed a similar pattern to the pre-grazing pasture mass during the autumn rotation (Figure 4.3). During the second spring rotation, lucerne was consistently grazed to a residual of 700 kg DM/ha whereas the post-grazing pasture mass of lupin-cocksfoot ranged between 400 and 1100 kg DM/ha.

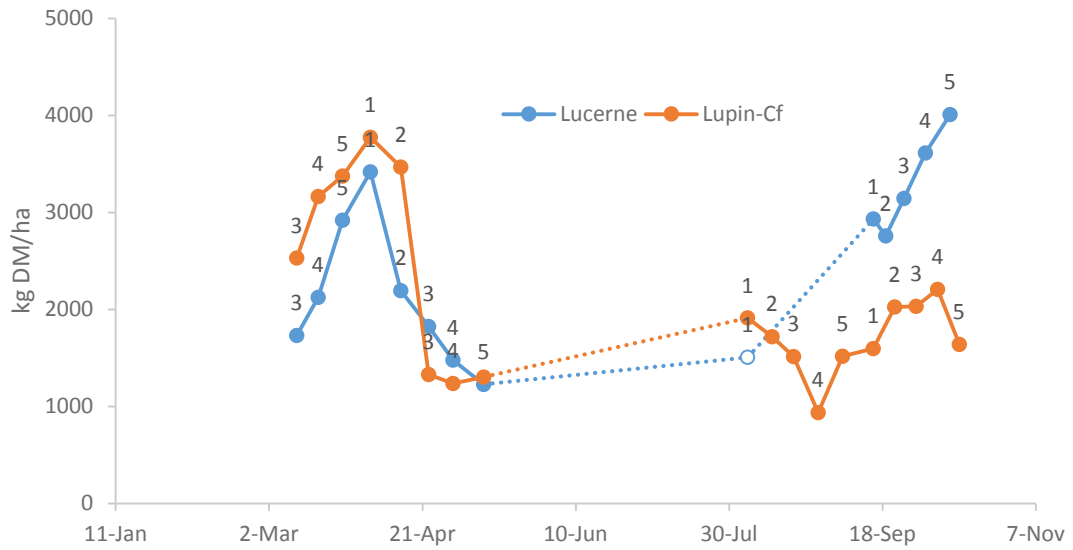


Figure 4.2 Pre-grazing herbage mass of lucerne and lupin-cocksfoot (Cf) pastures rotationally grazed by sheep during autumn (11 March – 19 May) and spring (5 August - 20 October 2014) at Lincoln University, Canterbury. Note that in spring, grazing started on the lupin-cocksfoot on the 5<sup>th</sup> of August and on lucerne on the 15<sup>th</sup> of September. Numbers above data points represent the paddock grazed in the rotation.

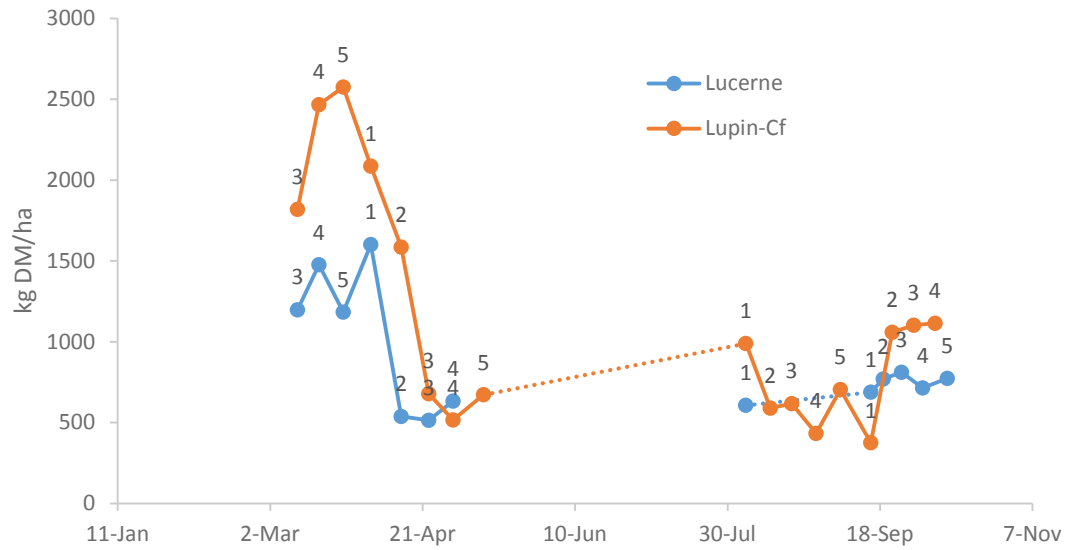


Figure 4.3 Post-grazing herbage mass of lucerne and lupin-cocksfoot (Cf) pastures rotationally grazed by sheep during autumn (11 March – 19 May) and spring (5 August - 20 October 2014) at Lincoln University, Canterbury. Note that in spring, grazing started on the lupin-cocksfoot on the 5<sup>th</sup> of August and on lucerne on the 15<sup>th</sup> of September. Numbers above data point represent the paddock in rotation. Numbers above data points represent the paddock grazed in the rotation.

#### 4.4 Herbage defoliation

During autumn the lupin-cocksfoot pasture had a pre-grazing mass of 2500 kg DM/ha compared with 2100 kg DM/ha for lucerne (Figure 4.4). Lucerne had a lower ( $P<0.05$ ) post-grazing pasture mass of 969 kg DM/ha compared with 1550 kg DM/ha for the lupin-cocksfoot pasture. The majority of the pre-grazing pasture mass of the lupin-cocksfoot pasture was made up of lupin leaf, unsown species and cocksfoot, which contributed 780, 680 and 500 kg DM/ha respectively (Figure 4.5). The lupin leaf had the greatest decrease in DM during grazing of 470 kg DM/ha followed by cocksfoot and unsown species, which decreased by 290 and 250 kg DM/ha, respectively. Lucerne leaf was the major contributor (900 kg DM/ha) to the pre-grazing mass of the lucerne pasture followed by stem (570 kg DM/ha) and unsown species (520 kg DM/ha) (Figure 4.6). The lambs grazed 80% of the lucerne leaf on offer and 50% of the lucerne stem and unsown species.

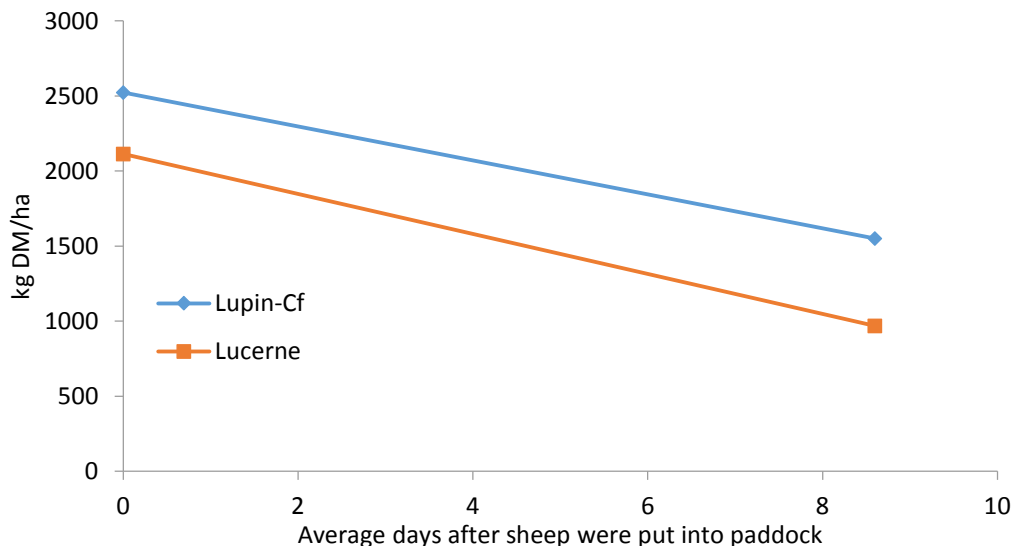


Figure 4.4 Average pre- and post-grazing herbage mass of lucerne and lupin-cocksfoot (Cf) pastures when grazed by Merino lambs during autumn (11 March - 19 May 2014) at Lincoln University, Canterbury.

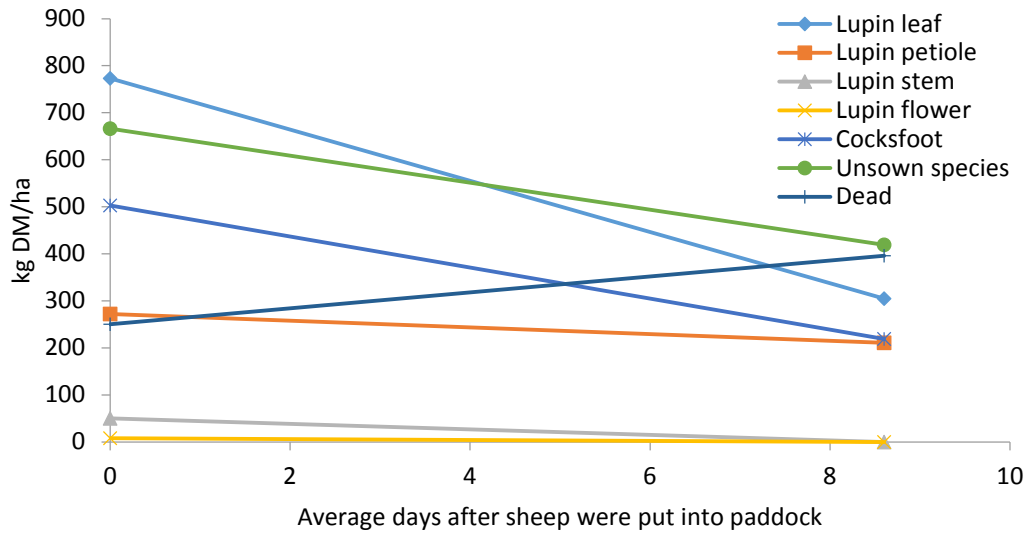


Figure 4.5 Average disappearance of botanical components of lupin-cocksfoot pastures grazed by Merino lambs in a grazing rotation between 11 March and 19 May 2014 at Lincoln University, Canterbury.

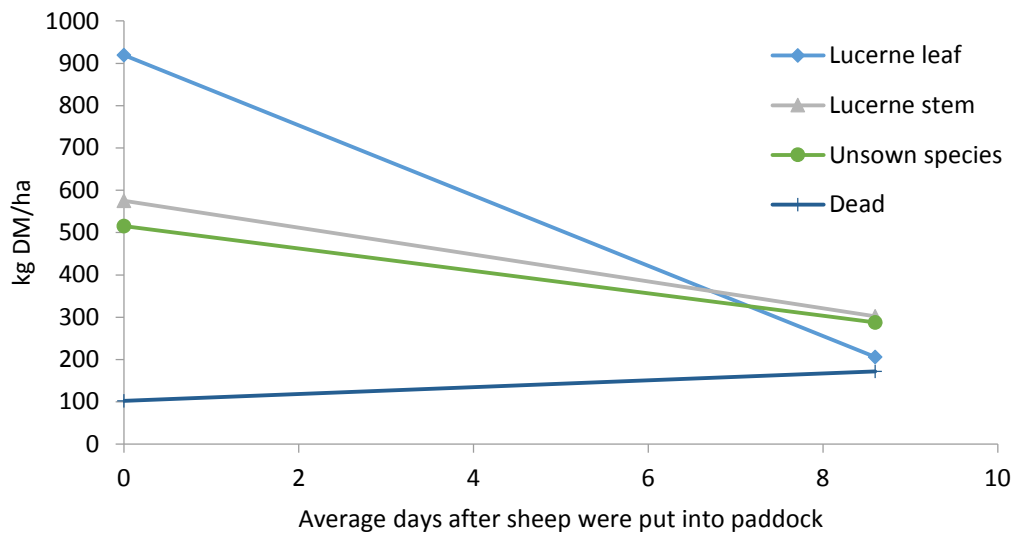


Figure 4.6 Average disappearance of botanical components of lucerne pastures grazed by Merino lambs in a grazing rotation between 11 March and 19 May 2014 at Lincoln University, Canterbury.

During early-spring, the pre and post-grazing herbage of the lupin-cocksfoot pastures between 5<sup>th</sup> of August to 15<sup>th</sup> of September were 1520 and 670 kg DM/ha, respectively (Figure 4.7). The pre-grazing mass was mostly cocksfoot (900 kg DM/ha), followed by unsown species (180 kg DM/ha) and lupin leaf (150 kg DM/ha) (Figure 4.8). The pastures were grazed to a residual of 670 kg DM/ha, with 65% of cocksfoot, 76% of unsown species and 83% of lupin leaf grazed.

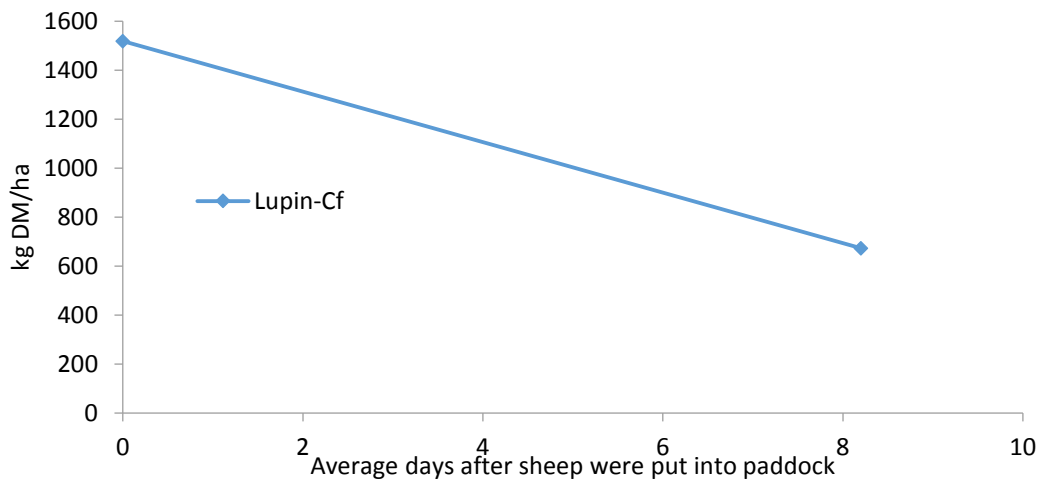


Figure 4.7 Average pre- and post-grazing herbage mass of lupin-cocksfoot (Cf) pasture when grazed by Coopworth hoggets during early-spring (5 August – 15 September) at Lincoln University, Canterbury.

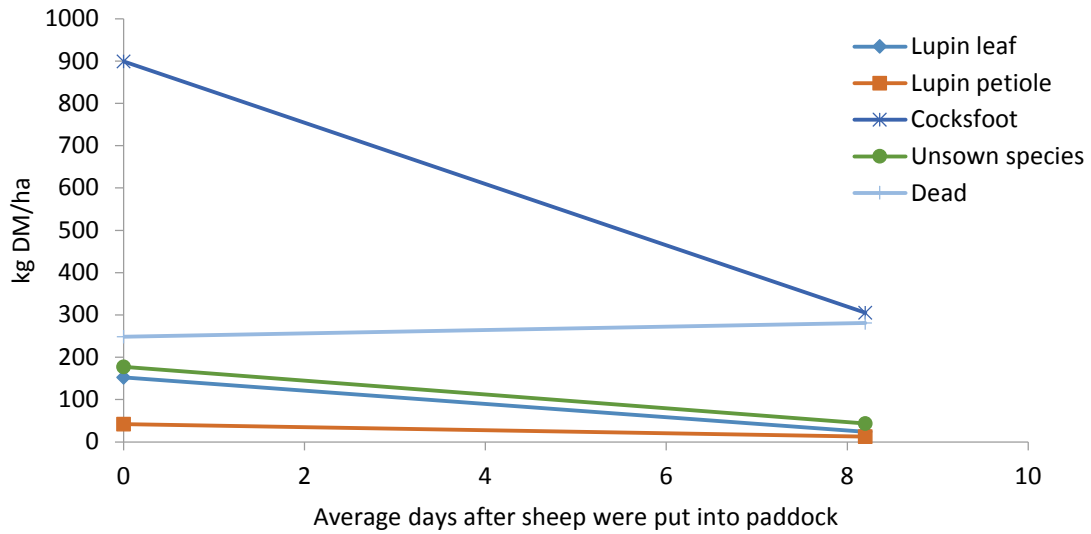


Figure 4.8 Average disappearance of botanical components of lupin-cocksfoot pastures grazed by Coopworth hoggets in a grazing rotation between 5 August – 15 September 2014 at Lincoln University, Canterbury.

During mid-spring, the pre-grazing pasture mass of the lucerne (3300 kg DM/ha) was greater ( $P < 0.001$ ) than the lupin-cocksfoot pasture (1900 kg DM/ha) from the 15<sup>th</sup> of September to 20<sup>th</sup> of October (Figure 4.9). The pre-grazing mass of the lucerne pasture was mostly lucerne leaf (1550 kg DM/ha) followed by lucerne stem (1000 kg DM/ha) (Figure 4.11). In the lupin-cocksfoot pasture, cocksfoot contributed 1000 kg DM/ha to the pre-grazing pasture mass followed by 350 kg DM/ha of lupin leaf (Figure 4.10). Both the lucerne and lupin-cocksfoot pastures were grazed to a similar residual (Figure 4.9). Almost all (95%) of the lucerne leaf on offer was grazed compared with 70% of the lupin leaf and 52% of the cocksfoot on offer.

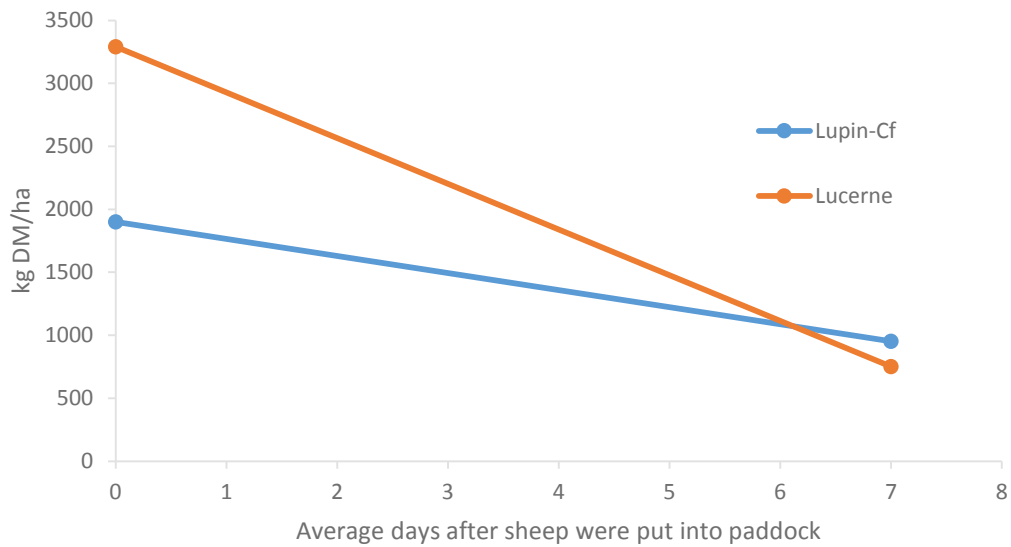


Figure 4.9 Average pre- and post-grazing herbage mass of lucerne and lupin-cocksfoot (Cf) pastures when grazed by Coopworth hoggets during spring (15 September – 20 October) at Lincoln University, Canterbury.

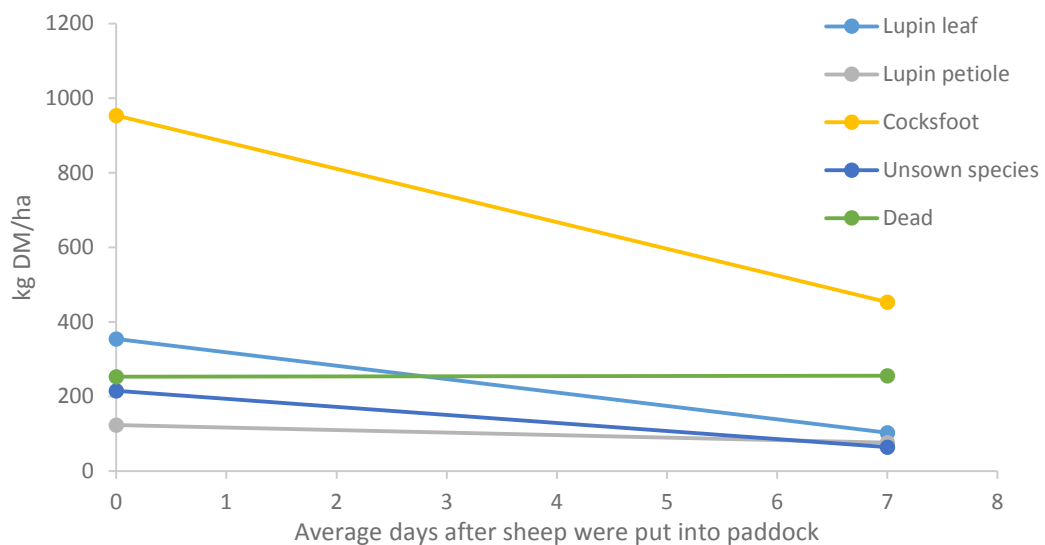


Figure 4.10 Average disappearance of botanical components of lupin-cocksfoot pastures grazed by Coopworth hoggets in a grazing rotation during spring (15 September - 20 October 2014) at Lincoln University, Canterbury.

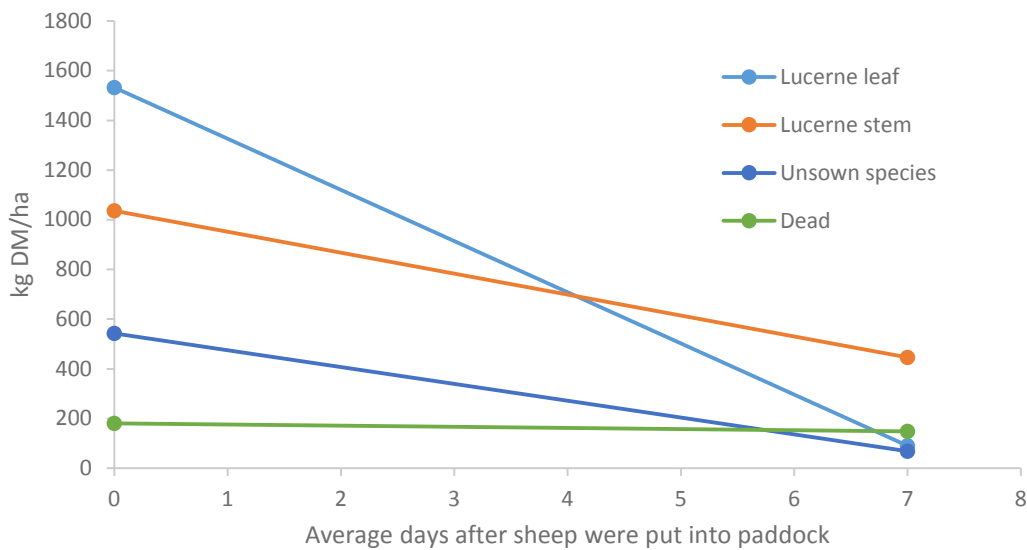


Figure 4.11 Average disappearance of botanical components of lucerne pastures grazed by Coopworth hoggets in a grazing rotation in spring (15 September - 20 October 2014) at Lincoln University, Canterbury.

Figure 4.12 shows the defoliation of botanical components, an indicator of grazing preference during the grazing period of one paddock (paddock 2) in spring, by the Coopworth hoggets grazing the lupin-cocksfoot pasture over 7 days (22 September – 29 September). Over the first 2 days after the hoggets were put into the paddock, cocksfoot and lupin were defoliated by a similar amount. Over days 3 and 4 cocksfoot was preferentially grazed (560 kg DM/ha) whereas lupin leaf was grazed at a similar rate to the first 2 days. After the fourth day cocksfoot was grazed less and the rate of grazing of lupin leaf decreased. The herbage mass of lupin petiole, dead material and unsown species remained relatively similar over the 7 day grazing period.

Figure 4.13 shows the grazing preference by the hoggets on lucerne when they grazed the same paddock 2 over 6 days (19 September – 25 September) in spring. Over the first 2 days lucerne leaf was grazed from 1400 to 900 kg DM/ha, while unsown species were grazed at a similar rate over the first day and began to plateau after the second day of grazing. After 2 days of grazing the lucerne leaf and stem had a similar herbage mass of 800 kg DM/ha. After this point

the sheep began to graze on the lucerne stem. Over the 6 day grazing period lucerne leaf decreased linearly and the dead material remained similar.

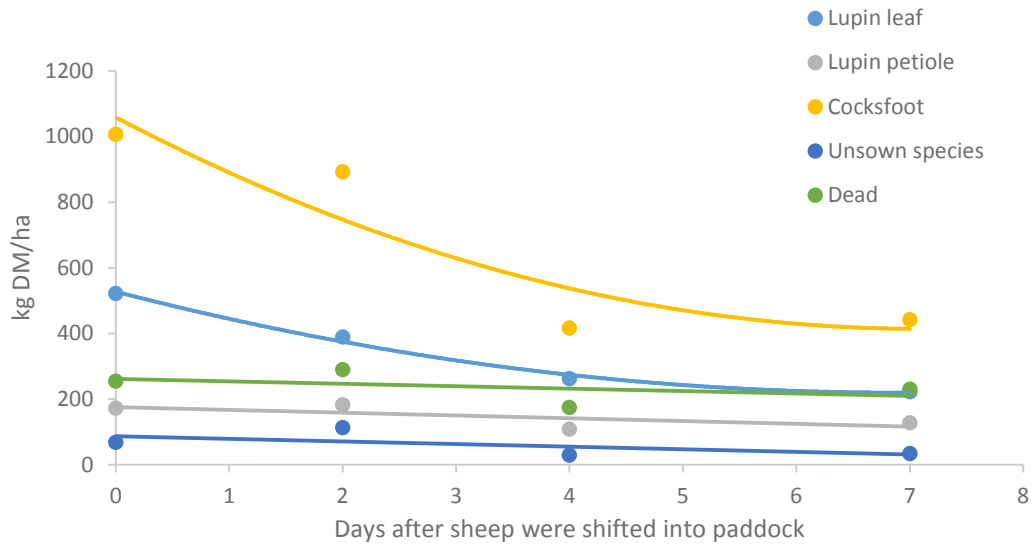


Figure 4.12 Average disappearance of botanical components, an indicator of grazing preference, of lupin-socksfoot pastures grazed by Coopworth hoggets within one paddock (paddock 2) over a grazing period of 7 days in spring (22 September - 29 September 2014) at Lincoln University, Canterbury.

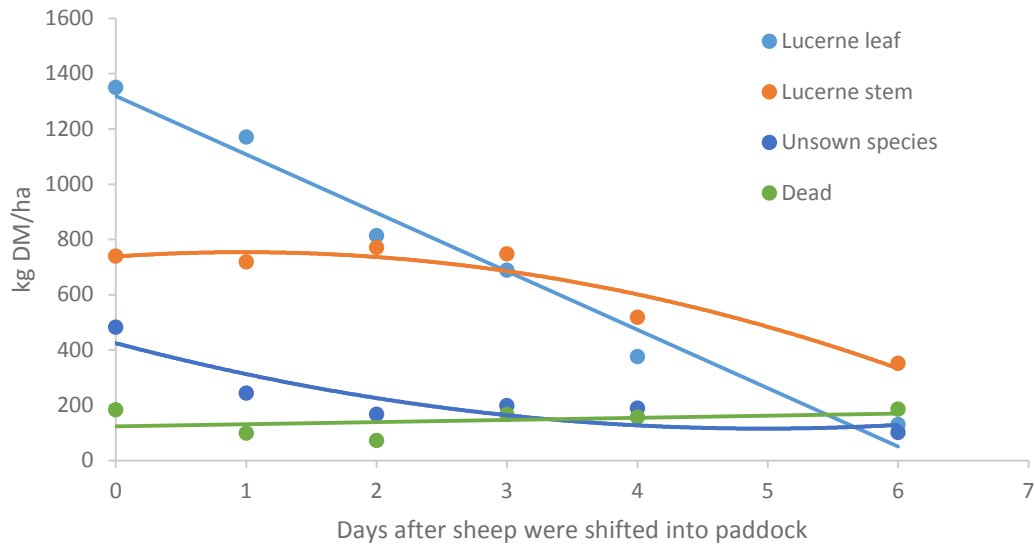


Figure 4.13 Average disappearance of botanical components, an indicator of grazing preference, of lucerne pastures grazed by Coopworth hoggets within one paddock (paddock 2) over a grazing period of 6 days in spring (19 September - 25 September 2014) at Lincoln University, Canterbury.

#### 4.5 Botanical composition of pre-grazing herbage over time

Lupin provided the majority of the pasture mass during the first autumn rotation (Figure 4.14) after which regrowth was slow (Figure 4.16) and cocksfoot provided the majority of the pasture mass through the end of the autumn rotation, winter and first two spring rotations. The contribution of lupin began to increase in late winter and early spring. The amount of unsown species decreased after the first rotation in autumn, but the dead material increased and remained relatively similar throughout the rest of the experiment.

In the lucerne pasture, lucerne provided the majority of the herbage mass over the period of the experiment (Figure 4.15). During the first autumn rotation unsown species contributed up to 40% of the herbage mass on offer but after the first rotation that decreased to less than 10%. The contribution of lucerne remained relatively stable through winter and began to increase in spring.

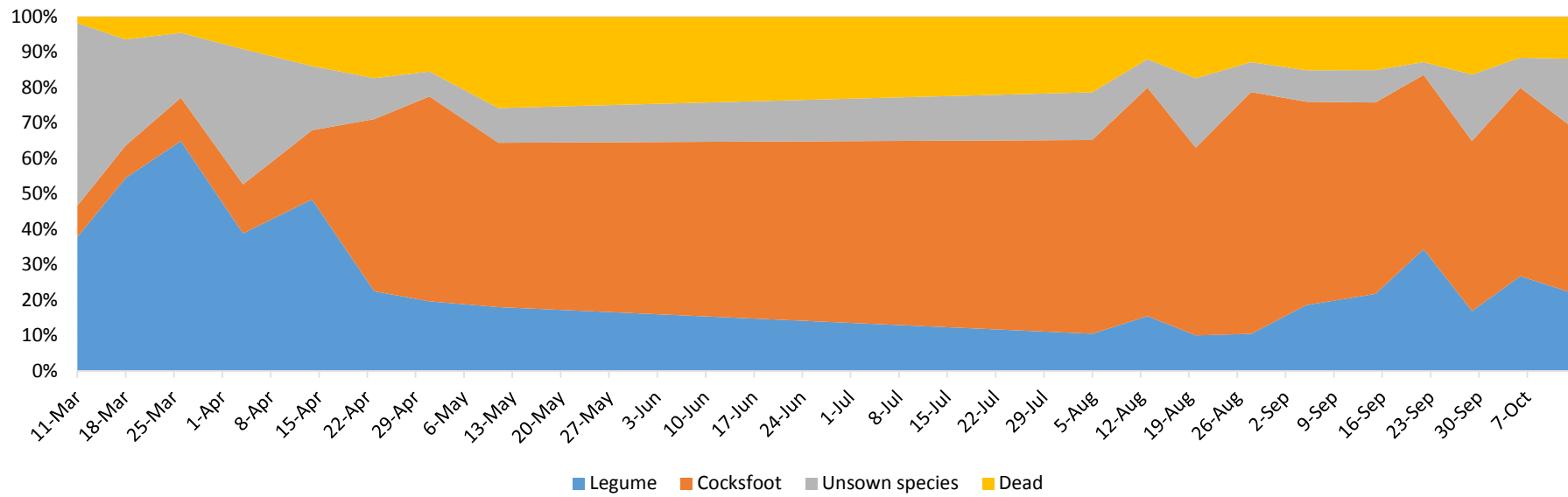


Figure 4.14 Botanical composition of pre-grazing herbage mass of lupin-cocksfoot pasture from 11 March to 20 October 2014 at Lincoln University, Canterbury.

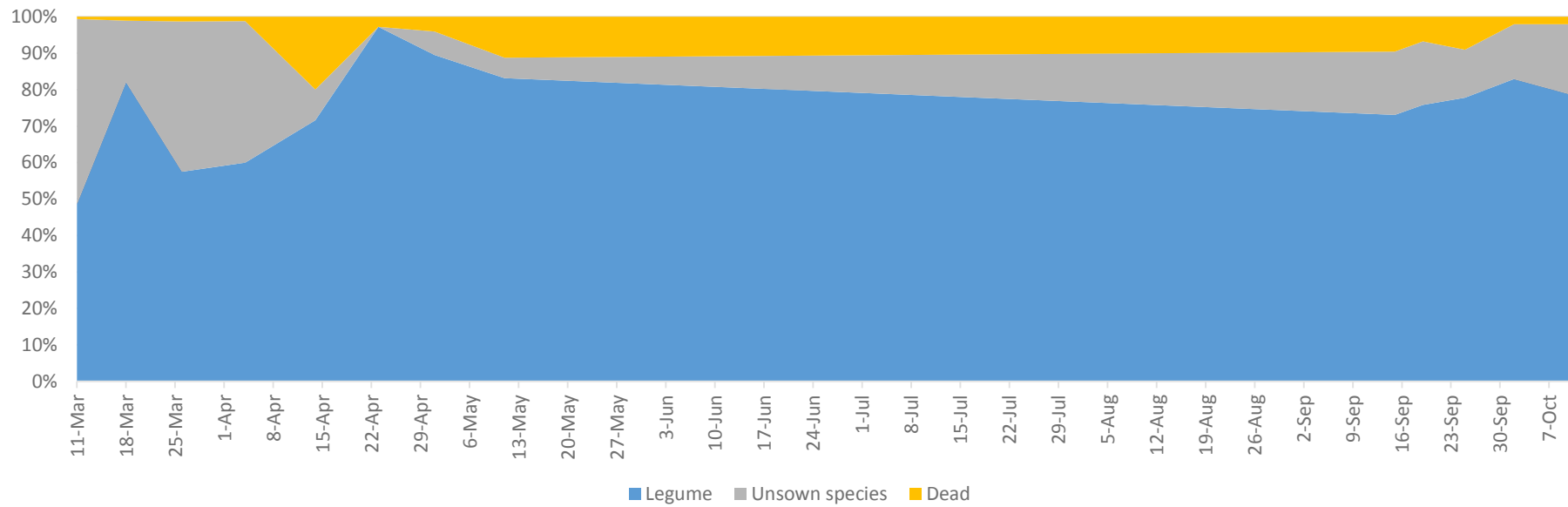


Figure 4.15 Botanical composition of pre-grazing mass of lucerne pasture from 11 March – 20 October 2014 at Lincoln University, Canterbury.

#### 4.6 Dry matter yield

The accumulated DM from sowing to 19<sup>th</sup> of May was greater ( $P<0.05$ ) for lupin-cocksfoot (3647 kg DM/ha) than lucerne (2979 kg DM/ha) (Table 4.7). However, the accumulated yield from 19<sup>th</sup> of May to 20<sup>th</sup> of October was greater ( $P<0.05$ ) for lucerne (2521 kg DM/ha) than lupin-cocksfoot (2099 kg DM/ha). This resulted in similar accumulated total DM yield from sowing to 20<sup>th</sup> of October for lucerne and lupin-cocksfoot pastures.

Table 4.7 Accumulated yield of lucerne and lupin-cocksfoot pastures of autumn growth (5 December 2013 – 19 May 2014), winter/spring growth (19 May – 20 October) and total accumulated yield since sowing (5 December 2013 – 20 October 2014) at Lincoln University, Canterbury.

Species	Autumn	Spring	Accumulated
		kg DM/ha	
Lucerne	2979	2521	5540
Lupin-Cocksfoot	3647	2099	5722
SED	232	215	238
P	<0.05	<0.05	NS

NS = not significantly different

#### 4.7 Regrowth after grazing

The pre-grazing heights for the lupin-cocksfoot pasture for the first grazing after sowing were 30-38 cm (Figure 4.16). The pre-graze heights for the second grazing in autumn progressively decreased from 18 to 14 cm for lupin-cocksfoot paddocks 3, 4 and 5 (Figure 4.16). Over winter, paddock 1 increased from 4 cm on the 14<sup>th</sup> of April to 19 cm on the 5<sup>th</sup> of August when the first spring grazing rotation on the lupin-cocksfoot commenced. The pre-grazing pasture heights of the next four paddocks decreased from 13 cm to 9 cm during the first spring rotation. The pre-grazing pasture heights for the second rotation increased from 12 cm to 21 cm for paddocks one to five.

The pre-grazing pasture heights of the lucerne at first grazing after sowing increased for the first four paddocks in the rotation from 25-39 cm and the height of the fifth paddocks was slightly less at 35 cm at the first grazing (Figure 4.17). The regrowth of paddocks 3, 4 and 5 had a decreasing pre-grazing pasture height of 28, 25 and 17 cm respectively. Post-grazing residual height of 6-7 cm was standard. On the 5<sup>th</sup> of August, the regrowth height of the lucerne in paddock 1 had increased to 12 cm since the post-grazing residual height of 4 cm on the 14<sup>th</sup> of April, therefore it was not grazed. The first spring grazing rotation on lucerne began on 15<sup>th</sup> of September with a pasture height of 17 cm in paddock 1. The pre-grazing pasture height of the lucerne in paddocks 2, 3, 4 and 5 was 19, 28, 35 and 39 cm from the 19<sup>th</sup> of September to 10<sup>th</sup> of October.

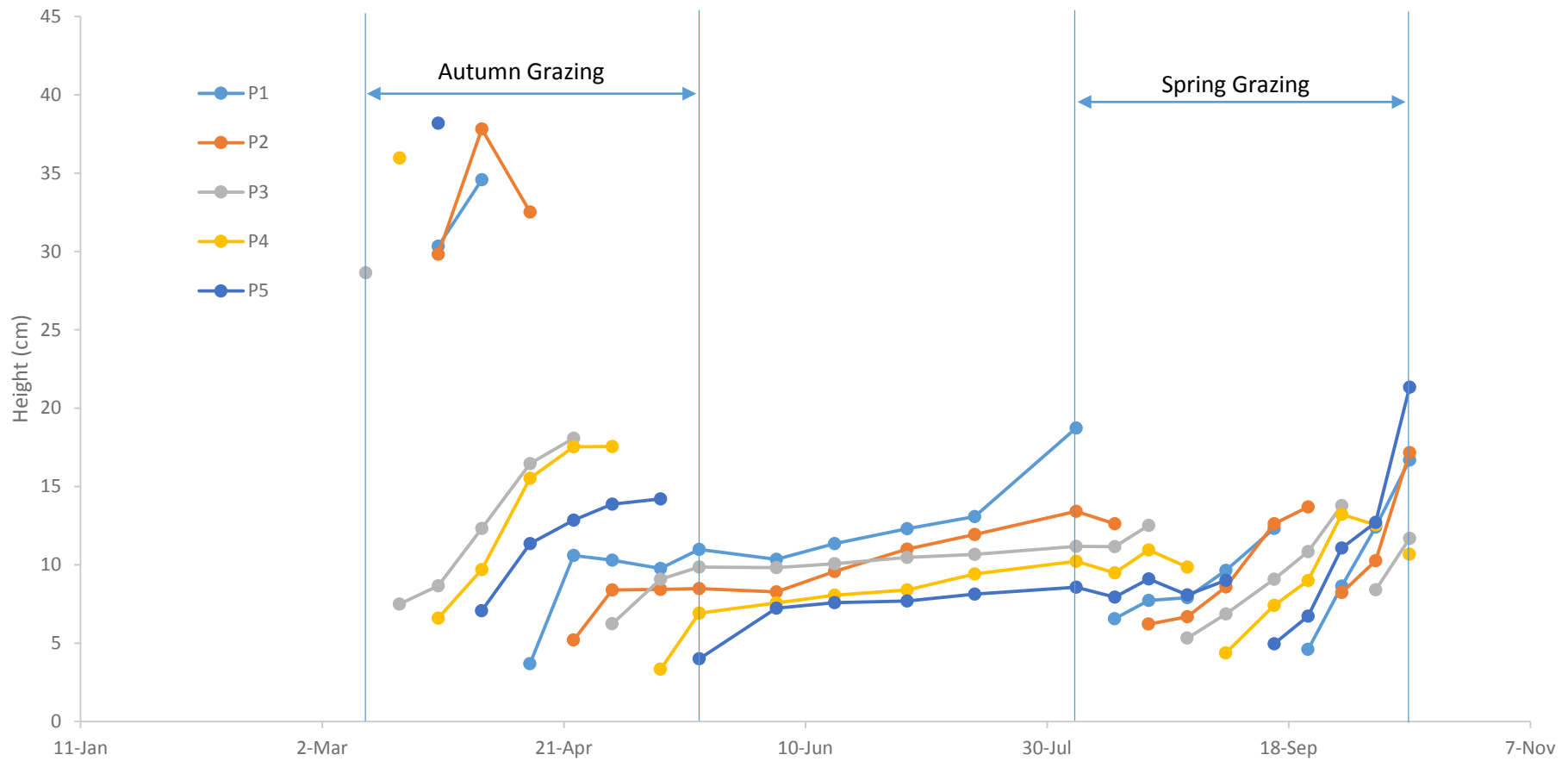
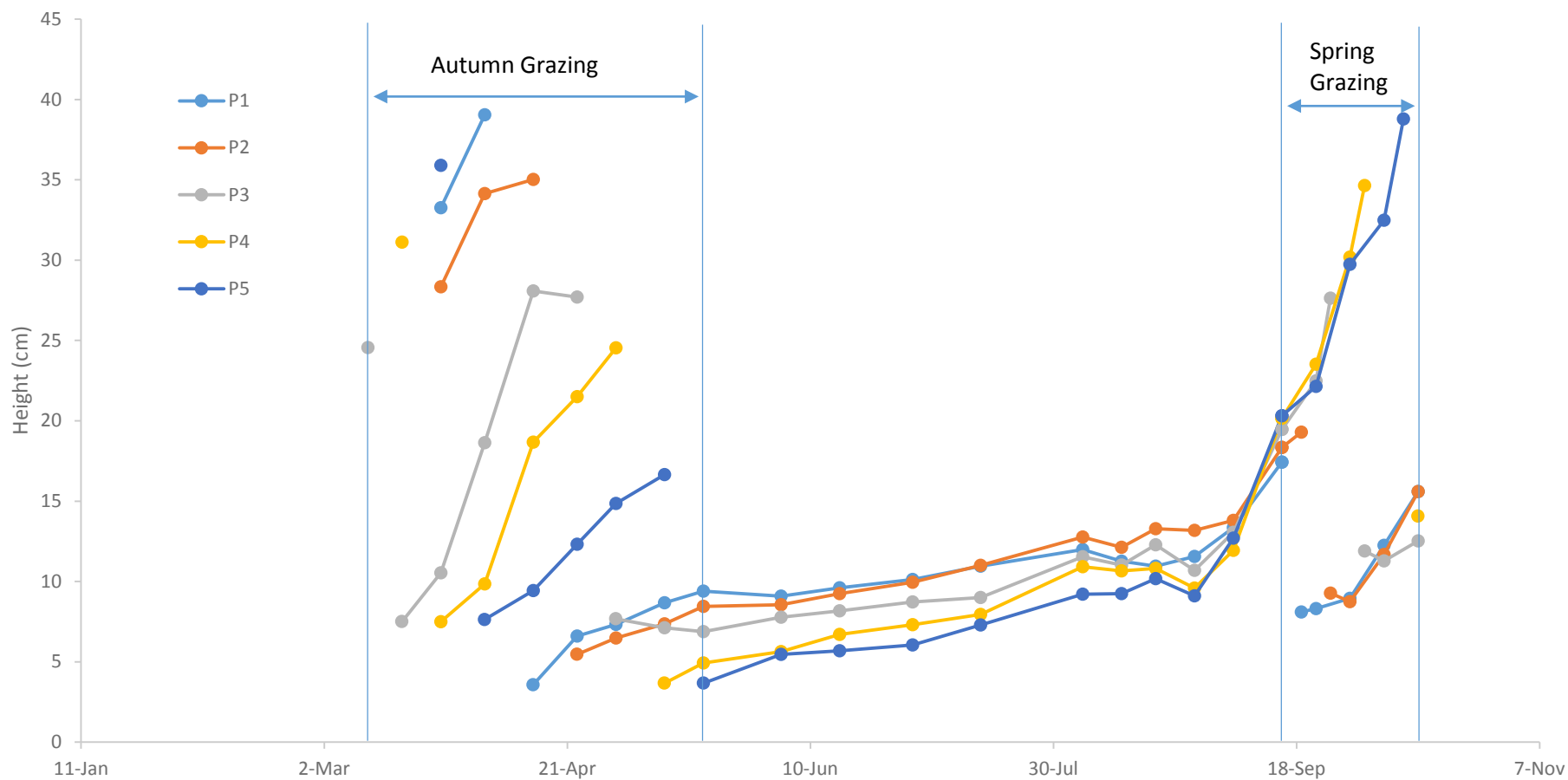


Figure 4.16 Regrowth of lupin-cocksfoot pasture in each paddock (P) of a five paddock grazing rotation by sheep in autumn (11 March – 19 May) and spring (5 August – 20 October) at Lincoln University, Canterbury.



## 5 Discussion

The aim of this study was to compare the sheep liveweight gain, nutritive value and DM yield of lupin-cocksfoot pasture with lucerne. The study was supported by three decades of research, in Tekapo in the Mackenzie Basin and other high country sites in the South Island of NZ, which confirmed that perennial lupin are able to survive and thrive in extensively grazed grasslands with low fertiliser inputs, confirming that perennial lupins are a persistent high country forage option. However, there was little published information of the performance of sheep grazing lupins and their nutritive value and regrowth after grazing compared with conventional forage legumes like lucerne.

The 3 year grazing trial at Sawdon Station (Black *et al.*, 2014; Wilson, 2013) showed that Merino ewes and lambs grazing on lupins performed almost as well as Merino ewes and lambs grazing on lucerne, although differences in sheep performance between the two pastures could not be explained in detail because of the scale of that on-farm trial. Therefore, the lupin grazing trial described in this dissertation was established at Lincoln University to compare the sheep and DM production of lupin-cocksfoot pasture directly with lucerne and help explain some of the sheep performance results from Sawdon. Overall the data collected from the first year of this experiment showed that sheep liveweight gains were generally better on lucerne than on the lupin-cocksfoot pasture (Table 4.1 and Figure 4.1) which supports the results from the Sawdon trial. Because this experiment used Merino lambs as the biological indicator of pasture performance in autumn and Coopworth hoggets in spring, the animal and pasture results from the two grazing seasons need to be discussed separately.

### 5.1 Autumn

In autumn, the Merino lambs grazing on the lupin-cocksfoot pasture grew 32 g/day slower than the lambs on the lucerne, but stocking rates were the same and liveweight gains per hectare were

not significantly different between the two pastures (Table 4.1). The herbage allowance offered to the lambs was the same for the two pastures and the apparent DM intake was also similar (Table 4.2). This suggests that the faster growth rate of the lambs on the lucerne than on the lupin-cocksfoot pasture was related to differences in the nutritive values of the two pastures and not pasture allowance or total pasture intake. It was difficult to compare these results with growth rates from Scott *et al.* (1994) as the author grazed Merino wethers on perennial lupins between November and March and this experiment measure Merino lamb growth rates between March and May.

The nutritive value analyses of the herbage offered to the Merino lambs in autumn indicated that the total herbage of the lucerne was similar in DMD, crude protein and ME to the total herbage of the lupin-cocksfoot pasture (Table 4.3). The chemical analysis of the separated components also indicated that the DMD of the leaves plus petioles of the lucerne was only slightly higher than the leaves of the lupins, while crude protein and ME contents were the same (Table 4.4). However, the chemical analyses also showed that the DMD, crude protein and ME contents varied greatly between the separated fractions (Tables 4.5 and 4.6). For example, the DMD and ME contents of leaves of the lupin and cocksfoot were similar (67.4% and 10.0-11.7 MJ/kg DM), but the crude protein content of the lupin leaf was higher (24.2%) than cocksfoot leaf (10.3%). In contrast, the leaves of lucerne were higher in DMD, crude protein and ME than the stems. The high crude protein content and ME of lupin leaf in this study were consistent with values reported by Kitessa (1992) and also DMD reported by Wilson (2013). Therefore, the higher growth rates of lambs on the lucerne was probably because the lambs consumed more high quality leaf material in this pasture than in the lupin-cocksfoot pasture.

The amount of herbage offered to the Merino lambs (pre-grazing pasture mass) was marginally greater for the lupin-cocksfoot pasture than lucerne in the first half of the autumn grazing period, and similar for both pastures in the late autumn (Figure 4.2). This can be explained

as during autumn lucerne stores N and carbon (C) in the crown and taproot to be remobilised to support shoot regrowth (Avice *et al.*, 2001). This pattern was also seen in the post-grazing herbage mass results (Figure 4.3). However, any differences in pre- and post-grazing herbage mass between the two pastures did not appear to be biologically meaningful as stocking rate (Table 4.1), herbage allowance per lamb and apparent intake of total herbage (Table 4.2) were all the same. The average disappearance of total herbage mass between the day sheep were put into a paddock and the day they were taken out, which was similar for the two pastures (Figure 4.4) supports this conclusion.

The most important differences between the two pastures were shown in the botanical composition results (Figures 4.14 and 4.15). In the first half of the autumn grazing period, the lupin-cocksfoot pasture consisted mostly of lupin and annual weeds (mainly fathen) (Figure 4.14). As the autumn grazing period continued into May, the proportions of lupin and weeds declined, but the proportion of cocksfoot increased. In contrast, the lucerne pasture was predominantly lucerne, with weeds declining as the autumn grazing season progressed (Figure 4.15). These data, and those of the nutritive values of the separated fractions, indicate that the Merino lambs would have had an opportunity to select a high proportion of high quality components in their diet.

Accurate and reliable measurements of the amount and composition of forage consumed by grazing animals is inherently difficult and costly. However, by quantifying the composition of herbage on offer (pre-grazing) and comparing that to the composition of herbage refused (post-grazing), it was possible to get some idea of the apparent composition of the diet of the lambs. These data revealed that, on the lupin-cocksfoot pasture, the lambs appeared to consume more cocksfoot and lupin leaf material than lupin petiole and lupin stem (Figure 4.5), which was consistent with Kitessa (1992). They also appeared to eat the palatable weed (unsown species) fractions and rejected the dead material. In contrast, the lambs on the lucerne appeared to consume much more lucerne leaf than stem and unsown species, while dead material was also

refused (Figure 4.6). This evidence supports the idea that a high proportion of the diet of the lambs on the lucerne was leaf material, which had a higher nutritive value than the stem and most of the separated functions in the lupin-cocksfoot pasture.

## **5.2 Spring**

In spring, the sheep liveweight gain and pasture results were consistent with those recorded in the autumn grazing period. However, the Coopworth hoggets were allowed to go back onto the lupin-cocksfoot pasture on 5<sup>th</sup> of August, which was 41 days earlier than when the hoggets were able to start on the lucerne again. This management was justified because on the 5<sup>th</sup> of August the pre-grazing herbage mass of the lupin-cocksfoot pasture was 1900 kg DM/ha compared with only 1500kg DM/ha for the lucerne (Figure 4.2). Over that 41 day period the hoggets on the lupin-cocksfoot gained 174 g/day at a stocking rate of 15.4 hoggets/ha, resulting in an extra 110 kg/ha of liveweight gain. The ability to graze a pasture in early spring on farms is significant, and was probably because of the cocksfoot component of the lupin pasture, which dominated the pasture over winter and early spring (Figures 4.7 and 4.14). Regardless of the composition the lupin-cocksfoot pasture yielded more than the lucerne through the autumn grazing period, winter and early spring (Figures 4.16 and 4.17 and Table 4.7) which meant that the lupin-cocksfoot pasture could be grazed sooner than the lucerne.

By the 15<sup>th</sup> of September the hoggets on the lupin-cocksfoot pasture had completed one full grazing rotation of the five paddocks. They were put back into paddock 1 on the 15<sup>th</sup> of September which was the same day the hoggets started in paddock 1 of the lucerne. From then through to the 20<sup>th</sup> of October the hoggets completed a full rotation of the five paddocks on both pastures. However, the hoggets on the lupin-cocksfoot were shifted about every 7 days, whereas the hoggets on the lucerne were shifted faster in the first half of the rotation and slower in the second half. This was necessary because there was no feed wedge on the lucerne plots and the growth rate of the lucerne was accelerating, which resulted in greater herbage masses (Figures

4.2 and 4.3) and sward heights (Figures 4.16 and 4.17) for the lucerne in spring which was because of stored N and C being remobilised from the crown and tap root to support shoot regrowth (Avice *et al.*, 2001).

The greater herbage masses (Figures 4.2 and 4.3) and DM production (Table 4.7) of the lucerne compared with the lupin-cocksfoot after the 15<sup>th</sup> of September meant that the stocking rate of hoggets on the lucerne was higher (Table 4.1). The growth rate of hoggets on lucerne was also higher than on the lupin-cocksfoot pasture. This mean that the lucerne pasture produced about the twice the amount of liveweight gain per hectare than the lupin-cocksfoot pasture from 15<sup>th</sup> of September to the 20<sup>th</sup> of October. However, the lupin-cocksfoot pasture produced nearly the same amount of liveweight gain per hectare than the lucerne over the whole spring period when its first spring rotation was taken into consideration. Thus, for the spring period, sheep liveweight gains were related not only to the amount of spring DM produced but also to the quality of the herbage on offer.

Unlike the autumn grazing period, the herbage allowance offered to the hoggets on the lucerne was higher than that offered to the hoggets on the lupin-cocksfoot pasture during the same period (Table 4.2). This resulted in an increase in apparent total DM intake for hoggets on the lucerne, and helps to explain the higher liveweight gains per hectare for lucerne in spring (Table 4.1 and Figure 4.1). This result was unexpected as grazing management attempted to maintain a similar herbage allowance between the two treatments at all times by adjusting stocking rate. This stocking rate on the lucerne was probably less than it could have been at that time, so this result needs to be highlighted while interpreting the liveweight gain results.

The nutritive values of the two pastures and their separated fractions were also contributing factors to the growth rates of the hoggets in spring, as they were in autumn. Again, the nutritive values of total herbage on offer were not different between the two pastures (Table 4.3). The chemical composition of the leaf fraction was also similar between lucerne and lupin

(Table 4.4). However, differences were again seen in nutritive values between the separated components of both pastures (Tables 4.5 and 4.6), which were consistent with the results described for the autumn grazing period. The botanical composition of the two pastures were also different, with the lucerne pasture containing only 10%-15% weeds while the lupin-cocksfoot pasture was predominantly cocksfoot with the proportion of lupin on offer ranging from 10% to almost 40% (Figures 4.14 and 4.15).

The analysis of the average disappearance of total herbage mass and herbage components between the day hoggets were put onto a paddock and when they were taken out, was also useful to explain liveweight gain differences in spring. The disappearance of total herbage mass was clearly greater for lucerne than cocksfoot (Figure 4.9), which was consistent with the apparent intake results (Table 4.2). Furthermore, the hoggets on the lucerne consumed more lucerne leaf than stem and unsown species, and refused most of the dead material (Figure 4.10). This is again consistent with the apparent grazing behaviour of the Merino lambs in autumn, and supports the hypothesis that grazing sheep have a greater preference for the highly digestible fractions of a sward than lower quality fractions. Similar results were seen on the lupin-cocksfoot pasture, where the hoggets appeared to consume more cocksfoot and lupin leaf than lupin petiole and unsown species, and they rejected the dead material, which had the lowest nutritive values (Table 4.5).

While comparisons of pre-and post-grazing herbage mass and composition provided some information about the apparent intake of the Merino lambs and Coopworth hoggets, the acceptability of the various fractions by the sheep was not clear. Therefore, the defoliation of the components of both pastures was quantified in more detail for one paddock (paddock 2) in spring. This set of measurements was different to the others because samples were collected every 2 to 3 days throughout the time the paddock was grazed to get a better idea of what fractions the sheep preferred to graze (Figures 4.12 and 4.13). The results for the lucerne pasture

met expectations, as the hoggets appeared to consume more lucerne leaf than stem and unsown species in the first few days and then grazing on more of the lucerne stem in the last few days after most of the leaf had been consumed. Dead material was clearly rejected during the entire grazing period. In the lupin-cocksfoot pastures, the hoggets showed an apparent preference for cocksfoot in the first few days but also for leaf of the lupins, while lupin petioles and unsown species were less preferred and dead material was refused which was consistent with Kitessa (1992). This result was encouraging because perennial lupins are often misconceived as not being palatable and even toxic to sheep. Lupin forage is known to contain low concentrations of alkaloids making them sour-tasting but not toxic. However, sheep adapted to the taste of lupins and this study has shown that they will even consume some lupin leaf in the first few days they are put into a paddock of lupin-cocksfoot.

### 5.3 Conclusions

This study has determined the feeding value of perennial 'Russell' lupin for sheep. Specific conclusions from the study were:

1. In autumn, Merino lambs had higher growth rates on the lucerne (60 g/day) compared with the lupin-cocksfoot (32 g/day) pastures. In spring, the animal performance of Coopworth hoggets was similar with a faster growth rate (103 g/day) on the lucerne than the lupin-cocksfoot pastures.
2. The nutritive value of total herbage in autumn and spring of the lucerne was similar in DMD, crude protein and ME to the total herbage of the lupin-cocksfoot pastures. However, for both growing season the chemical analyses showed that the DMD, crude protein and ME contents varied greatly between the separated fractions.
3. The total accumulated DM yield from sowing to 20<sup>th</sup> of October was similar between lucerne and lupin-cocksfoot pastures. However, from sowing to the 19<sup>th</sup> of May the DM yield was greater for lupin-cocksfoot than lucerne pastures and the opposite was found for the spring regrowth period.
4. Coopworth hoggets on the lupin-cocksfoot pasture showed apparent preference for cocksfoot in the first few days. However, sheep adapted to the bitter taste of lupins and this study has shown that they will even consume some lupin leaf in the first few days they are put into lupin-cocksfoot pasture.
5. In early-spring, Coopworth hoggets were able to begin grazing the lupin-cocksfoot (1900 kg DM/ha) pastures 41 days before the lucerne (1500 kg DM/ha) pastures. The ability to graze pasture in early spring on farms is advantageous, and was probably because of the cocksfoot component of the lupin pasture. Regardless of the composition of the lupin-cocksfoot pasture, the greater DM yield of lupin-cocksfoot pastures meant it could be grazed earlier than lucerne pastures.

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