Feeding value of dryland lupin/cocksfoot pasture compared to lucerne pasture for sheep

A dissertation

submitted in partial fulfilment

of the requirement for the Degree of

Bachelor of Agricultural Science

at Lincoln University

by

C. C. Hutchinson

Lincoln University

2017

Abstract of a Dissertation submitted in partial fulfilment of the requirement
for the Degree of Bachelor of Agricultural Science

Feeding value of dryland lupin/cocksfoot pasture compared to lucerne pasture for sheep

By

C. C. Hutchinson

New Zealand South Island high country farms are typically nitrogen (N) deficient with environmental challenges that limit the production and persistence of traditional legumes like white clover (*Trifolium repens*) and lucerne (*Medicago sativa*). The perennial Russell lupin (*Lupinus polyphyllus*) has thrived on the roadsides of the high country since its introduction in 1952. Lupin is capable of growth in acidic, low fertility soils with high levels of Al, and well suited to moderate to high rainfall areas of the high country. Agricultural stands of perennial lupin are present on some high country farms, including Glenmore Station and Sawdon Station, but are generally utilised as a mature plant. While recent work on perennial lupin has looked at quantifying liveweight gain from pasture production, there is a lack of published knowledge on the feeding value of lupin as a pasture component of a pasture mix within a rotational grazing system and its contribution to the feeding value of cocksfoot (*Dactylis glomerata*)-based pasture mixtures in dryland environments. The objective of this study was to compare the feeding value of dryland cocksfoot/lupin pasture for sheep in comparison to pure lucerne pasture as a control. The two pasture types were compared in a grazed experiment at Lincoln University, using data collected during the complete 2016/17 growing season. This growing season was the fourth year of the experiment after the two pasture types were sown in December 2013. A group of young Coopworth ewe sheep were rotationally grazed on each pasture type (six 0.13 ha paddocks per pasture type) from August 17th 2016 to June 1st 2017 (288 days), spending 7 - 11 days in each paddock. There was no significant difference in herbage allowance between each group, and all sheep were shifted to the next paddock on the same day. Liveweight gain of sheep, herbage mass, herbage height, botanical and morphological composition of herbage and nutritive value were recorded throughout the trial period. Sheep grazing cocksfoot/lupin pasture gained 60% as much liveweight per hectare as sheep grazing lucerne pasture over the over the year ($P<0.001$). Herbage intake was 1.496 kg DM/sheep/day on lucerne pasture, higher than the 0.986 kg DM/sheep/day gained by sheep on cocksfoot/lupin pasture ($P<0.001$). Pre-grazing herbage mass was higher on lucerne pasture than cocksfoot/lupin pasture, allowing for a higher stocking rate on lucerne pasture at 20.8 head/ha compared with 13.6 head/ha on cocksfoot/lupin pasture. Leaf was the most rapidly consumed morphological pasture component, followed by petiole/pseudostem, and stem for both pasture types. The lupin fraction of the cocksfoot/lupin pasture was consumed within the first 4 days of the 10 day grazing period. Dead material was avoided by sheep grazing both pasture types. There was no significant difference in annual ME between cocksfoot/lupin and lucerne pasture, but lucerne pasture had greater ME FCE. Pre-grazing herbage mass and pasture composition indicated more opportunity for sheep to select high ME components on lucerne pasture than cocksfoot/lupin pasture. With adequate soil moisture lucerne pasture has the potential for high liveweight gain per hectare, making it a better pasture option for young lambs than cocksfoot/lupin pasture. However the feeding value of cocksfoot/lupin pasture is adequate for liveweight gain in young sheep. In the high country environment where the rooting depth of lucerne is restricted by high Al soils, limiting lucerne growth, cocksfoot/lupin pasture can be used as an alternative forage crop.

Keywords: *Dactylis glomerata*, dryland, *Lupinus polyphyllus*, *Medicago sativa*, pasture composition, sheep liveweight gain

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

1 INTRODUCTION

New Zealand South Island high country pastures are typically nitrogen (N) deficient, with the incorporation of legumes a traditional strategy for increasing N availability and improving feed quality. There are several challenges associated with growing pasture species, including legumes, in the high country. Soils are typically acidic with low phosphorus (P) and sulphur (S) availability (Scott *et al.* 1985) and concentrations of exchangeable aluminium (Al) in the acidic soils frequently reach levels that are toxic to most legumes (Moir & Moot 2014). The acidic, low fertility soils of the high country limit the growth and persistence of conventional legume species such as white clover (*Trifolium repens*) and lucerne (*Medicago sativa*) (Scott *et al.* 1995). The high country environment also experiences high seasonal variability in temperature and moisture availability, with low inland basins having a non-growing period of 4 - 5 months (Scott *et al.* 1985). Therefore legumes selected for the high country environment require high nutrient use efficiency, tolerance of acidic soils and high exchangeable Al, the ability to survive and spread and good nodulations and N fixation (White 1995). Due to the extensive nature of farming in the region selected legumes should also have easy low-cost establishment, tolerance to pasture pests and be tolerant of close grazing.

'Russell' lupin, or perennial lupin, (*Lupinus polyphyllus*) is an introduced perennial legume that has thrived on the roadsides of high country New Zealand since 1952 (Scott 1989). Similar to lucerne it also has a tap root and grows from a crown that is dormant through the winter. Russell lupin is capable of growth in moderate temperatures and altitudes, and is moderately tolerant of prolonged water stress (Scott 1985). It has been identified as a successful legume in low fertility loose textured soils with high exchangeable Al and is well suited to moderate to high rainfall areas of the high country (Scott 1989). Several pasture grass companion species have been trialled with lupin, including cocksfoot (*Dactylis glomerata*), chewings fescue (*Festuca rubra* ssp. *commutate*), tall oat grass (*Arrhenatherum elatius*) and fescue tussock (*Festuca novae-zelandiae*) (Black & Ryan-Salter 2016; Pollock & Moot 2016; Scott 2008). Cocksfoot is a hardy perennial pasture grass recognised as a productive and persistent dryland pasture grass option (Brown *et al.* 2006; Woodman *et al.* 1996). It persists on stony low fertility soils and in low variable rainfall areas. Cocksfoot also exhibits a strong response to N, so benefits from establishment with a legume (Brown *et al.* 2006). Therefore, a lupin and cocksfoot pasture mix has potential to be persistent and productive in a high country environment, leading to improved sheep production compared to undeveloped high country.

When initially exposed to lupins, sheep are slow to begin grazing them due to the alkaloid content (Gibbs 1988) instead selecting other pasture components (Kitessa 1992; Scott *et al.* 1994). However, Kitessa (1992) found after a short adjustment period sheep rapidly consume lupin, with no significant difference in consumption over the grazing period between sheep accustomed to lupin and sheep unaccustomed to lupin. Russell lupin contains bitter alkaloids that are present in higher numbers in leaves over summer (Scott 1989). This can limit the palatability of lupin over this period. The nutritive value of Russell lupin changes throughout the growing period, with Kitessa (1992) reporting decreasing nutritive value of stem and petiole with increased plant maturity.

The feeding value of Russell lupins is suggested to be lower than that or more conventional legumes. In a grazing trial comparing liveweight gain of Merino wethers Scott *et al.* (1994) found the wethers gained weight faster on red clover (*Trifolium pratense*) and alsike clover (*Trifolium hybridum*) compared to lupin. A t3 year on farm study from Black *et al.* (2014) at Sawdon Station near Lake Tekapo investigated the performance of Merino ewes and lambs grazing mature Russell lupins in comparison to lucerne and other conventional legume-based pastures. Ewes and lambs grazing lupin pasture were found to have lower liveweight gain than those grazing control pastures. Lambing percentage was higher on lupin pasture (average 111%), than on control pasture (average 105%). Lupin pastures had no effect on wool quality when compared with control pasture, but wool production was significantly different with sheep grazing lupin pasture producing a fleece weighing 4.64 kg while control pasture sheep produced a 4.92 kg fleece. In this trial the yield, stocking rate and quality of the control pastures was not quantified, limiting the ability to explain differences in sheep production between the two pasture types. An evaluation of feeding value of summer dry cocksfoot/lupin pasture and lucerne pasture from Black & Ryan-Salter (2016) found live weight yield per hectare of lambs grazing cocksfoot/lupin pasture was 50-68% of the live weight yield for the corresponding lucerne treatment over 3 years. Dry matter intake of cocksfoot/lupin pasture averaged 68% of the 1.7 kg DM/sheep/day consumed on the lucerne pasture, contributing to the lower per hectare lamb growth rate. Cocksfoot/lupin pasture also produced 50-80% less herbage than lucerne pasture and contained more dead material. The cocksfoot/lupin pasture contained higher metabolisable energy (ME) and lower crude protein (CP) when contrast with lucerne. However lower pre-grazing pasture mass and botanical composition of pasture indicated there were less high-quality components available for sheep to select on cocksfoot/lupin pasture, potentially contributing to lower daily weight gain in cocksfoot/lupin pastures compared with lucerne pasture. The Black & Ryan-Salter (2016) trial occurred on the same trial plots as this recent experiment, using data from the first 3 years, while this recent trial uses data from the fourth year.

While recent research has been undertaken to explain the liveweight gain of sheep grazing lupin there is limited information relating the liveweight gain of sheep to the nutritive value of the lupin pasture. There is also little information available on the consumption of cocksfoot/lupin pasture components by sheep over the duration of the grazing period. The feeding value of a pasture combines both dry matter intake and nutritive value attributes, and can be quantified as animal performance. This study was carried out on 4 year old cocksfoot/lupin and lucerne pastures at Lincoln University with the aim of further investigating Russell lupin as an alternative pasture legume in a summer dry environment. Feeding value

1.1 Aims and objectives

The objective of this study was to compare the feeding value of dryland cocksfoot/lupin pasture for sheep in comparison to a pure lucerne pasture. Specific questions investigated included:

- What is the production of young sheep on a cocksfoot/lupin pasture mix compared to a pure lucerne pasture?
- What is the difference in feed intake of sheep on cocksfoot/lupin pasture compared with lucerne pasture?
- How does morphological composition of cocksfoot/lupin pasture and lucerne pasture affect pasture intake?

- What is the nutritive value of a cocksfoot/lupin pasture compared to a lucerne pasture?

1.2 Null hypothesis

There is no difference between dryland cocksfoot/lupin and lucerne pasture in their feeding value for sheep.

2 REVIEW OF THE LITERATURE

2.1 Review objective

The objective of this literature review was to explore the agronomic and animal production potential of perennial lupin as an alternative legume in the high country. It covers the challenges facing legume growth in the high country, the requirements of perennial lupin for growth, the nutritive value of lupin, and animal production on lupin.

2.2 Persistence of legumes in the high country

Traditional legumes like white clover and lucerne often lack productivity and persistence in the high country (White 1995; Woodman *et al.* 1992). Woodman *et al.* (1992) trialled 21 cultivars of conventional and alternative grass and legume species in Omarama on dry soil with a typical soil moisture deficit from October to April and found conventional legume species like white clover, red clover, alsike clover, and subterranean clover (*Trifolium subterraneum*) either did not survive or had poor persistence. In addition to moisture limitations, Al toxicity also limits legume growth in the high country (Moir & Moot, 2014). High levels of exchangeable Al occur in the soil at a low pH, becoming toxic to many legumes when pH is below 5.7. While surface lime can be used to reduce the level of exchangeable Al Moir & Moot (2014) found this process slow, and on 3 sites over 3 years after only achieved a subsoil (7.5-15 cm) pH above 5.7 at the Mt Pember site in Lees Valley, Canterbury with 8 t/ha of lime added. White (1995) summed up the requirements of a successful high country legume as having high nutrient use efficiency, the ability to compete with resident vegetation, tolerance of acid soils and high soluble Al, good N fixation, low cost easy establishment, the ability to survive and spread, growing points to survive close grazing, tolerance to plant pests, high dry matter (DM) production and good commercial seed production.

Compared with other common pasture legumes, lupin thrives in the high country (Scott 2008). Initial reports from Scott *et al.* (1985) suggested lupins were unsuitable for wet, acidic, and infertile soil, but Scott (2014) later identified they first established on roadsides in wet areas, acidic soils, eroding subalpine soils, with high Al, and low P. Lupins are cold tolerant (Black *et al.* 2014), suit moderate temperature and altitude environments, low-medium soil fertility sites, and are moderately tolerant to moisture stress (Figure 2.1) (Scott *et al*. 1985). While lupins are an obvious presence on un-grazed roadside areas they are not found in adjacent grazed areas so can be controlled through grazing (Scott 2014). They are considered by some to be a weed as they form dense stands on braided rivers, increasing the speed of water flow in channels around lupins and ruining the habitat of native birds (Department of Conservation 2012).

Material removed due to copyright compliance

Figure 2.1 The most suitable role of some legume species in relation to environmental factors of temperature, soil moisture and soil fertility. Names of species more suited to lax grazing are given in capital letters (Scott *et al.* 1995).

A 26 year long grazing trial involving 25 different species mixes, 35 different S and P treatments, and a range of stocking rates and combinations from Scott (2008) at Lake Tekapo identified lupin as a dominant plant (Table 2.1). Out of the different species trialled lupin was quick to establish as the dominant species under low and moderate fertiliser levels. Lupin generally was not the dominant species in irrigated pasture, with the exception of mob stocking at a low stocking rate from Years 5-12. In Years 17-20 lupin was the dominant species under low soil fertility conditions. Stocking rate varied across the trials from 0.8-8 stock units/ha, and was found to have less impact on the dominant species type than soil fertility.

Table 2.1 Changes in species dominance over six periods in 25 years related to fertiliser levels (superphosphate in kg/ha/yr: 1 = nil, 2 = 50, 3 = 100, 4 = 250, and 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).

Material removed due to copyright compliance

A similar study from Scott (2014) trialled different legume varieties sown in a single plot. Out of 11 different legume varieties sown lupin was the most successful over 19 years (Figure 2.2). *Trifolium* species, the next most successful species, declined at a rate of 10%/year, while lupin declined at 2%/year. Lupin not only persisted it also increased over the trial duration with the ability to spread seed in the presence of repeated close grazing.

Material removed due to copyright compliance

Figure 2.2 Changes in overall species proportions over two decades of strips of 14 different legumes cross sown with 16 different grasses/herb strips. Lup = *Lupinus polyphyllus*; Trif = *Trifolium hybridum, T. repens, T. medium, T. ambiguum*; Dg = *Dactylis glomerata*; Sp = *Schedonorus phoenix*; Ao = *Anthoxanthum odoratum*; Ac = *Agrostis capillaris*; Pp = *Poa pratensis*; Fr = *Festuca rubra*; Bin = *Bromus inermis*; and Ban = *B. tectorum, B. diandrus, B. mollis* (Scott 2014).

Woodman *et al.* (1996) also found lupin to be a persistent legume in the New Zealand South Island high country. In a trial run in the southern Mackenzie Basin on strongly to moderately leached yellow-brown shallow and stony soils initial establishment of all legumes (lucerne, red clover, birdsfoot trefoil (*Lotus corniculatus*), and perennial lupin) was adequate. Lupins had the lowest establishment rate at 8 seedlings/m^2, while birdsfoot trefoil was highest at 66 seedlings/m^2 (Figure 2.3). Low seedling establishment from perennial lupins may be a result of hard seed and/or non-inoculation. Substantial losses occurred across all legume species in 1988-90. All species but perennial lupin continued to either slowly decline or remain at the level they fell to after this point. Perennial lupin plants/m^2 increased rapidly in 1983 to become one of the best preforming legumes in the 9 year trial along with birdsfoot trefoil. No red clover survived after 9 years and the few lupin plants remaining were yellowed and spindly, likely due to low sulphur.

Material removed due to copyright compliance

Figure 2.3 Sown legume plant numbers (/m^2) for the period 1989 -1995 at Tara Hills, Mackenzie Basin (Woodman *et al*. 1996).

Grazing affects the abundance of lupin in the presence of a mixture of other legume species (Scott 2001). No grazing treatment effects were noted on lupin in the early years of Scott's trial, but in Years 11-16 it reduced to moderate/low abundance in moderate and high set stocked treatments. Lupin in the low set stocking treatment was unaffected. In years 17-

19 it declined slightly in general importance across all treatments as abundance of other species increased, with the greatest decrease in importance in the low stocking rate treatment.

The ability of lupin to re-seed is a major component of its persistence in the high country (Scott 2014; Woodman *et al*. 1996). Woodman *et al.* (1996) found lupin had excellent re-seeding ability that allowed it to increase the number of plants/m^2 while other legumes decreased (Figure 2.3) When growing in low fertility soils with natural ground cover of 50-70% hawkweed (*Hieracium pilosella*), 20-30% bare ground, and remainder sheep sorrel (*Rumex acetosella*), adventive grasses and native species lupin re-seeded in autumn and spring from 1993-96 while birdsfoot trefoil re-seeded a little in 1995-96 (Table 2.2). The re-seeding of birdsfoot trefoil was lower than that of lupin, ranging from 0.06-0.33 seedlings/m^2 in spring 1995 while lupin re-seeding was 0.66 seedlings/m^2.

Table 2.2 Re-seeded seedling numbers (/m^2) of Goldie, Dryland, Granger and Empire *Lotus corniculatus*, and perennial lupin at Tara Hills, Mackenzie Basin (Woodman *et al.* 1996).

Material removed due to copyright compliance

2.3 Soil fertility and conditions for lupin

Perennial lupins are adapted to growing in a wide range of soil types including those unsuitable for common grazing legumes (Scott 1989). They are most suited to rocky, sandy, or other loose textured soils of moderate to low fertility and can grow in moist acid lose textured soils with low fertiliser application. Scott (1989) suggested they are not suited to fine textured soils or clays, and Burtt (1981) reported unsuccessful attempts at growing lupins in heavy wet Southland soil and pumice soils of the central North Island.

Lupin grows in South Island high country soils which typically have low fertility with major S and P deficiency (Scott *et al.* 1985). A trial from Jarvis *et al.* (1997) in low fertility tussock rangeland (S and P deficient) found in the absence of applied S lupin plants grew to a maximum height of 10 cm and produced very little DM. A late application of S (60 kg S/ha) caused a large increase in lupin DM from 0.5 t/ha to 3.4 t/ha, but despite this analysis of leaf tissue indicated S levels to be below optimum (0.08-0.14%). Applying P at establishment improved the effect of late S application, suggesting application of fertiliser at lupin establishment will set up strong plant growth. The same trial found DM production was affected more by the application of S than P possibly due to lupin's proteoid roots that secrete citrate when adequate S is available to render soil phosphates more available in infertile soils.

Davis (1991) also noted the ability of lupin to grow in the absence of P, noting two lupin varieties (*Lupinus polyphyllus* and *Lupinus arboreus*) produced more than 5 t DM/ha while common pasture legumes failed to respond until the application of 200-800 kg/ha P. Davis (1991) also noted lupin had few surface roots, which could be a disadvantage when P is applied to the surface of high P absorbing soils. Davis (1991) suggested three factors that improve P extraction by lupin plants over other legume species. Factor one is the geometry and extension of the roots. Lupin roots are wide and long an enable the plant to explore a greater soil area. Factor two involves the enhancement of acid and chelating substances excreted by the roots and or extracellular root P activity. Root phosphatase excretion can hydrolyse some forms of organic P present in the soil solution or close to roots. By acidifying the rhizosphere by excreting H^+ and/or chelating substances lupin can potentially increase P uptake. Factor three involves the potential involvement of free living or symbiotic microorganisms with lupin roots. It is plausible a microorganism aids in P availability and uptake in lupins, although it is currently unconfirmed.

Davis (1991) also found at low P, mineralizable N levels were much higher under lupin than birdsfoot trefoil or white clover. This indicates an increased rate of N fixation occurs under P availability. Adding 100 kg P/ha to birdsfoot trefoil and white clover increased N levels to a level equal to lupin with no added P, but adding P to lupin had no effect on N levels.

Low and no P fertiliser are adequate for moderate to high lupin abundance, with Scott (2001) finding slightly more lupin present in low/no P plots. Scott (2001) identified S is the key nutrient affecting lupin growth at Lake Tekapo. Under low S fertiliser lupin declined in abundance, a trend that was apparent throughout the full 19 years of the trial. In Years 17-19 the absence or low rate of fertiliser caused a marked decrease in lupin abundance, indicating application of fertiliser every few years is beneficial to lupin. These trials also had different grazing treatments applied, impacting their long term persistence. In moderate to high stocked treatments lupin declined from Years 11-16. Where irrigation was applied and soil fertility was high, lupin decreased in importance as conditions were well suited to the growth of other species (Table 2.1).

Acidic soils (pH <5.7) are unsuitable for common legumes due to high levels of exchangeable Al found in the soil (Moir & Moot 2014), with levels higher than 1.0 milliequivalents (m.e.) causing toxicity (Davis 1981). In the case of lucerne lack of nodulation due to Al toxicity led to a lack of persistence at the Lees Valley (Berenji 2015). Perennial lupin appears to be unaffected by high levels of Al, with Scott (1989) reporting an accumulation of Al in its foliage and Davis (1981) finding low concentrations of Al in its roots, indicating an ability to exclude Al. A pot trial from Davis (1981) found at an exchangeable Al level of 3-3.5 m.e lupin had a lower concentration of Al in its roots than white clover, lotus, and *L. pedunculatus x L. corniculatus*. Uptake of Al is reported to be increased by low P, so the proteoid roots of lupin will assist in limiting the effect of Al on plant growth. As lupin nodulation and growth is unaffected by soil pH, lime has no effect on its density and decreases its proportionate appearance in pasture as other pasture species respond to lime (Pollock & Moot 2016). In an experiment at Glenmore Station, Lake Tekapo, lupin (Russell and Blue) had less relative ground cover with the application of 3 t lime/ha, but overall pasture yield was not significantly affected as other pasture components increased in response to lime (Figure 2.4).

Material removed due to copyright compliance

Figure 2.4 Percentage ground cover of the perennial lupin pasture components on 19 November 2014 at Glenmore Station in response to treatments applied before sowing (lime) and at sowing (sowing rate and lupin type) in December 2012 (Pollock & Moot 2016).

Lupins are cold tolerant (Black *et al.* 2014) with an autumn frost tolerance similar to red clover (Scott 1998). They germinate rapidly under cold spring conditions (Scott 1989) with a suggested base temperature of 2 ^{o}C for emergence, and 3 ^{o}C for establishment, requiring 190 ^{o}Cd for emergence, and 412 ^{o}Cd for establishment (Wangdi 1990). They are most successful in mid to high rainfall areas of the high country (Scott 1989).

2.4 Morphology of Russell lupin

Russell lupin is a herbaceous perennial legume that develops a single stout tap root with few surface roots (Davis 1981). It produces palmate leaves with 9-15 leaflets at 5 – 15 cm long (Ryan-Salter *et al.* 2012), as seen in Plate 2.1. Leaves grow from the crown with 15 – 40 cm long petioles. Stems are usually inconspicuous during vegetative growth, but reach heights of 1.5 m when reproductive (Plate 2.2). Flowering typically occurs in November/December, but it is plausible lupin will flower in any conditions good for growth.

Seeds are produced in woolly pods 2.5 – 5.0 cm long containing approximately 9 seeds. Plants are winter dormant, dying back to the crown over winter to avoid frost damage.

Plate 2.1 Perennial lupin palmate leaves in cocksfoot/lupin pasture at Lincoln University.

Plate 2.2 Lupin reproductive stem and flower in cocksfoot/lupin pasture at Lincoln University.

2.5 Seed production and inoculation

Lupin seed production has highly variable yields (100-250 kg/ha) and is predominately for the North American ornamental market, with a niche domestic market to small too justify investment (Monks *et al.* 2016). A sowing rate of 8 kg/ha of perennial lupin (Blue and Russell mix) along with 2 kg/ha of cocksfoot was found to be adequate with no great yield response at higher sowing rates (Moot *et al.* 2014). At this level lupin contributed 79% to annual yield and 90% to spring yield. Note that in this trial the perennial 'blue' lupin, as it is colloquial called by the seed supplier, is a variety of the perennial lupin *Lupinus polyphyllus* and is not the more common annual blue lupin (*L. angustifolius*). Blue lupin in this trial was found to have 10% higher germination and emergence, so yielded slightly more. While this is an optimal rate lower seed rates can be used if there is adequate moisture and seedbed preparation to minimise impact of resident species.

Wangdi (1990) found mechanical and acid scarification improved establishment rates (76% and 64% respectively compared with 55% control). However there is potential for abnormal seedlings, with 51% and 53% respectively at 24 days after sowing while unscarified seed produced 45% abnormal seedlings.

Lupin seed should be inoculated, although uninoculated seed will nodulate eventually (Scott 1989). The rhizobia bacteria that inoculate perennial lupin are found in the soils of the South Island high country, hence why wild roadside lupin plants are heavily nodulated (Ryan-Salter *et al.* 2014). The rhizobia bacteria that forms functional nodules on lupins was identified as belonging to the genus *Bradyrhizobium* from a range of roadside and uninoculated agricultural populations of lupin collected in South Island high country sites. It is currently unknown if the origins of the rhizobia are from a previous inoculant used by farmers, a strain from outside New Zealand that became established with early lupin populations, or if it is naturally occurring. Ryan-Salter *et al.* (2014) identified the Group G inoculant for annual lupin is also effective on perennial lupin. The presence of *Bradyrhizobium* in the soil means inoculant is suggested not required at establishment. However there is potential to develop elite inoculation strains that give greater growth in the future.

2.6 Nutritional value of perennial lupin

2.6.1 Crude protein and N content

In a grazed experiment at Lincoln University N concentration in Russell lupin declines with maturity, with Kitessa (1992) identifying a decline from 4.2% to 2.4% from October to January. Two significant drops occurred during this period, one 3 weeks preceding flowering beginning, and the other 3 weeks before the last sampling at the dry pod stage. The first drop in N concentration was the greatest, declining at 0.6 %/day, while the rest of the sampling period declined by less than one-hundredths of this rate. At the lowest N concentration (2.4%) lupin contained more than 15% crude protein. N concentration in stems, leaves and pods declined linearly, while petiole declined quadratically (Figure 2.5). N concentration was highest in the pods, then leaves, then stems, and last petioles. Flower and dead material N concentration appear unaffected by harvest time, with N concentrations in the DM ranging from 4.5% - 5.2% and 2.2% - 3.4% respectively. Black *et al*. (2014) measured N content over a longer period (October – June) with similar results. Like Kitessa (1992), Black *et al*. (2014) found N content was highest in leaves, flowers and green seed pods, and lowest in petiole, stem, and dead material. Over the growth season leaf N decreased from 5.4% to 3.8%, petiole N from 3.1% to 1.5%, stem N ranged from 4.3% to 0.7% and dead material N ranged from 0.6 to 1.7% (Figure 2.6). Values for CP found in lupin in a second study from Black & Ryan-Salter (2016) were consistent with those from Black *et al.* (2014) and Kitessa (1992). Black & Ryan-Salter (2016) found lower CP content in lupin leaf/petiole than lucerne leaf/petiole, but similar CP content in stem between lupin and lucerne.

Material removed due to copyright compliance

Figure 2.5 Regression of N concentration in Russell lupin stems, petioles, leaves and pods on harvest time (number of days since beginning of grazing) (Kitessa 1992).

Material removed due to copyright compliance

Figure 2.6 Nitrogen concentrations of Russell lupin leaf, petiole, stem, flower and dead material at Sawdon Station, Lake Tekapo (Black *et al.* 2014).

2.6.2 DM digestibility

Kitessa (1992) showed the whole plant DM digestibility (DMD) of lupin had a quadratic relationship with maturity (Figure 2.7), declining from 76.5% on October 5th 1989 to 56% 100 days later. Stem, petiole and pod DMD decreased linearly while dead mater declined quadratically. The DMD of leaves and flowers showed little change with variation between 84% - 86% and 81% - 84%, respectively. Of all lupin parts leaves were the most digestible. Stem had the highest digestibility at the initial cut but it declined rapidly and after the development of pods became the least digestible plant part. Similarly Black *et al.* (2014) found leaf DMD was stable across the whole season (October – June) at 80%, while other lupin components decreased in DMD (Figure 2.8). Petioles declined in DMD from 80% to 60% - 70%, stem from 80% to 45% - 55%, dead material from 30% - 56%, and flower DMD varied between 81 and 84%.

Figure 2.7 Regression of DM digestibility of whole plant, stem, petioles, pod and dead matter of Russell lupin at harvest time (number of days since beginning of sampling) (Kitessa 1992)

Material removed due to copyright compliance

Figure 2.8 *In vitro* DM digestibility of Russell lupin leaf, petiole, stem, flower and dead material at Sawdon Station, Lake Tekapo (Black *et al.* 2014).

2.6.3 Neutral detergent fibre

At Lincoln, neutral detergent fibre (NDF) concentration of Russell lupin increased linearly in all lupin parts, so that the whole plant NDF increased by approximately 0.21%/day to 46% by the final cut (October – January) (Figure 2.9) (Kitessa 1992). Leaves and flowers had the lowest NDF concentration, increasing by less than 5% over the whole period. NDF was highest in stem and pods. Dead matter NDF ranged between 34% - 52% and showed no relationship with lupin maturity.

Material removed due to copyright compliance

Figure 2.9 Regression of NDF concentrations in whole plant, stem, petiole and leaves of Russell lupins at harvest time (Kitessa 1992).

2.6.4 Metabolisable energy

Kitessa (1992) quantified ME of lupin components, finding consistent ME in leaf material and declining ME in the stem, leaf, and pod over the growth period. Leaf ME ranged from 12.2 – 12.8 MJ/kg DM over October to January. Over this same time period stem ME fell from 13.2 to 10.1 MJ/kg DM and petiole ME from 3.8 to 5.8 MJ/kg DM. The ME of dead material was variable throughout this period, ranging from 2.6 – 7.5 MJ/kg DM. Relative to lucerne, Black & Ryan-Salter (2016) found ME was greater in lupin stem than lucerne stem and similar in the leaves/petiole component.

2.6.5 Lupin alkaloids

Perennial lupin leaves decline in palatability as summer begins due to their bitter alkaloids (Scott 1989). This leads to selection by sheep grazing on lupin for young lupin buds and other species in the sward. All plant parts are considered palatable to sheep again in winter. In contrast Kitessa (1992) found during full bloom sheep had an initial preference for the leaves. Poisoning as a result of lupin alkaloid is currently unreported in New Zealand. It is possible to breed lupin for reduced alkaloid but it provides insect protection (Gladstones 1970), and as stock adapt to the taste of lupin over time (Black *et al.* 2014; Scott 1989), there is no apparent benefit to breeding for lower alkaloid content (Gibbs 1988).

2.7 Sheep acceptance of perennial lupin

The alkaloids present in perennial lupins leaves over summer months make them less palatable than other lupin components and pasture species (Scott 1989). Flowers are reported by Black & Ryan-Salter (2016) and Pollock & Moot (2016) to be the most palatable and desired lupin component by sheep. However Kitessa (1992) noted during full bloom (November -December) sheep did not show a strong initial preference for flowers. Further work from Scott *et al*. (1994) comparing red clover and lupin in the high country identified lupin as the less acceptable legume. While sheep adjust to lupin preference for other pasture components under initial grazing or laxer stocking conditions is beneficial as lupins are able to set seed and increase in dominance.

Kitessa (1992) monitored the disappearance of lupin components in a grazing trial at Lincoln. Sheep were initially slow to graze the lupins, grazing weeds and grass before rapidly consuming them. During the full bloom stage leaves were the first to be consumed, at 77% and 66% of total DM disappearance during the first 2 and 4 days of grazing respectively (Figure 2.10). Petiole consumption began around day 2 while stem and flower consumption began after the fourth day of grazing. By the final grazing day only some stem remained. At the green pod stage the whole plant disappearance followed a more rapid linear pattern. Leaves were again consumed first, and all other plant parts except for stem showed a decline in DM after day 2 of grazing. Stem disappearance occurred after day 4. While the consumption of pods was second to that of leaves, residual DM following grazing was primarily pods and stem. At the dry pod stage whole plant disappearance followed a linear pattern. All plant parts, with the exception of stem, were removed rapidly with pods the most popular. Stem had a very low rate of disappearance, only dropping by 3.6 g DM/plant. No significant difference in lupin disappearance between sheep accustomed to lupin and unaccustomed sheep occurred throughout the trial.

Material removed due to copyright compliance

Figure 2.10 The pattern of disappearance of (a) whole plant and (b) plant parts of Russell lupin over successive grazing days by sheep at full bloom (Kitessa 1992).

2.8 Lupin pasture composition

The Black *et al*. (2014) 3 year lupin trial at Sawdon Station reported changes in lupin pasture composition over the season and between years. Herbage present in October 2012 was 41% lupin leaf/petiole, 1% stem, 51% dead and 7% other species (Figure 2.11). In December it changed to 42% leaf/petiole, 35% stem, 7% flower, 8% dead and 9% other species. By

February it changed to 24% leaf/petiole, 36% stem, 1% flower, 10% dead and 29% other species. The dead fraction as predominately stem, with some from the previous year. Over the autumn grazing period (March – May) green lupin declined and dead stem increased, so that by May most herbage on offer was dead stem. Similar trends in pasture composition occurred in the final year of the trial. September 2013 herbage was 40% leaf/petiole, 58% dead stem and 2% other species. December was 37% leaf/petiole, 35% stem, 12% flower, 13% dead material and 3% other species. Sheep were returned to plots after a month spell for autumn (April - May). April pasture composition was 22% leaf/petiole, 1% green stem and 73% dead. May pasture composition was 4% leaf/petiole and 87% dead. The majority of the dead material was stem. CP and digestibility are lower in dead material and stem than lupin leaves and flowers, but the herbage available to ewes and lambs was sufficient for growth.

In a cocksfoot/lupin pasture at Lincoln University, Black & Ryan-Salter (2016) found the lupin herbage averaged 98% leaf and petiole and 2% stem and flower. As sheep were rotationally grazed over the growing season it limited the lupin's ability to set seed. The lupin component of the pasture also appeared to decline by half each year of the 3 year trial, possibly due to crown and root rot.

Material removed due to copyright compliance

Figure 2.11 Seasonal pattern of average herbage mass and composition of a perennial lupin stand grazed by Merinos at Sawdon Station, Lake Tekapo (Black *et al.* 2014).

2.9 Complimentary species for perennial lupin

Initially it was recommended by Scott (1989) not to sow lupin with grass species as lupin is sensitive to competition. However recent experiments have successfully grown lupin with other grass species (Black *et al*. 2014; Black & Ryan-Salter 2016; Pollock & Moot 2016). Pollock & Moot (2016) trialled 2 kg/ha of ‘Vision’ cocksfoot along with six different lupin sowing rates and found it a suitable complimentary species. The cocksfoot DM yield was similar to that of the resident pasture species, and the cocksfoot benefited from the N provided by the lupin. Addition of lime benefited cocksfoot but not lupin, indicating lime could be utilised to maintain the cocksfoot fraction of the pasture. Black & Ryan-Salter (2016) also found cocksfoot to be a suitable companion for lupin, with a cocksfoot/lupin pasture mix yielding 50-68% as much herbage mass as lucerne annually under dryland conditions at Lincoln University.

Scott *et al*. (1985) evaluated a wide range of pasture grasses for their suitability in hill and high country sites. Cocksfoot was reported as suited to cool temperatures, high altitudes and southerly aspects. It has moderate suitability to low soil fertility sites but is of greatest value in low to medium fertility sites. Cocksfoot is moderately to highly tolerant to moisture stress for long and short periods. Scott *et al.* (1985) determined a similar environment to be suitable for lupin growth.

Like lupin, the cocksfoot cultivar ‘Grasslands Kara’ grows best under lax grazing (Stevens *et al*. 1992), with Woodman *et al*. (1992) noting it was more vigorous when continuously grazed for only one part of the growing period. ‘Grasslands Kara’ ranked highly in a study from Woodman *et al*. (1992) comparing 121 grass and legume cultivars over 7-8 years in a dryland environment. All cocksfoot cultivars trialled ranked high for plant survival, spring vigour, drought tolerance, autumn vigour, and frost tolerance, although Stevens *et al*. (1992) reported ‘Grasslands Kara’ to be more susceptible to frost than some other cocksfoot cultivars due to its winter activity. Digestibility and protein content of ‘Grasslands Kara’ was similar to perennial ryegrass (‘Nui’) during an experiment by Stevens *et al.* (1992) where ‘Grasslands Kara’ digestibility was 71.9%, 72.1% and 69.3% over spring, summer, and autumn respectfully, and over the same seasons its CP contents were 27.2%, 23.0% and 22.0%

2.10 Animal production response to lupin

Initial trials of sheep performance on perennial lupin were carried out at Lake Tekapo by Scott *et al.* (1994). Merino weathers were set stocked from November to April each year on the developed high country legume pastures (red clover, alsike clover or perennial lupin) for a 5 year period. Animals were weighed monthly over the grazing period and stocking rate was set as to allow a similar amount of herbage per sheep. There was a highly significant difference in the pre-graze herbage, with lupin highest and increasing over the 5 year period, red clover stable due to high autumn growth, and alsike declining over time. The highest animal growth rates occurred in late spring and slowed through summer and autumn (Figure 2.12). A high level of variation in growth rates within and between years occurred, with summer growth causing the most variation. Individual animal mean daily weight gain was 58 g/day on perennial lupin, 77 g/day on alsike clover and 110 g/day on red clover. Growth rates on perennial lupin were 53% of that of red clover, making it the poorest legume for per head liveweight gain. However as perennial lupins can support more stock than the other legume options, particularly in the last 2 years of the trial, Scott *et al*. (1994) believed it to be a superior high country forage for growth in lower fertility soils compared to red clover and alsike clover.

Material removed due to copyright compliance

Figure 2.12 Daily liveweight gain (g/day) of young Merino wethers set stocked on perennial lupin, red clover and alsike clover at Lake Tekapo. Mean of 5 years. Least significant difference assuming independence of measurement in each period (Scott 1994).

Black *et al*. (2014) also evaluated sheep performance on a perennial lupin pasture at Sawdon Station over a 3 year period using two-tooth Merino ewes and their lambs. The rotationally grazed lupin pasture (a mix of perennial lupin, oats (*Avena sativa*), barley (*Hordeum vulgare L.*), Italian ryegrass (*Lolium multiflorum*) and white clover) was compared to rotationally grazed lucerne and on occasion grass/clover based pasture as a control. Sheep were put on the lupin pasture in December – February to monitor ewe and lamb growth rates, and March-June to determine lupins suitability for flushing and mating.

Black *et al*. (2014) found during the 2011/2012 season lambs on lupin grew an average 150 g/day from tailing to weaning while the control lambs grew 217 g/day. Over the 2 month summer period ewes on lupin lost 3 kg, while ewes on control pasture gained 5 kg. This loss could be due to the lack of available leaf material or due to grazing preference, feed allowance, or feed quality. Over autumn (March-May) ewes on lupin gained 7 kg (125 g/day) while the control ewes gained 9 kg (161 g/day).

The next season (2012/13) lambing percentage of the lupin ewes at tailing (December) was 103%, higher than the 93% from the control pasture. Lamb weight at tailing was 20 kg on lupins and 21 kg on the control pasture. At weaning (February) lamb weight increased to 28 kg on lupin (mean growth rate 121 g/day), and 31 kg on control pasture (151 g/day). Lupin ewes lost 8 kg over lambing while control ewes lost 2 kg, and gained 2.6 kg (64 g/day) and 4.9 kg (120 g/day) respectively over autumn (April-May).

Lambing percentage at tailing (2013/14) increased to 120% for lupin ewes and 117% for control ewes, with lambs weighing 19 and 17 kg respectively. At weaning both mobs of lambs averaged 30 kg, with 166 g/day growth on lupins and 194 g/day growth on control pasture. Lupin ewes lost 4.3 kg during lambing, while control ewes gained 4 kg. Over summer lupin ewes gained 1.3 kg while control ewes lost 3.6 kg, and over autumn (April – May) 1.7 kg (63 g/day) and 2.6 kg (96 g/day).

Black *et al*. (2014) also evaluated lupin effects on wool production and quality (Table 2.3). Fleece weight was significantly different between the two pastures at 4.64 kg for lupin and 4.92 kg for control pasture. Staple length and micron length were similar between lupin and control pastures, at 79 mm and 18.6 µm compared with 80 mm and 18.5 µm respectively.

Table 2.3 Wool characteristics at shearing in September, 2013, of Merino ewes that had been grazing perennial lupins during the previous two growth seasons compared with ewes that had grazed on lucerne and clover-based pastures (control) at Sawdon Station Lake Tekapo (Black *et al*. 2014).

Material removed due to copyright compliance

Black *et al*. (2014) showed Merinos on lupin can perform almost as well as other improved pastures at Sawdon Station. This trial was limited by the lack of information available regarding the control pastures, limiting the ability of the authors to explain differences in stock performance. In addition to providing acceptable fodder for lambing, mating, and wool production lupin also provided shelter for new born lambs.

In another 3 year study Black & Ryan-Salter (2016) evaluated lamb growth on a cocksfoot/lupin pasture compared with a lucerne pasture at Lincoln University. Liveweight gain per hectare was greater on lucerne than cocksfoot/lupin for all 3 years of the study, with Year one 107 kg/ha compared with 58 kg/ha, Year two 1134 kg/ha compared with 768 kg/ha and Year three 1347 kg/ha compared with 674 kg/ha respectively. These differences were due to daily liveweight gain, with Year 2 lupin lambs gaining 183 g/sheep/day while lucerne lambs gained 251 g/sheep/day. The continuation of this trial is outlined in this dissertation, with the quantification of animal production and feeding value for the fourth year after sowing.

2.11 Conclusions

Russell lupin is well suited to the high country environment, with the ability to be productive and persistent on acidic, low fertility soils with high exchangeable Al. They are best suited to areas with moderate to high rainfall and loose textured soils. Russell lupin is suitable for sheep production, with ewes and lambs gaining liveweight while grazing and no detrimental effects on wool quality. The grazing of perennial lupin has primarily occurred on mature lupin stands, with limited information regarding its feed value as a component of a rotationally grazed pasture sward. While the liveweight gain of sheep grazing lupin and the nutritive value of lupin have been quantified separately there is little material investigating the relationship between nutritive value and liveweight gain in lupin. There is also a lack of information available regarding the disappearance of lupin within a rotationally grazed pasture.

3 MATERIALS AND METHODS

3.1 Site and preparation

This experiment was conducted at the Horticultural Research Area (Paddock H12) at Lincoln University, Canterbury, New Zealand (43^{o}38’53’’ S, 172^{o}27’24’’ E, 9 m above sea level.) The soil type was a Templeton moderately deep silt loam with moderately well-drained drainage (Landcare Reaserch 2014). Soil pH was 6.0, Olson P 17 mg/litre and sulphate S 1 mg/kg in the top 75 mm. The climate is temperate with cool moist winters and warm dry summers with a prevailing north east breeze. Temperatures and rainfall data at the Broadfields meteorological station approximately 2 km north of the experimental site shows a minimum monthly rainfalls of 2 mm in February 2017 and a maximum temperature of 17^{o}C in January/February 2017 (Figure 1).

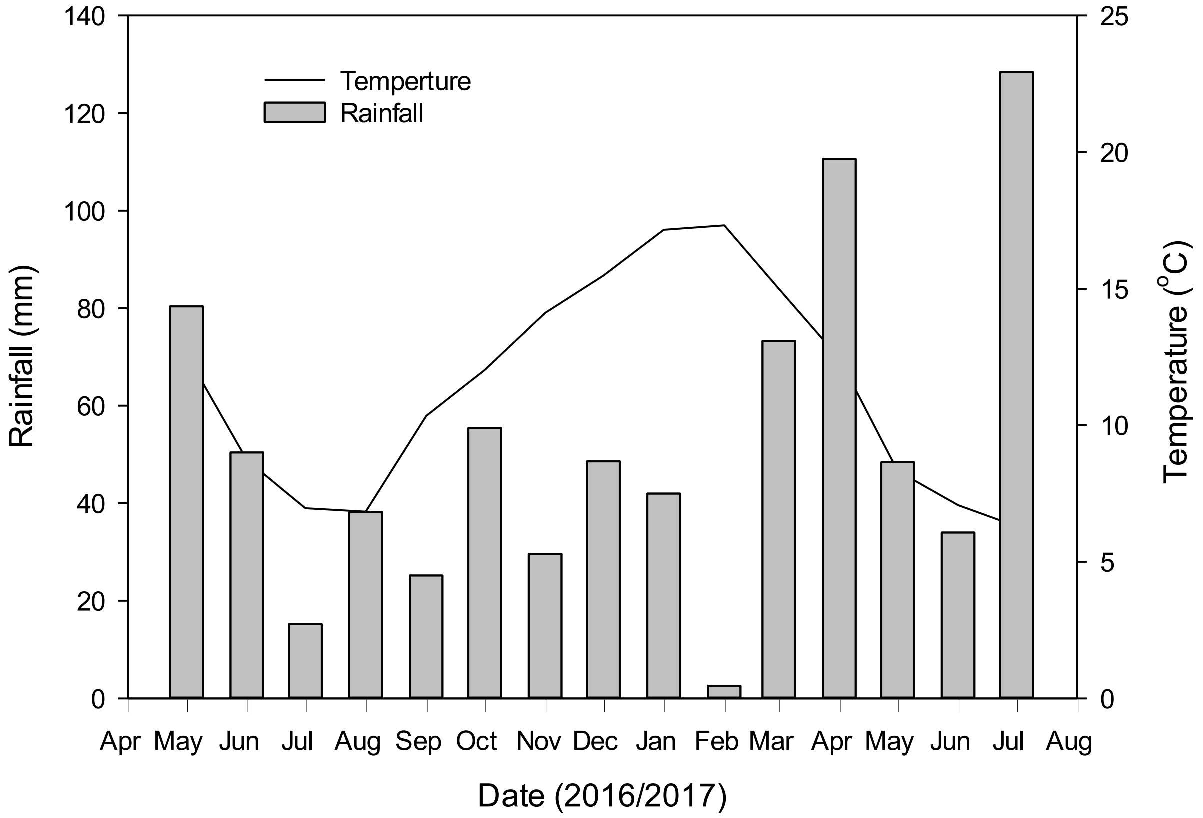


Figure 3.1 Mean rainfall (mm) and temperature (°C) from April 2016 – July 2017 at Broadfields metrological station, approximately 2 km north of the experimental site.

The current pasture types (cocksfoot/lupin and Lucerne) were established in December 2013. Paddock design and grazing techniques have altered through the years leading up to the 2016/2017 growing season, but there has been no change in pasture type or stock class. Initial pasture of the 2 ha paddock was a grass/clover mix (primarily *Lolium perenne* and *Trifolium repens*), followed by one crop of forage oats (*Avena sativa*). The oats were harvested October 2013 and the paddock irrigated (approximately 50 mm over 2 weeks), ploughed, and tilled in 2013.

3.2 Experimental design

The experimental site was a rectangular 2 ha paddock divided into three replicate blocks of 59 x 90 m along its longest axis, connected by an un-grazed laneway (Figure 3.2). Each block was divided into two 29.5 x 90 m plots (0.26 ha) and the two pasture types (cocksfoot/lupin and lucerne) were randomly allocated to the two plots within each block. Each plot was further divided using temporary electric fences into two paddocks (0.13 ha) to a total of six individual paddocks for each pasture type (Plate 3.1).

Block three		Block two		Block one	
Plot 6	Plot 5	Plot 4	Plot 3	Plot 2	Plot 1
Un-grazed laneway					
Paddock 5	Paddock 5	Paddock 3	Paddock 3	Paddock 1	Paddock 1
Paddock 6	Paddock 6	Paddock 4	Paddock 4	Paddock 2	Paddock 2
Lucerne	CF/Lupin	CF/Lupin	Lucerne	Lucerne	CF/Lupin

Figure 3.2 Experimental site layout showing blocks, plots, paddocks, and pasture type.

Plate 3.1 Experimental site showing Plot 1 Paddock 2 cocksfoot/lupin pasture in the foreground. Sheep are grazing Paddock 4, with those grazing lucerne towards the front, and those grazing cocksfoot/lupin to the rear.

3.3 Plant material

Perennial lupin seed was supplied from a local commercial grower: Rosavear & Co. Ltd., Ashburton, New Zealand. Two varieties of perennial lupin were used in this trial, colloquial called 'blue' and 'Russell' by the seed supplier (Moot & Pollock 2014). The 'blue' perennial lupin should not be confused with the common forage annual 'blue lupin' (*Lupinus angustifolius*). Russell lupin seed is likely from the roadside hybrid of *L. polyphyllyus* and *L. arboreous* (Scott, 1989). First commercially released in 1930 the first major roadside planting occured in 1952 near Sawdon Station, Lake Tekapo. Lupin seed was scarified and inoculated with Group G *Bradyrhizobium* inoculant the day before planting. Scarification improves establishment (Wangdi 1990), and *Bradyrhizobium* has been identified as the rhizobia bacteria found in wild perennial lupin populations (Ryan-Salter *et al.* 2014). The cocksfoot cultivar 'Grasslands Kara' was supplied by Agricom, New Zealand. Kara is distinguished by its upright growth habit, winter activity, and preference for lax grazing in comparison to other cocksfoot cultivars (Stevens *et al*. 1992). The lucerne cultivar was SF Force 4 (Seed Force, New Zealand). On the international winter dormancy scale 1-10 (1 = highly winter dormant, 10 = highly winter active) it scores a 4 (Seed Force). SF Force 4 shows good early growth and long term persistence. The seed was supplied inoculated by rhizobia.

3.4 Pasture establishment

The two pasture types were sown 5 December 2013 using a precision drill fitted with coulters spaced 0.15 m apart (Flexiseeder, Christchurch, New Zealand). 30 kg/ha of lupin (50:50 mix of 'Russell' and 'blue' varieties) was sown with 10 kg/ha of cocksfoot, and lucerne pasture sown at 15 kg/ha. To aid pasture establishment irrigation was applied at approximately 50 mm over 2 weeks in February 2014. Each plot was fenced with permanent wire netting and plumbed with a portable water trough. A raceway was added along the western boundary to connect the plots. Initially each plot was subdivided into five small paddocks (0.052 ha) using temporary electric fences. At the beginning of the 2016 growth season those temporary fences were removed and the plots were split into two paddocks (0.13 ha), for a total of six paddocks across each treatment. No fertiliser was applied at establishment and for the duration of the experiment.

3.5 Stock

In Year 1 (5 December 2013- 30 June 2014) Merino ewe lambs from Sawdon Station, Lake Tekapo, were grazed on the pastures. Several developed hoof problems so further grazing trials were carried out using Central Progeny Test (CPT) or Coopworth stud ewe lambs from Ashley Dene. In Year 4 (2016/2017) Coopworth ewe lambs were put on pastures on August 17th 2016. Lambs were shorn November 3rd 2016 and removed from the plots February 13th 2017. A new flock of Coopworth ewe lambs were added to pastures February 14th 2017 and removed June 1st 2017. Both pasture types were grazed for 288 days. For each flock of a sheep a number were selected as 'core' sheep from which liveweight gain was determined. These sheep remained on the pasture to achieve the same herbage allowance for both pasture types using a 'put and take' method whereby sheep were either added or removed if necessary from the group prior to being shifted to each paddock in the grazing rotation.

3.6 Grazing management

Sheep were split into two groups and rotationally grazed (approximately 60 days) with one group per paddock on both pasture type. Sheep spent 7-11 days in each paddock, depending on pasture growth rate. Both groups were shifted to the next paddock in the rotation on the same day. The number of sheep in a group was adjusted for herbage mass in order to maintain a similar herbage allowance for each pasture type. The stocking rate was altered using a 'Put and Take' policy where a core group of sheep were maintained on the plot and additional sheep added or taken away according to requirements. When the temperature dropped and restricted plant growth causing insufficient feed the pastures were spelled for winter. Plots were neither irrigated nor fertilised in Years 2-4.

3.7 Measurements

3.7.1 Sheep liveweight

When stock were shifted to the next paddock (7-11 days) they were weighed unfasted. The sheep were weighed to the nearest 0.1 kg using a Pratley weigh crate (Tumuka, New Zealand) with Gallagher scales (Hamilton, New Zealand). Live weight change was calculated as the mean live weight change in the core group of sheep (who remained in the experiment for the duration) multiplied by the weighted mean stocking rate. Weighted mean stocking rate was obtained in order to reflect a consistent stocking rate despite changes in stocking rate during a grazing period and differences in the length of a grazing period.

3.7.2 Herbage mass and botanical composition

Herbage mass was measured the day before the sheep entered the new pasture (pre-graze), every two days following, and the day they were removed (post-graze). Between February 2nd 2017 and June 1st 2017 herbage mass was also measured in two day intervals in the paddock sheep were grazing. Herbage mass was estimated by cutting three 0.5 m^2 quadrates across the paddock to 10 - 20 mm above ground level using battery powered clippers. For each sample a sub-sample was separated into morphological (leaf, stem, petiole) and botanical (sown legume, weed, grass, white clover) components. The entire sample was dried for 48 hours at 70°C in a force-draft oven to gain an estimate of DM for the pasture. To calculate the stocking rate for the new paddock a 200 g sub-sample was removed from the pre-graze cut and dried for 24 hours in the same oven. Pre-graze samples also had fresh weights recorded for both the bulk sample and separations. A sward stick (Jenquip, Feilding, New Zealand) was used to record height pre and post grazing.

3.7.3 DM intake

DM intake was calculated as the difference between pre grazing and post grazing herbage mass, and also as the difference in herbage mass between the 2 day cuts during grazing from February 2nd and June 1st. The grazing period for DM intake per paddock change during grazing was between 9-11 days, with an average of 10.1 days. This method is subject to variability from sample error (Smit *et al.* 2005), but is an effective low time and cost method.

3.7.4 Nutritive value

Dried samples of lupin, cocksfoot and lucerne were ground through a 1 mm sieve using a Retsch ZM 200 grinder (Retsch, Germany) for nutritive analysis. Each sample was scanned by near infrared reflectance spectroscopy (NIRS; FOSS NIRSystems 5000, FOSS NIRSystems Inc., Laurel, MD, USA) at Lincoln University to give CP, digestible DM (DMD), water soluble carbohydrates (WSC), and neutral detergent fibre (NDF). Organic matter and DMD was used to calculate ME. Calibration DGM for general pasture species was used for cocksfoot components, lucerne components, and pasture mixes. Lupin samples were analysed using a Dry Lupin calibration specifically designed for Russell lupin (Jiang *et al*. 2014). Analysis of samples that did not fit within the calibration equation are included, as they were within the range of other analysed plant material.

3.8 Statistical Analyse

Significance ($\alpha=0.05$) differences between cocksfoot/lupin and lucerne pastures was carried out using either one-way analysis of variance in Minitab 17 Statistical Software or linear regression using GenStat 16 Statistical Software. Significance values cannot be evaluated for accumulated values in the data set.

4 RESULTS

4.1 Animal production

Sheep grazing cocksfoot/lupin pasture gained a total 437 kg/ha of liveweight over the grazing period, 60% as much liveweight as the 1299 kg/ha from sheep grazing lucerne. Stocking rate on cocksfoot/lupin pasture was also lower than that of lucerne, at 13.6 head/ha to 20.8 head/ha (P=0.002) (Table 4.1). Average annual daily liveweight gain on lucerne pastures was not significantly different to cocksfoot lupin pasture (P=0.082), but was near double that of cocksfoot/lupin pasture at 217 g compared with 112 g.

Table 4.1 Average annual stocking rate (SR) and daily liveweight gain (DLWG) of young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

	Lucerne	Cocksfoot/lupin	P value	SED
SR (head/ha)	20.8	13.6	0.002	2.43
DLWG (kg/sheep/day)	0.217	0.112	0.082	0.0489

Accumulated liveweight gain on cocksfoot/lupin pasture occurred slower than lucerne pasture throughout the grazing season (Figure 4.1). Distinct changes in the rate of liveweight gain within pasture type occur, as indicated by arrows on Figure 4.1. The first growth period is occurs at the through the month of August, with higher liveweight gain of 0.296 kg/sheep/day on sheep grazing lucerne pasture compared to cocksfoot/lupin pasture at 0. 124 kg/sheep/day. The second growth period occurred during spring, and was the most rapid for both pasture types, with greater liveweight gain on lucerne pasture, at 0.250 kg/sheep/day, than on cocksfoot/lupin pasture at 0.161 kg/sheep/day. The change between rapid spring growth and slower summer growth occurred quickly in cocksfoot/lupin pasture, while lucerne pasture gradually curves into summer growth, as visible in Figure 4.1 Summer liveweight gain occurred at a similar rate for both pasture types from February 9th 2017 to March 13th 2017, with sheep grazing lucerne gaining 0.160 kg/sheep/day and sheep grazing cocksfoot gaining 0.121 kg/sheep/day There was a change in liveweight gain from summer to autumn in lucerne, but not in cocksfoot/lupin pasture, as stocking rate increased from 5 sheep/ha to an average 8.7 sheep/ha for cocksfoot/lupin pasture, and 14.2 sheep/ha for lucerne pasture in both pastures. Final accumulated liveweight was lower on cocksfoot/lupin pasture at 34% of the accumulated liveweight of lucerne.

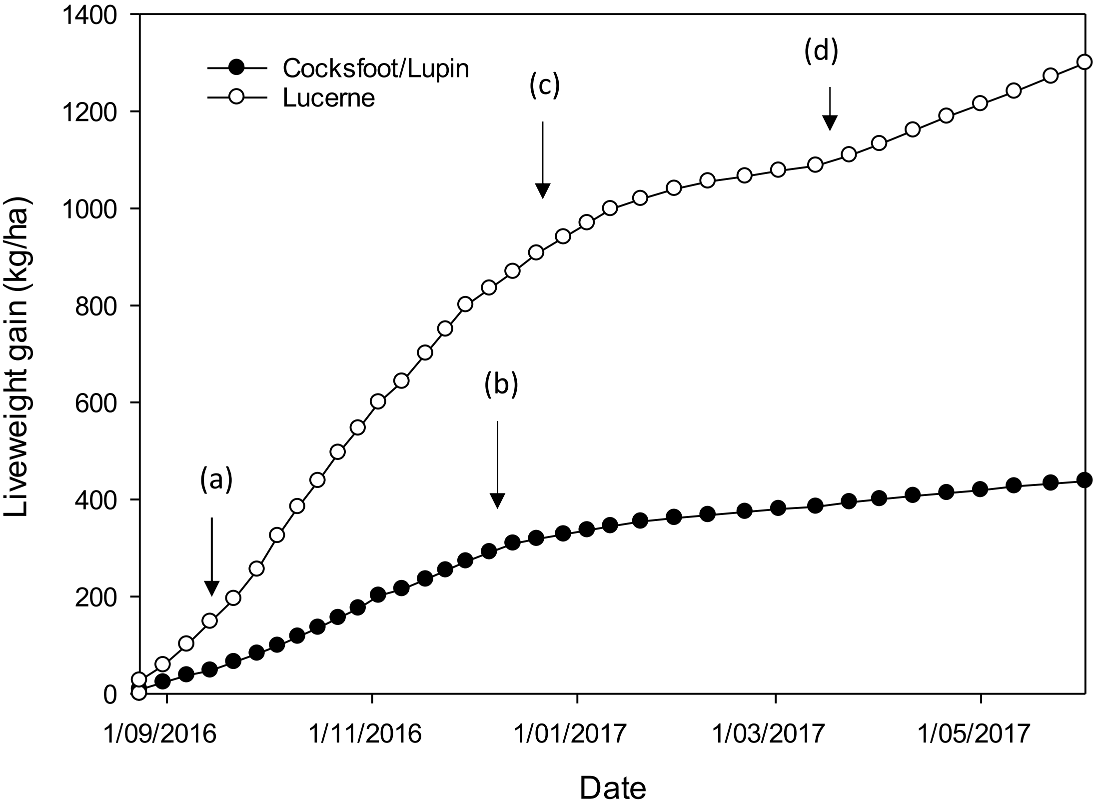


Figure 4.1 Accumulated liveweight gain per head of young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury. Arrows indicate changes in liveweight gain; (a) change from early spring to spring growth; (b) change from spring to summer/autumn growth in cocksfoot/lupin pasture; (c) change from spring to summer growth in lucerne pasture; (d) change from summer to autumn growth in lucerne pasture

The stocking rate of cocksfoot/lupin pasture was generally lower than that of lucerne throughout the entire growing season (Figure 4.2). Stocking rate of both pasture types was high through spring, declining through December-March, and increasing again in April. Lucerne stocking rate was much higher than cocksfoot/lupin through spring, with a notable difference until December. During the summer period both pasture types had a similar stocking rate. During autumn the lucerne stocking rate became much higher than cocksfoot/lupin again, but not to the same extent as spring.

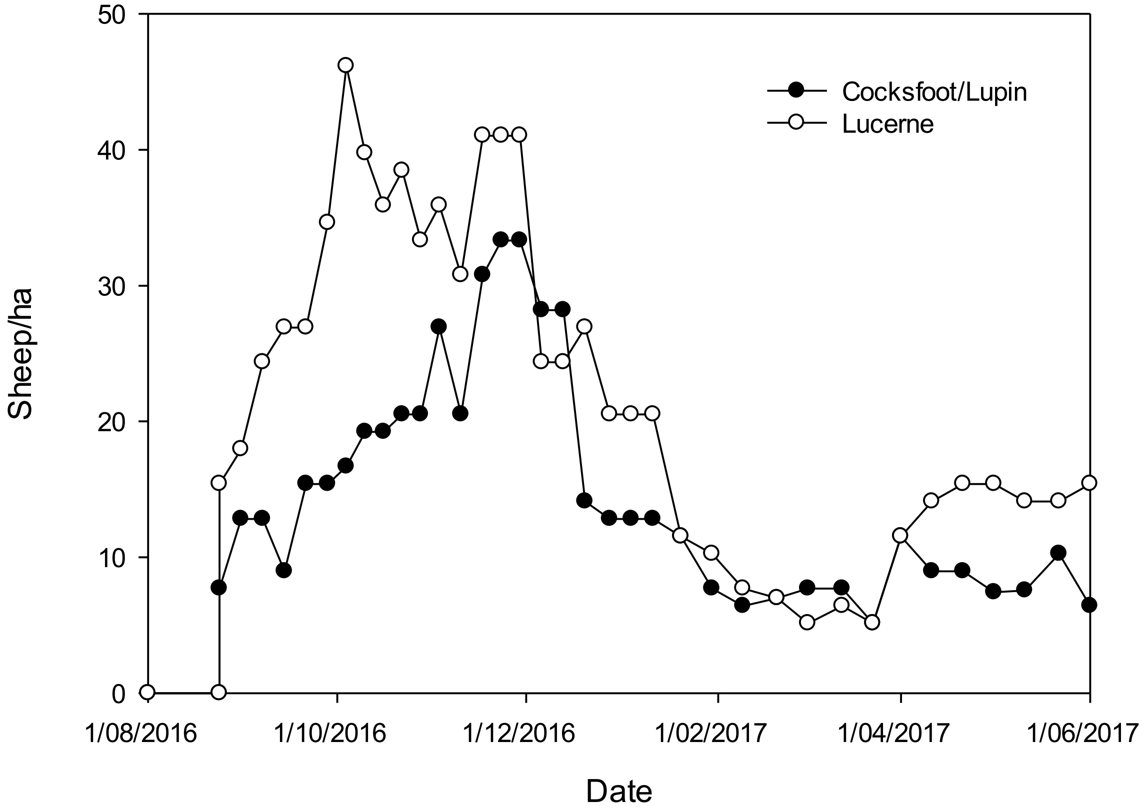


Figure 4.2 Mean stocking rate (sheep/ha) of young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

Cocksfoot/lupin pasture had lower live weights throughout the growing season than lucerne pasture (Figure 4.3). Liveweight growth rate was split into three distinct seasonal periods. Linear regression were applied to theses growth phases enabling a daily liveweight gain prediction (Table 4.2). These equations suggested daily growth rates of young sheep on cocksfoot/lupin pasture are 0.161 kg/sheep over spring, 0.093 kg/sheep over summer and 0.078 kg/sheep over autumn, compared with lucerne at 0.250 kg/sheep, 0.202 kg/sheep, and 0.183 kg/sheep respectively.

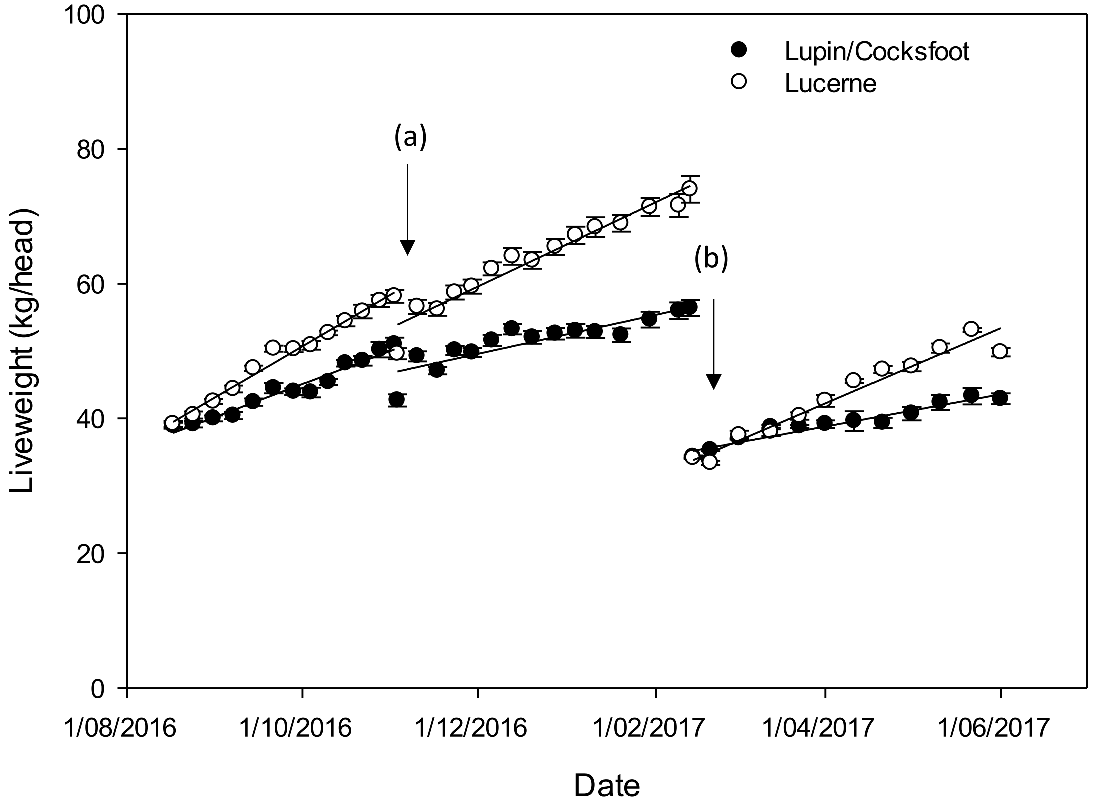


Figure 4.3 Mean liveweight per head of young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury. Arrows indicate changes in liveweight gain; (a) change from spring to summer growth; (b) change from summer to autumn growth.

Table 4.2 Daily per head growth rate (kg/sheep/day) over three distinct seasonal periods for young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

	Lucerne	Cocksfoot/lupin	P value	SED
Spring	0.2498	0.1613	<0.001	0.0141
Summer	0.2018	0.0934	<0.001	0.0192
Autumn	0.1833	0.0784	<0.001	0.0145

Sheep grazing lucerne consumed more DM for greater liveweight gain (P<0.001) than sheep grazing cocksfoot/lupin pasture (Figure 4.4). Initially cocksfoot/lupin and lucerne pasture gaining similar liveweight for the feed consumed until they reached a liveweight of 150 kg, although sheep grazing cocksfoot/lupin pasture gained liveweight slower (P<0.001) than sheep grazing lucerne due to a lower stocking rate. Once over this threshold lucerne consumption and liveweight gain continued a strong upwards trend while cocksfoot/lupin liveweight gain in response to feed consumption slows. A small spike in liveweight gain in cocksfoot/lupin pasture occurred toward the end of the growing season.

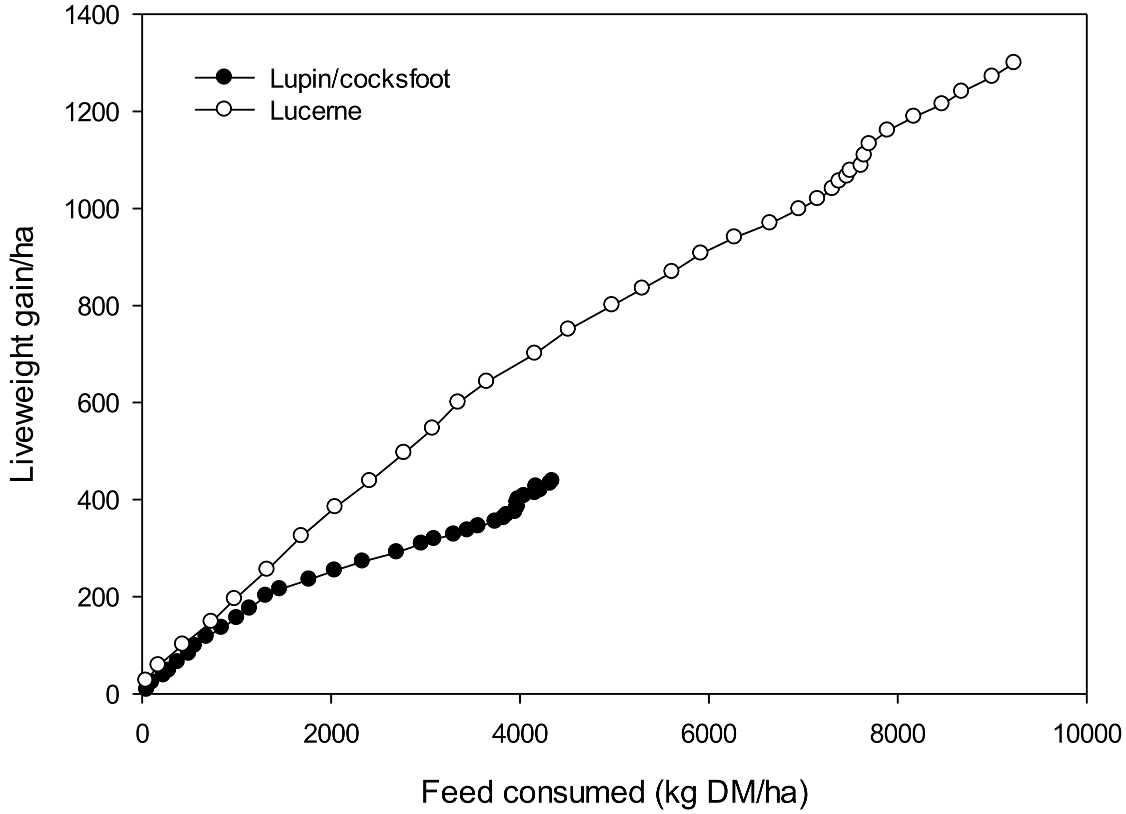


Figure 4.4 Mean actual liveweight gain (kg/ha) per amount of feed consumed (kg DM/ha) for young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

ME in feed consumed for liveweight gain is similar for sheep grazing cocksfoot/lupin and lucerne pasture is similar up until 200 kg/ha of accumulated liveweight (Figure 4.5). At this point lucerne sheep continued to consume the same ME content for the same liveweight gain. Sheep consuming cocksfoot/lupin pasture consumed less ME after this point for less liveweight gain. Sheep grazing lucerne pasture consumed more ME and gained more liveweight over the duration of this grazing trial than sheep grazing cocksfoot/lupin pasture, despite a similar ME of both pasture mixes (P=0.224)

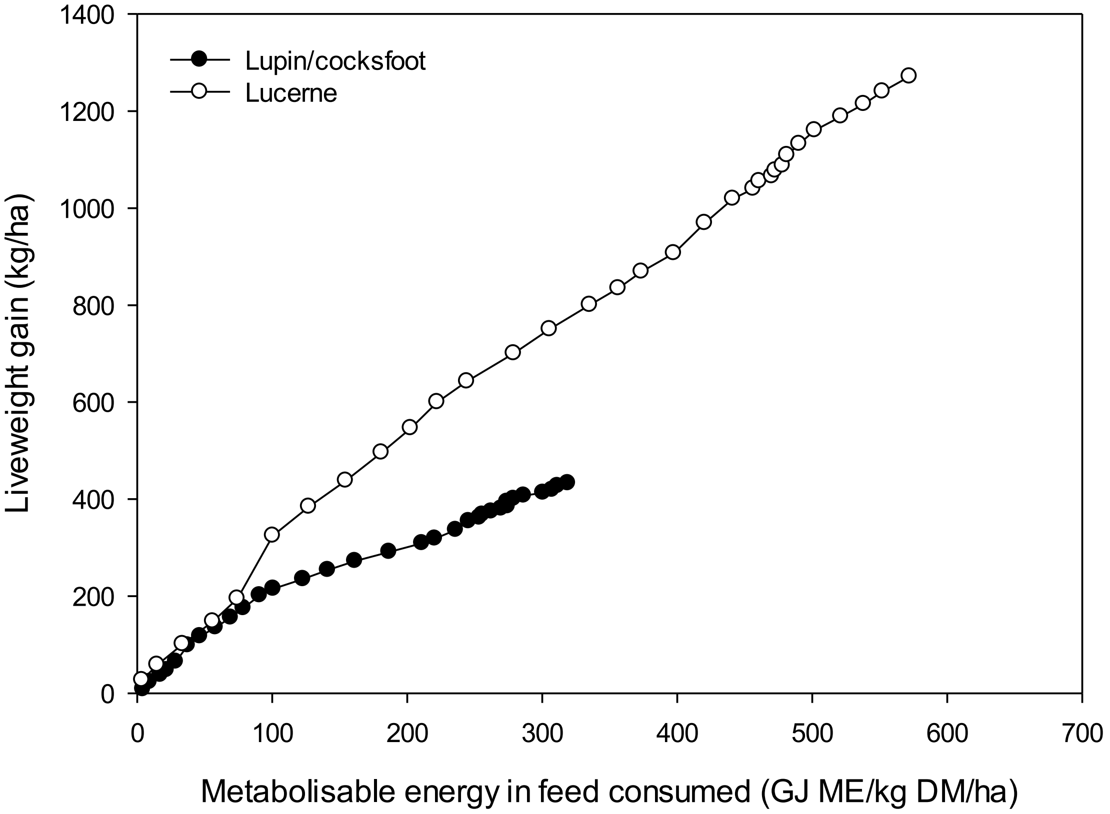


Figure 4.5 Average liveweight gain (kg/ha) per ME content (g/Kg DM) of feed consumed (kg DM/ha) by young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

Like ME, CP in feed consumed is lower in cocksfoot/lupin pastures than lucerne pastures (Figure 4.6). Sheep grazing both pasture types experience a similar pattern of liveweight gain per hectare in response to CP consumed, but the CP consumed and liveweight gain on lucerne was considerably greater. This indicates seasonal differences in CP impact liveweight gain accumulation.

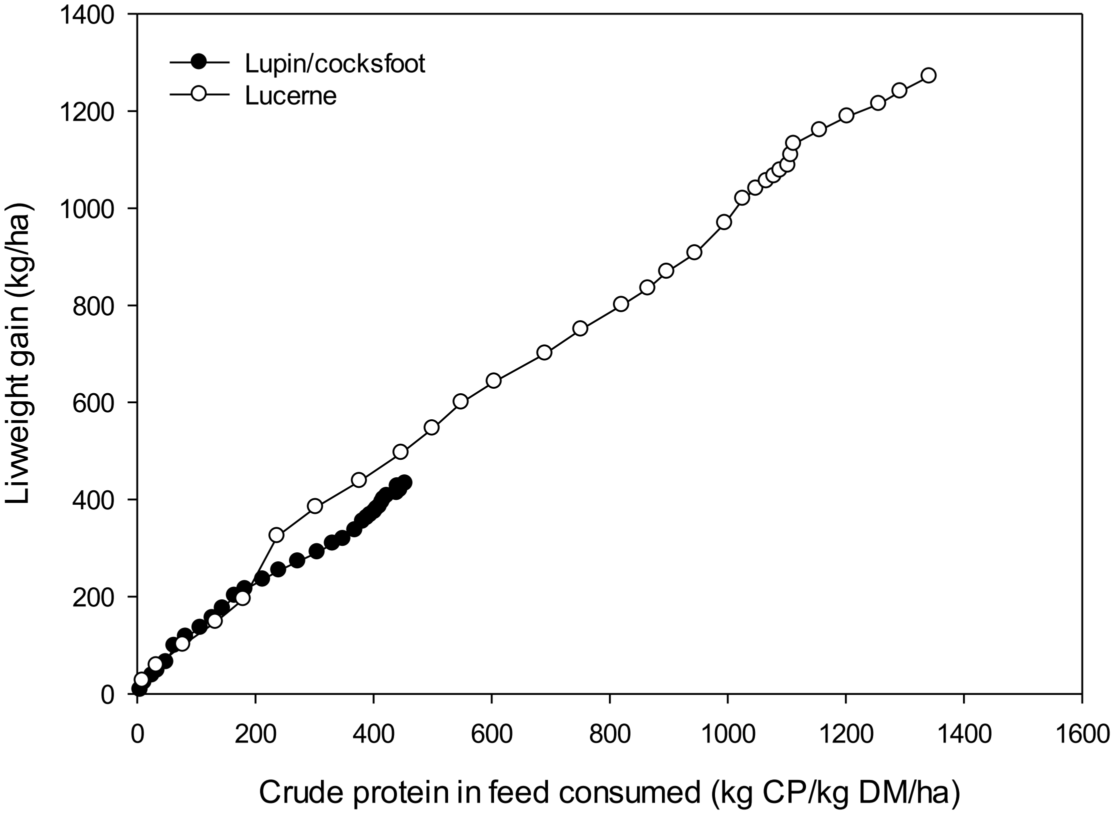


Figure 4.6 Average liveweight gain (kg/ha) per CP content (g/Kg DM) of feed consumed (kg DM/ha) by young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

Feed conversation efficiency (FCE) of DM for lucerne was greater than that of cocksfoot/lupin pasture, at 0.137 kg LWG/kg DM compared with 0.098 kg LWG/kg DM ($P<0.001$), however cocksfoot DM FCE appeared to change after 200 kg LWG/ha. FEC of ME was significantly greater for sheep grazing lucerne, at 2.24 kg/ha/GJ ME, than for sheep grazing cocksfoot/lupin pasture, at 1.13 kg LWG/GJ ME ($P<0.001$), but again cocksfoot ME FCE appeared to change after 200 kg LWG/ha. The FCE of CP is very similar between the two pasture types ($P=0.998$), with both at 1.129 (kg LWG//kg CP).

Table 4.3 FCE of DM, ME and CP for liveweight gain (kg/ha) in young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

	Lucerne	Cocksfoot/lupin	P value	SED
DM (kg LWG/kg DM)	0.137	0.098	<0.001	0.00596
ME (kg LWG/GJ ME)	2.24	1.31	<0.001	0.193
CP (kg LWG/kg CP)	1.129	1.129	0.998	0.0823

4.2 Herbage intake

Average annual herbage allowance was maintained at a similar level (P=0.421) in both cocksfoot/lupin pasture and lucerne pasture, at 2.358 kg and 2.460 kg DM/sheep/day respectively, for the duration of the grazing trial (Table 4.4). Daily herbage intake per head on cocksfoot/lupin pasture was lower than lucerne pasture (P<0.001), at 65% of that of lucerne pasture at 1.496 kg DM/sheep/day.

Table 4.4 Annual average daily herbage allowance (HA) and daily apparent herbage intake (HI) of young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

	Lucerne	Cocksfoot/lupin	P Value	SED
HA (kg DM/sheep/day)	2.460	2.358	0.421	0.126
HI (kg DM/sheep/day)	1.496	0.986	< 0.001	0.124

Herbage allowance of sheep grazing cocksfoot/lupin pasture and lucerne pasture was maintained to a similar level between pasture types throughout the growth season (P=0.421). Throughout the year some variation in herbage allowance occurred, with Figure 4.7 displaying an increasing trend. Variation in herbage allowance throughout the year, with pasture composition changes under dry conditions leading to high herbage allowance for both pasture types in autumn compared with other pastures.

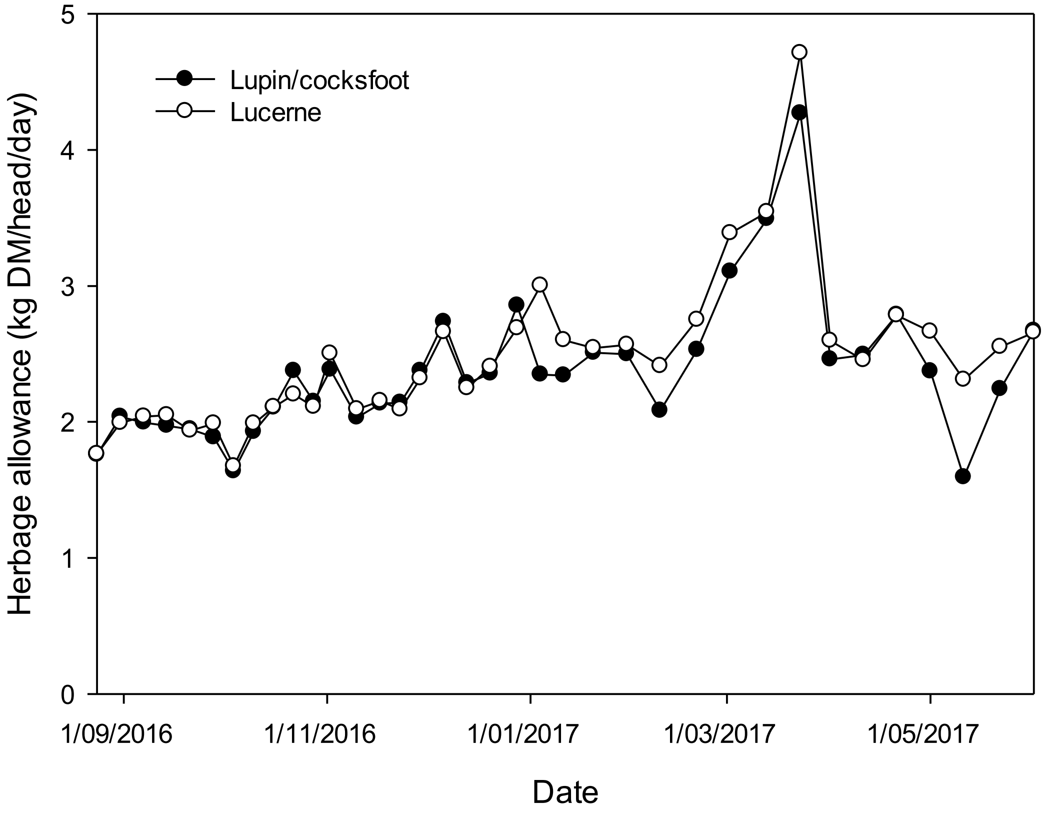


Figure 4.7 Daily herbage allowance (kg DM/sheep) for young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

Cocksfoot/lupin daily herbage intake was lower than lucerne herbage intake throughout the grazing season (Figure 4.8).

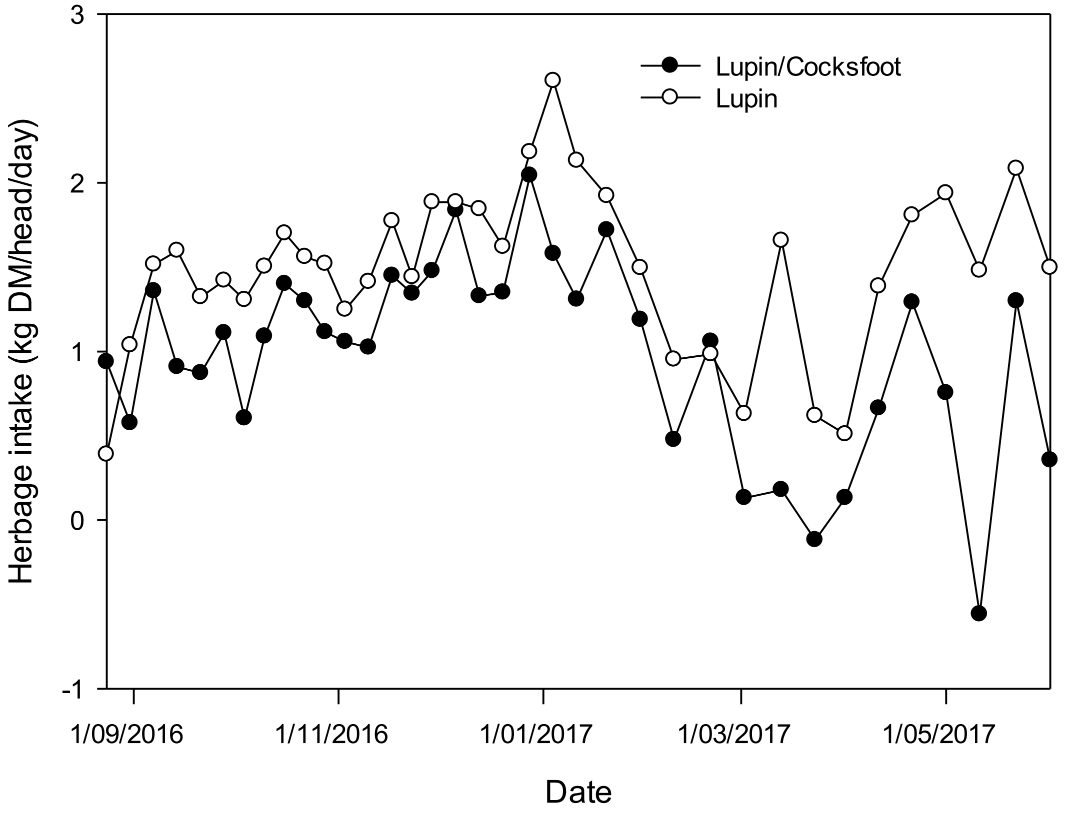


Figure 4.8 Apparent daily herbage intake (kg DM/sheep) for young sheep grazing a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

The decline of herbage mass throughout the grazing period gave an indication of apparent herbage intake. Herbage mass of both pasture types declined throughout the 10 day grazing period (Figure 4.9). Initial herbage mass of cocksfoot/lupin pasture was lower than that of lucerne pasture, but from Day six of grazing herbage mass within pastures was similar. The decline of lucerne pasture was rapid over the first 6 day period, and it flattened off over the remaining 4 days in the grazing period. The decline of cocksfoot/lupin pasture was less rapid to day six, and over the remaining 4 days in the grazing period pasture mass increased.

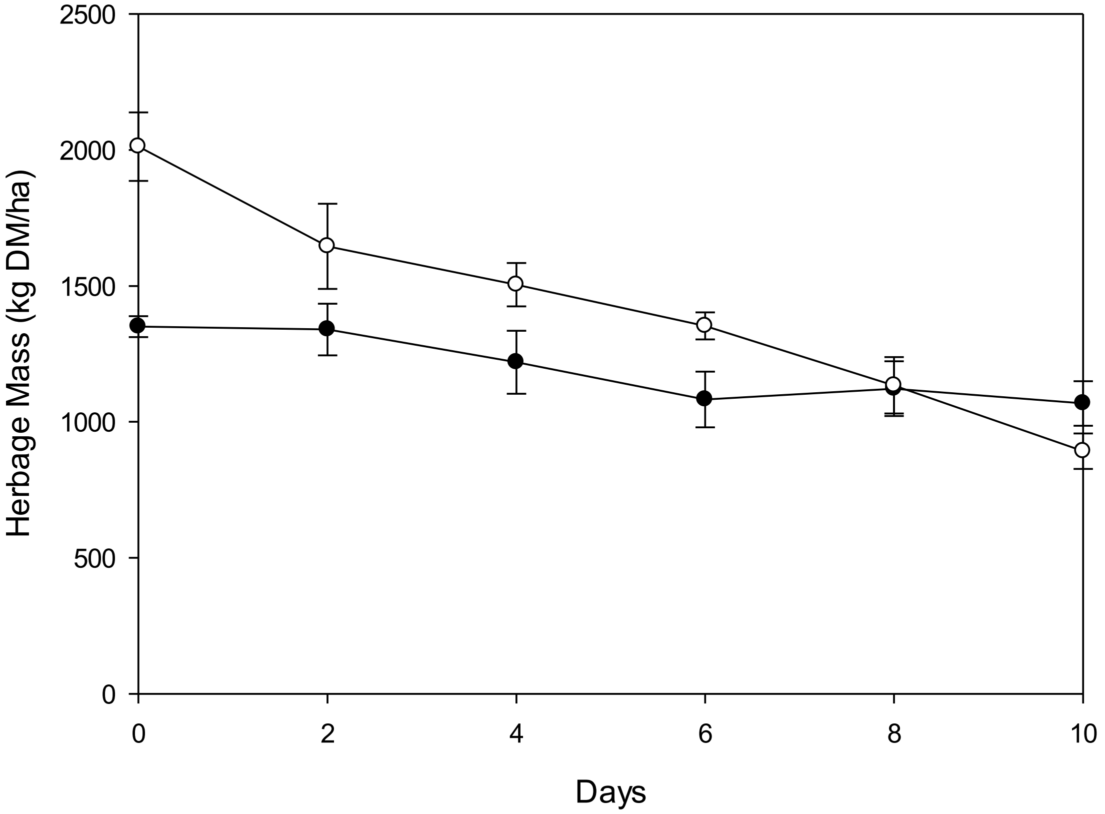


Figure 4.9 Mean herbage mass (kg DM/ha) change over the grazing period of a paddock grazed by young sheep grazing either a perennial cocksfoot/lupin pasture or a lucerne pasture under dryland conditions from February 2nd 2017 to June 1st 2017 over the 2016/2017 growing season at Lincoln University, Canterbury.

Herbage mass declined in cocksfoot/lupin and lucerne pasture throughout the duration of the grazing period (Figure 4.10 and Figure 4.11). Rate of decline varied between paddocks, and was more apparent in the second measured rotation (Figure 4.11). The second grazing rotation showed lucerne generally had a higher pre-graze pasture mass than cocksfoot/lupin pastures, with the gap in herbage mass between then narrowing around Day 8.

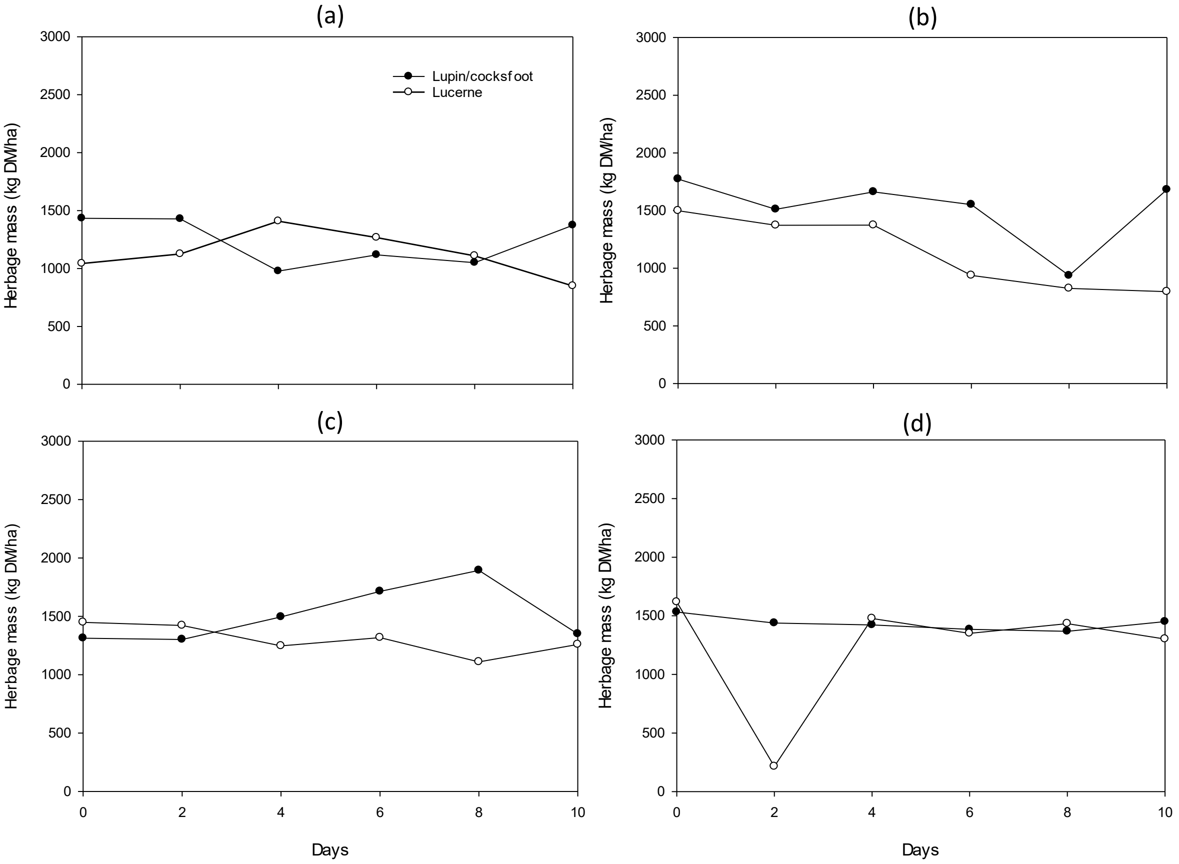


Figure 4.10 Apparent herbage intake as herbage mass (kg DM/ha) over the 10 day grazing period of (a) paddock 3, (b) paddock 4, (c) paddock 5 and (d) paddock 6 during the first grazing evaluation rotation of a cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

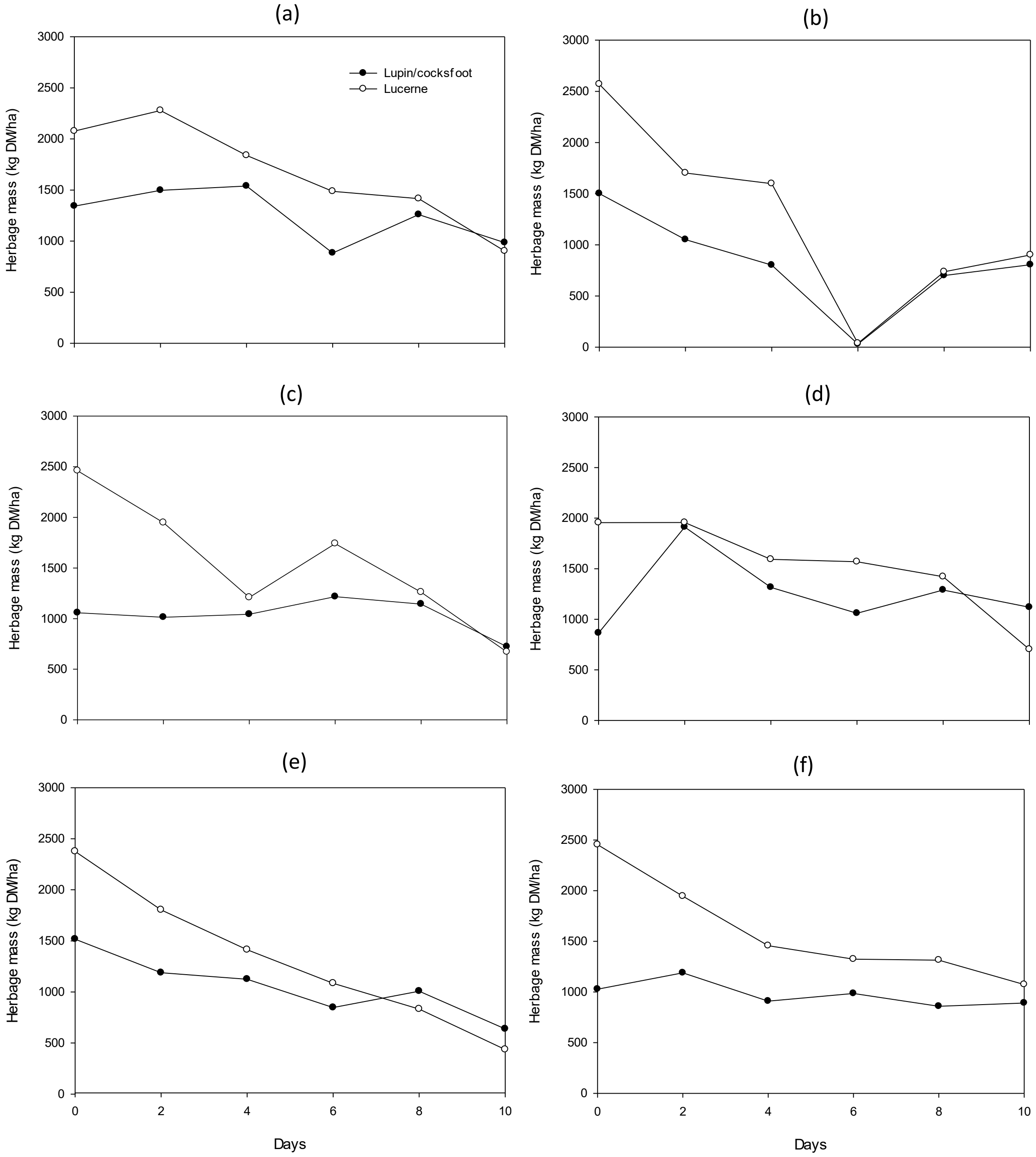


Figure 4.11 Apparent herbage intake as herbage mass (kg DM/ha) over the 10 day grazing period of (a) paddock 1, (b) paddock 2, (c) paddock 3, (d) paddock 4, (e) paddock 5 and (f) paddock 6 during the second grazing evaluation rotation of a cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

Individual paddock component consumption was similar across both grazing rotations (Figure 4.12 and Figure 4.13). Leaf was the most rapidly consumed component of both pasture types, dropping in the first 6-8 days, then diapering at a slower rate. Stem and petiole either declined slowly, or remained at a similar level throughout the trial. Dead material increased slightly in some paddocks Figure 4.12

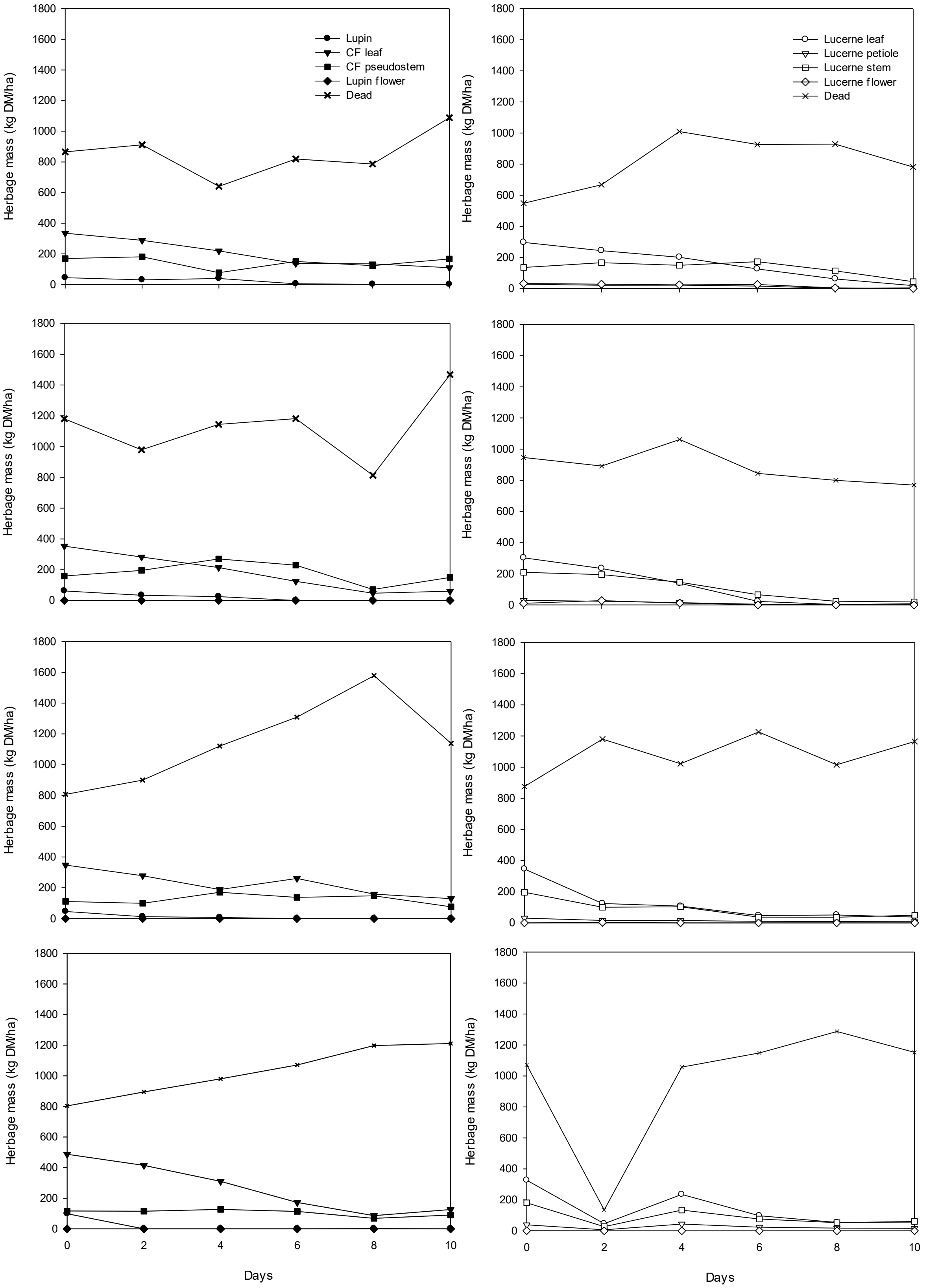


Figure 4.12e, f; Figure 4.13 b, g, k), but predominately shows little variation throughout

grazing days in the paddock. Variation between paddocks was likely due to the sampling method.

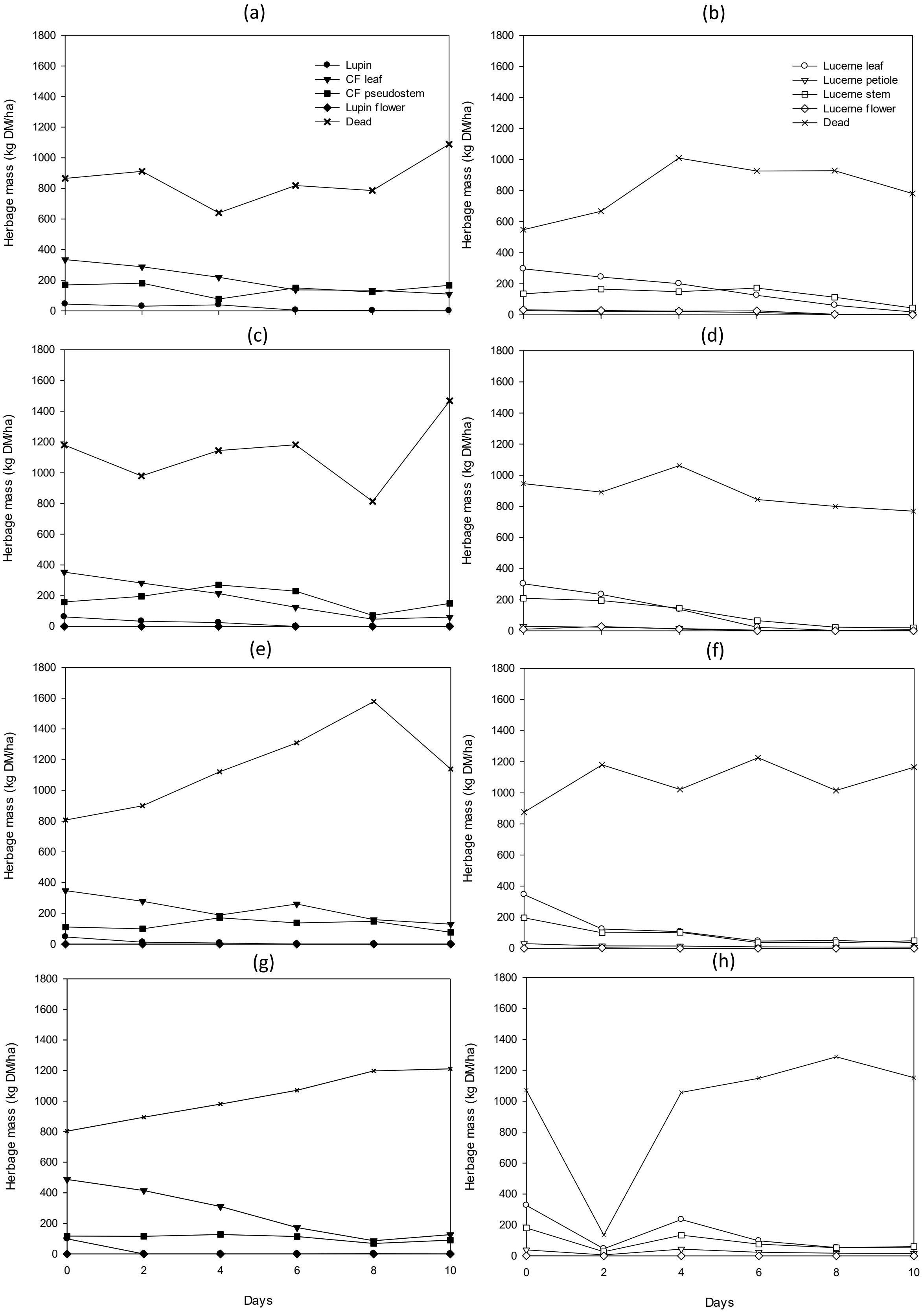
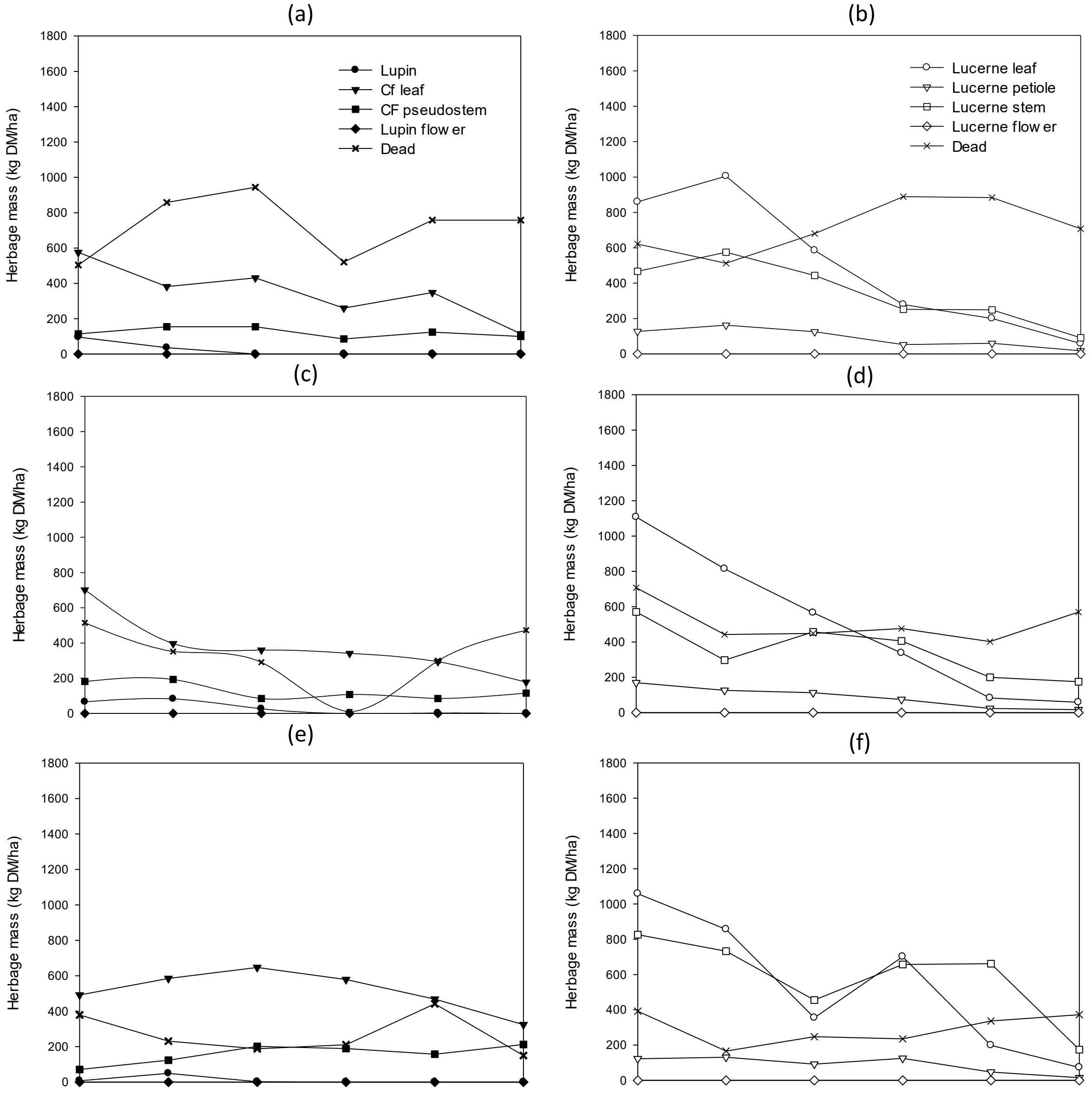


Figure 4.12 Disappearance of pasture components (kg DM/ha) over the 10 day grazing period of (a) paddock 3 cocksfoot/lupin pasture, (b) paddock 3 lucerne pasture, (c) paddock 4 cocksfoot/lupin pasture, (d) paddock 4 lucerne pasture, (e) paddock 5 cocksfoot/lupin pasture, (f) paddock 5 lucerne pasture, (g) paddock 6 cocksfoot/lupin pasture and (h)

paddock 6 lucerne pasture during the first grazing evaluation rotation of a cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

(a)
(b)
(c)
(d)
(e)
(f)
Herbage mass (kg DM/ha)
0
200
400
600
800
1000
1200
1400
1600
1800
Lupin
Cf leaf
CF pseudostem
Lupin flow er
Dead
Lucerne leaf
Lucerne petiole
Lucerne stem
Lucerne flow er
Dead

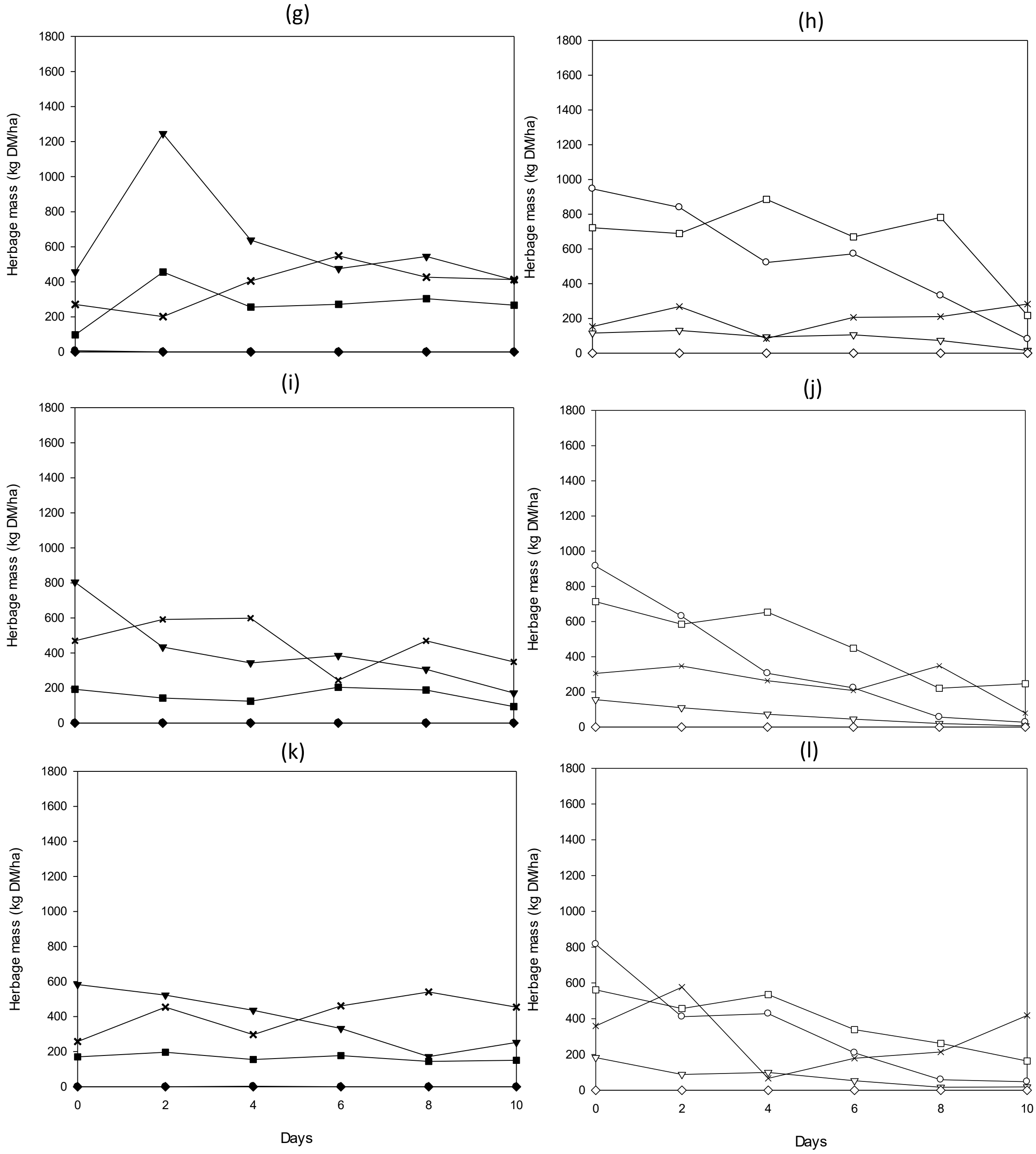


Figure 4.13 Disappearance of pasture components (kg DM/ha) over the 10 day grazing period of (a) paddock 1 cocksfoot/lupin pasture, (b) paddock 1 lucerne pasture, (c) paddock 2 cocksfoot/lupin pasture, (d) paddock 2 lucerne pasture, (e) paddock 3 cocksfoot/lupin pasture, (f) paddock 3 lucerne pasture, (g) paddock 4 cocksfoot/lupin pasture, (h) paddock 4 lucerne pasture, (i) paddock 5 cocksfoot/lupin pasture, (j) paddock 5 lucerne pasture, (k) paddock 6 cocksfoot/lupin pasture and (l) paddock 6 lucerne pasture during the second grazing evaluation rotation of a cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

4.3 Herbage mass

Average pre-grazing herbage mass of cocksfoot/lupin pasture was 1514 kg DM/ha, 66% of that of lucerne pasture at 2279 kg DM/ha (P<0.001) (Table 4.5.) Average post-grazing herbage mass of cocksfoot/lupin pasture and lucerne pasture was similar (P=0.457), with lucerne lower on average by 60.5 kg DM/ha. Mean pre-grazing herbage height of cocksfoot/lupin was 70% of that of lucerne, and there was no significant difference between mean post-grazing height of cocksfoot/lupin pasture and lucerne pasture (P=0.958).

Table 4.5 Average pre-grazing and post-grazing herbage mass (HM) and herbage height (HT) of a perennial cocksfoot/lupin pasture compared to a lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury

		Cocksfoot/lupin	Lucerne	P Value	SED
Pre-grazing	HM (kg DM/ha)	1514	2279	<0.001	151
	HT (cm)	19.11	27.30	0.017	3.35
Post grazing	HM (kg DM/ha)	790.1	739.6	0.457	67.5
	HT (cm)	11.38	11.23	0.958	2.76

Throughout the growing season pre-graze herbage mass was generally higher in lucerne than in cocksfoot/lupin pasture (P<0.001) (Figure 4.14). During spring pre-graze herbage mass increased rapidly for both pasture types, with lucerne considerably higher than cocksfoot/lupin. Pre-graze herbage mass declined into summer for both pasture types, leading to similar growth during February – March. Pre-graze herbage mass increased for both pasture types into autumn, but not to the extent of spring, with lucerne producing more than cocksfoot/lupin pasture. Post-graze herbage mass was similar between the two pasture types. It had a more gradual increase though spring and drop into summer compared with pre-graze herbage mass. Post-graze herbage mass increased into autumn for both pasture types, before gradually declining as the growing season ended. While both lucerne and cocksfoot/lupin pastures had similar post-graze herbage mass at times after spring cocksfoot/lupin pasture mass was higher.

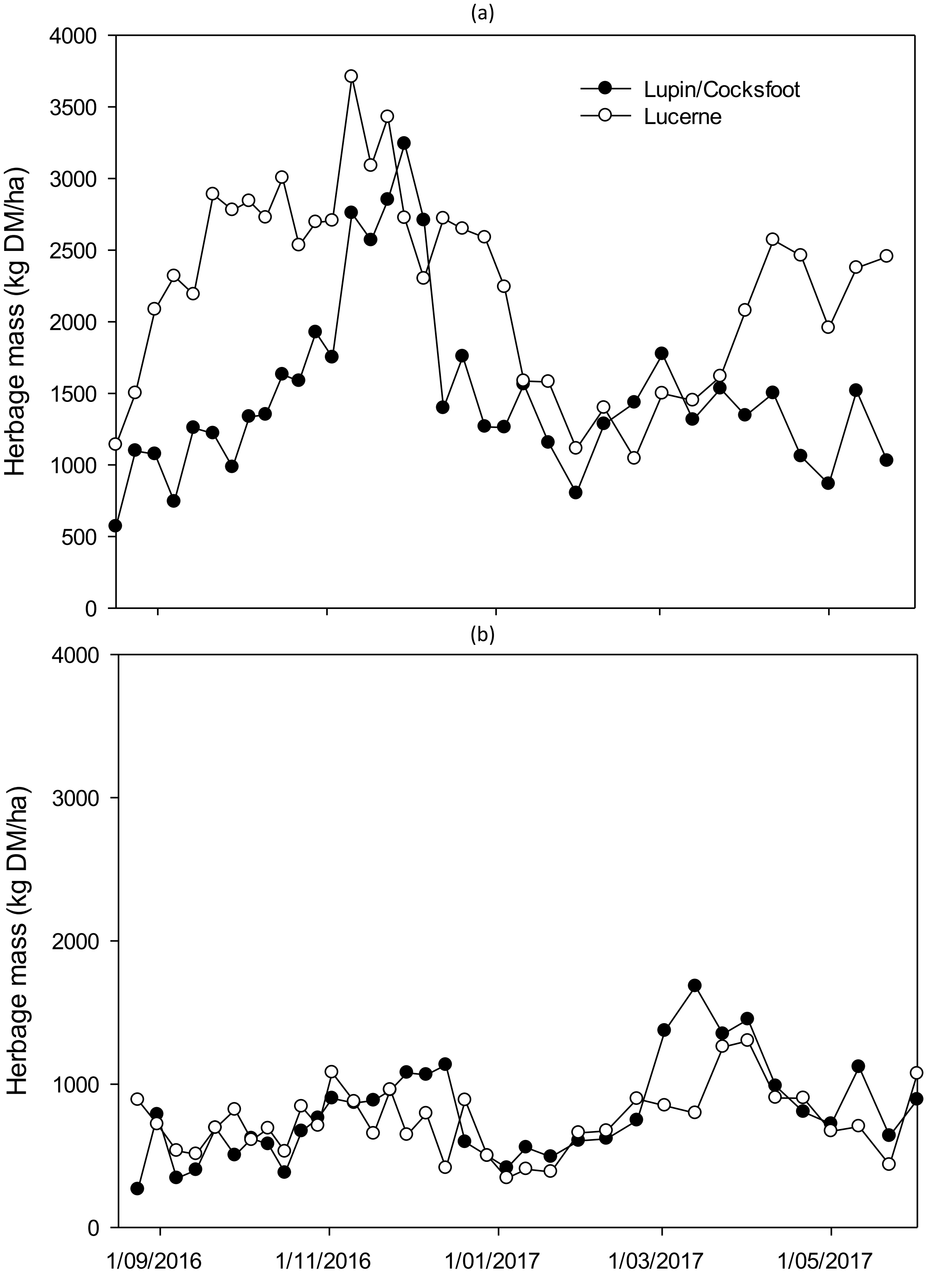


Figure 4.14(a) Pre-grazing and (b) post-grazing herbage mass (kg DM/ha) of a cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

Pre-grazing pasture height of both species increased through spring and declined into summer (Figure 4.15). It peaked once again at the beginning of May, before declining through the rest of the growth season. Pre-graze lucerne pasture was generally higher than cocksfoot/lupin pasture, particularly through spring, although cocksfoot/lupin pasture height spiked in December, passing the height of lucerne. Post grazing pasture height followed the same pattern as pre-grazing pasture height, but the December spike is cocksfoot/lupin pasture height was more noticeable in the absence of high lucerne.

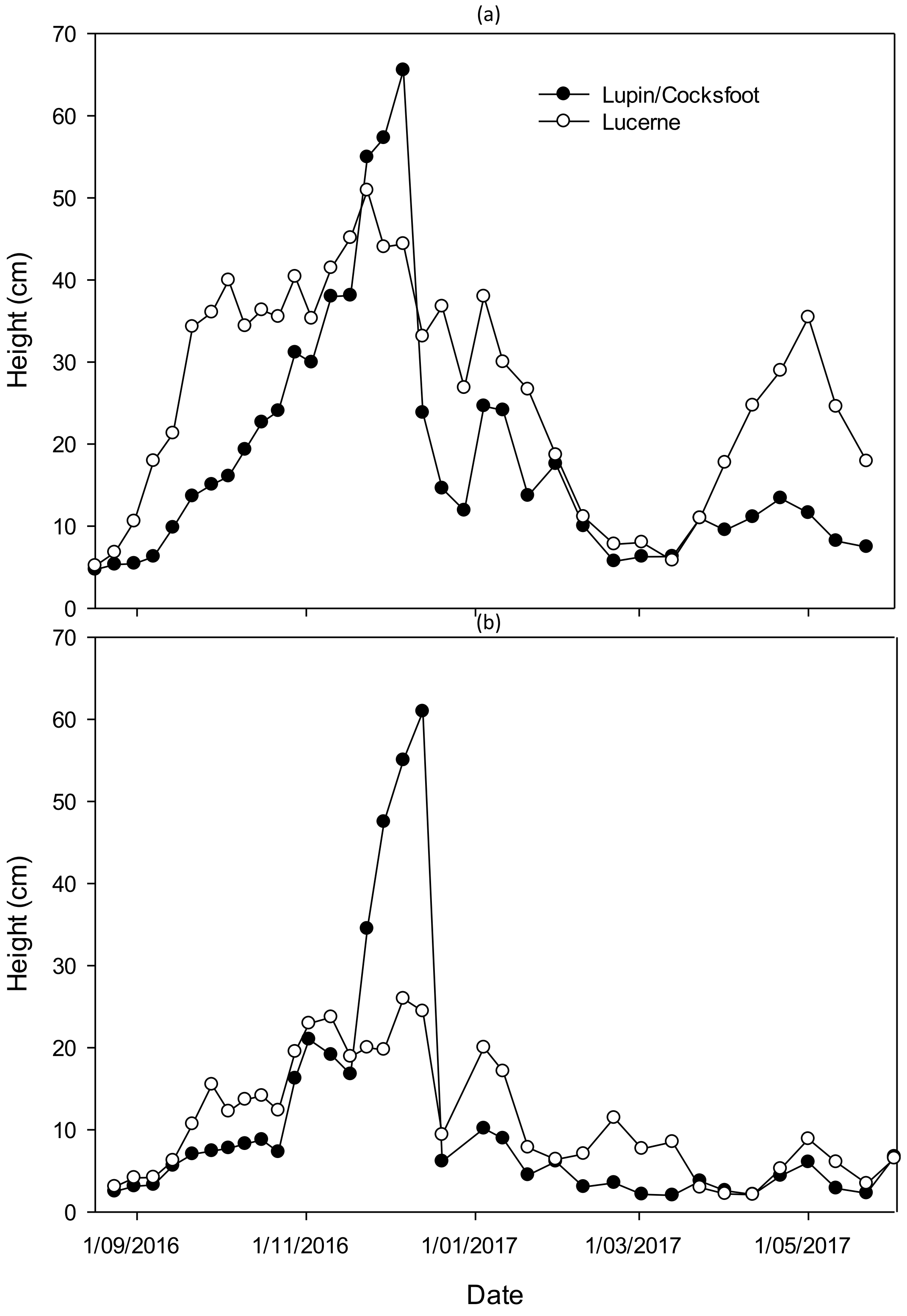


Figure 4.15(a) Pre-grazing and (b) post-grazing herbage height (cm) of a cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

The DM composition of cocksfoot/lupin pasture and lucerne pasture was not significantly different (P=0.149), at 25.47% of lucerne and 29.14% of cocksfoot/lupin pasture (Table 4.6). Cocksfoot/lupin pasture containd less live material than lucerne pasture (P=0.013), with cocksfoot/lupin pasture containing 86% of the live material of lucerne pasture. The legume content of the two pasture types was different (P<0.001), with cocksfoot/lupin pasture containing 14% of the legume present in lucerne pasture.

Table 4.6 DM (%), live material (%) and legume (%) composition of a perennial cocksfoot/lupin pasture compared to a lucerne pasture grazed by young sheep under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

	Lucerne	Cocksfoot/lupin	P Value	SED
Dry matter (%)	25.47	29.14	0.149	2.52
Live material (%)	81.93	70.86	0.013	4.38
Legume content (%)	96.56	13.94	<0.001	1.65

Dry matter percentage of cocksfoot/lupin and lucerne pasture followed a similar temporal pattern (Figure 4.16). Both pasture types had a peak DM percentage in February, and high water composition through spring (September – November) and autumn (April – May). The DM content of cocksfoot/lupin pasture is not significantly different (P<0.149) than that of lucerne pasture, but visually appears lower on Figure 4.16.

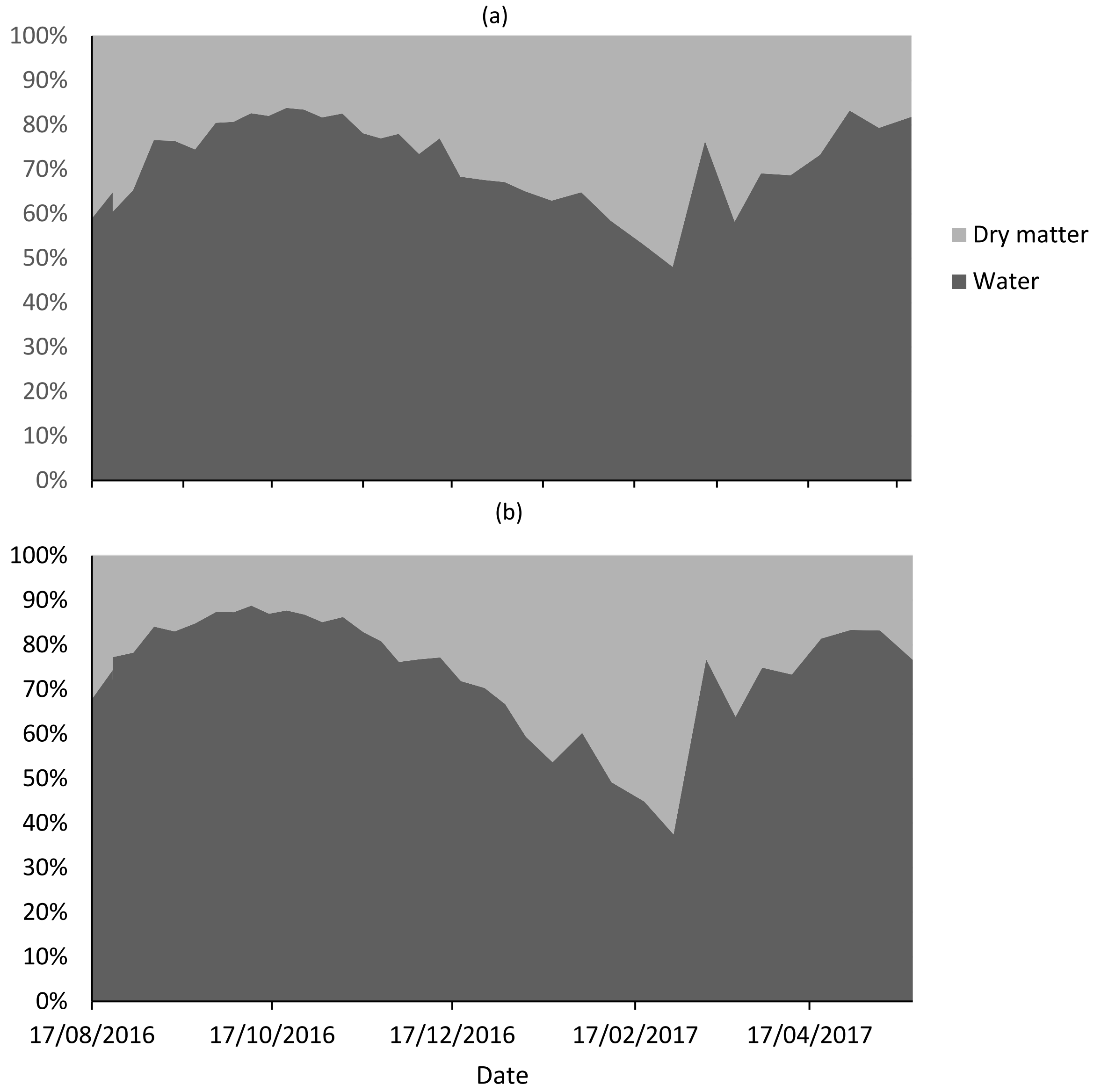


Figure 4.16 Pre-grazing DM and water content of (a) cocksfoot/lupin and (b) lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

Cocksfoot/lupin and lucerne pastures followed a similar temporal pattern through most of the season with high live material in spring and autumn, and high dead material in February (Figure 4.17). Cocksfoot/lupin pasture had a higher proportion of dead material through August but it quickly decreased to similar levels to lucerne pasture. Lucerne pasture annually contained more live material (P=0.013).

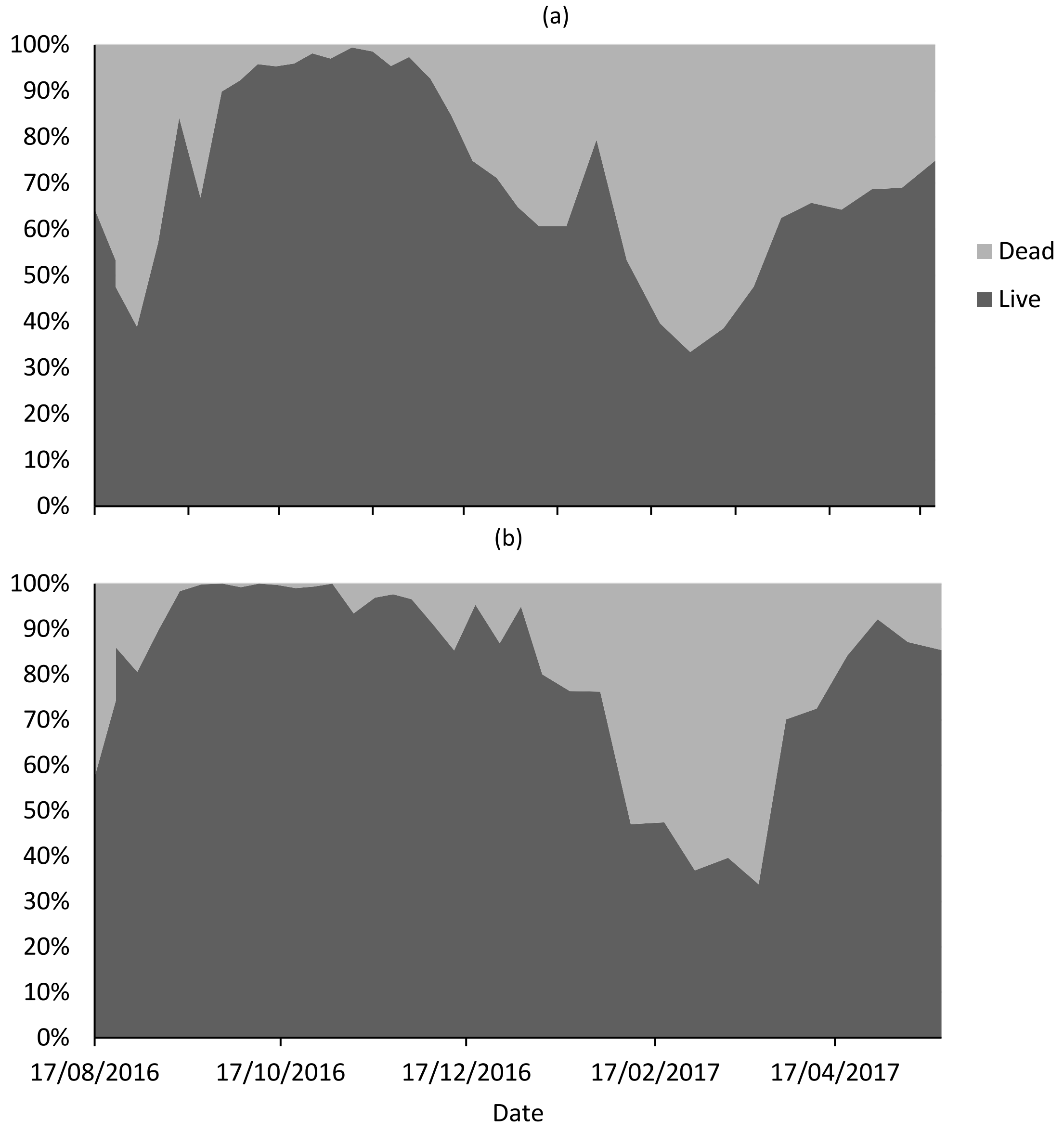


Figure 4.17 Pre-grazing dead material and live material composition of (a) cocksfoot/lupin and (b) lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

The predominate species of the cocksfoot/lupin pasture throughout the growing season was cocksfoot, with variation in its contribution to the sward affected by the legume population in the pasture (Figure 4.18). Lupin population in the cocksfoot/lupin pasture was between 5-35% during Its main contribution time of September – beginning April. Outside of these months lupin contribution to cocksfoot/lupin pasture was negligible, particularly from April onward. Other legumes white clover and subterranean clover contributed 0 -14% to the cocksfoot/lupin sward, with their highest contribution in the absence of lupin in April. Weeds were a minor component of cocksfoot/lupin pasture, appearing primarily in small numbers at the end of the growing season. Lucerne pasture is primarily lucerne, with up to 8% weed content occurring September – end December, and up to 25% in May. Volunteer white clover is present in low numbers. The key difference in species composition between the two pasture types was their legume content ($P<0.001$), with lucerne pasture reaching up to 100% legume while cocksfoot/lupin pasture maximum legume content at any one point was 36%.

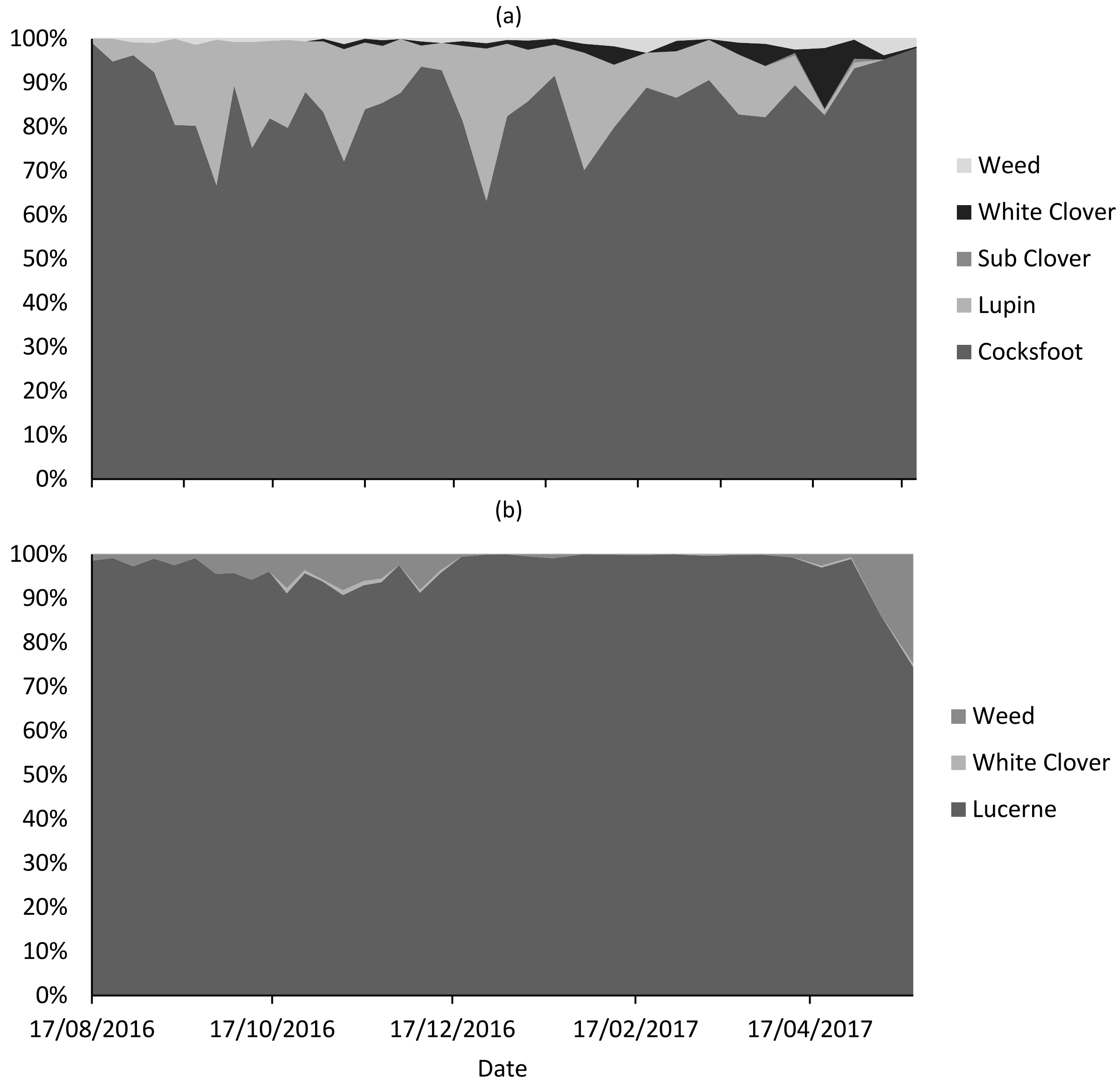


Figure 4.18 Pre-grazing species composition of (a) cocksfoot/lupin and (b) lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

Species component composition for cocksfoot/lupin pasture and lucerne pasture are different (Figure 4.19). Lupin was predominately leaf, with an average even proportion of 20% (SE ± 0.46) petiole throughout the whole season. Stem contributes above 5% through November – December, and was present in a small proportion from the beginning of the trial through to March. Cocksfoot was primarily composed of leaf and pseudostem material, with pseudostem accounting for up to 34% of cocksfoot composition when the two components were separated from February onward. Cocksfoot stem was only a primary component through November, with a small proportion recorded in February. An average of 61% (SE ± 1.55) of lucerne was leaf and petiole throughout the growing season, with higher leaf and petiole at the beginning of the growing season (August). Where leaf and petiole have been separate petiole contributed on average 6.7% (SE ± 0.50) to the lucerne population. Like leaf and petiole stem production was relatively consistent throughout the year, dropping in January –February. Flower production occurs January – February, with flowers contributing a maximum of 14% to lucerne composition.

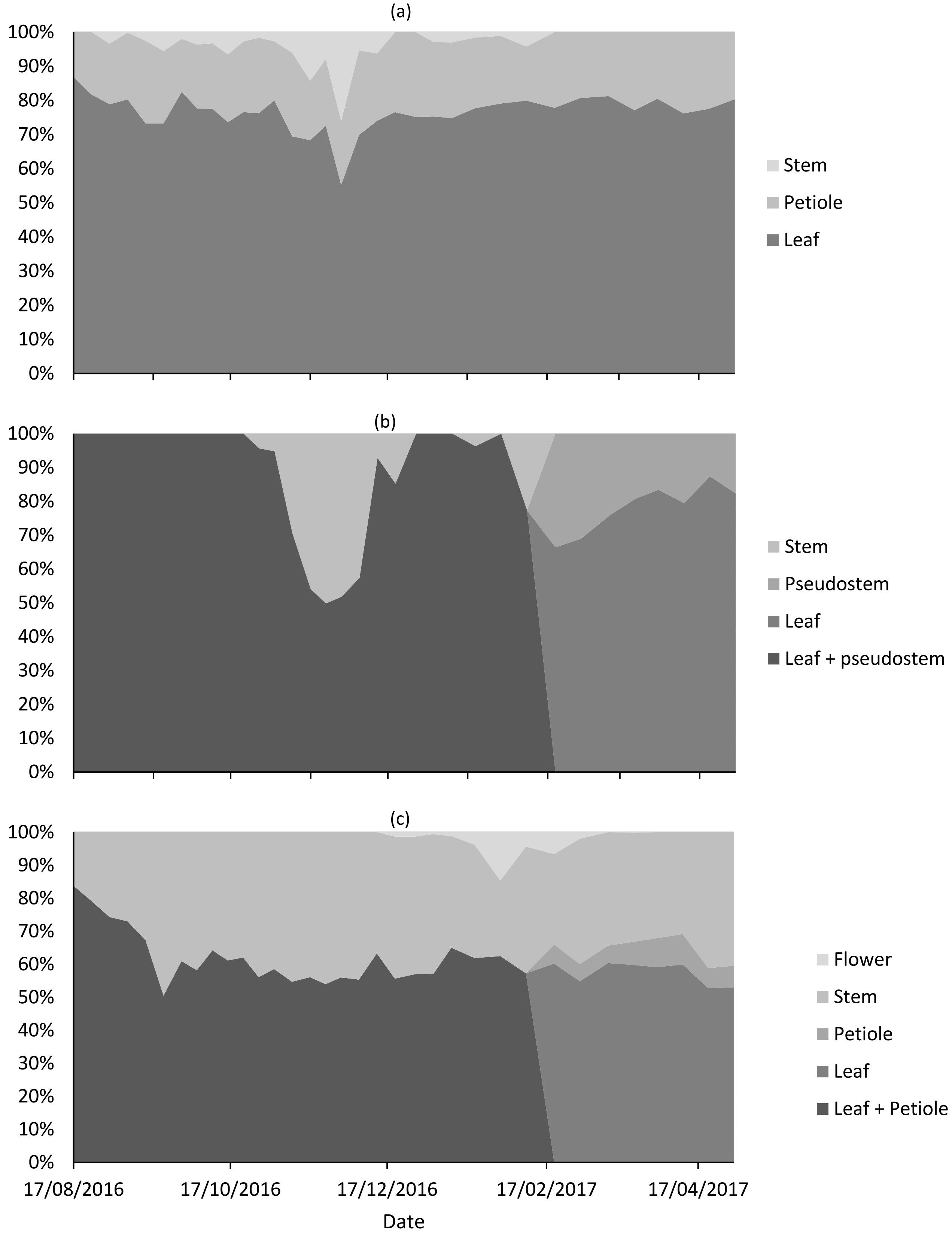


Figure 4.19 Pre-grazing species component composition of (a) lupin, (b) cocksfoot and (c) lucerne from cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury. Note morphological

composition of cocksfoot and lucerne recorded leaf and pseudostem/petiole together from the beginning of the trial to (date), where from then leaf and pseudostem/petiole were recorded separately.

4.4 Nutritive value

There was no significant difference between cocksfoot/lupin pasture mix and lucerne pasture mix pre-grazing ME (P=0.224), pre-grazing DMD (P=0.264), and post-grazing ME (P=0.407) (Table 4.7). There were significant differences in the CP and NDF fractions of pre-grazing cocksfoot/lupin pasture and lucerne pasture. Cocksfoot/lupin pasture contained a lower percentage of CP, at 14.8% compared with 23% (P<0.001). NDF content was higher in cocksfoot/lupin pasture, at 52.5% compared with 34.5% in lucerne pasture (P<0.001).

Table 4.7 Pre-grazing ME, CP, dry matter digestibility (DMD), neutral detergent fibre (NDF) and post-grazing ME content of a cocksfoot/lupin pasture mix and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury

		Lucerne	Cocksfoot/lupin	P Value	SED
Pre-grazing	ME (MJ/kg DM)	10.3	10.6	0.224	0.256
	CP%	23.0	14.8	<0.001	0.998
	DMD%	67.4	69.4	0.264	1.88
	NDF%	34.5	52.5	<0.001	1.81
Post grazing	ME (MJ/kg DM)	8.7	8.9	0.407	0.372

Pre-grazing ME was similar for cocksfoot/lupin and lucerne pastures through spring/early summer, with lucerne slightly higher particularly through spring (Figure 4.20). Lucerne ME dropped February – March, before returning to usual levels through April. Post grazing ME was more variable than pre-grazing ME in both cocksfoot/lupin and lucerne pastures. While there was no significant difference in average ME between the two pasture types (P=0.407) post grazing ME was generally higher in cocksfoot/lupin pastures, with the exception of March onward, where ME increased in lucerne and decreased in cocksfoot/lupin. Post-graze lucerne ME dropped from November through to April.

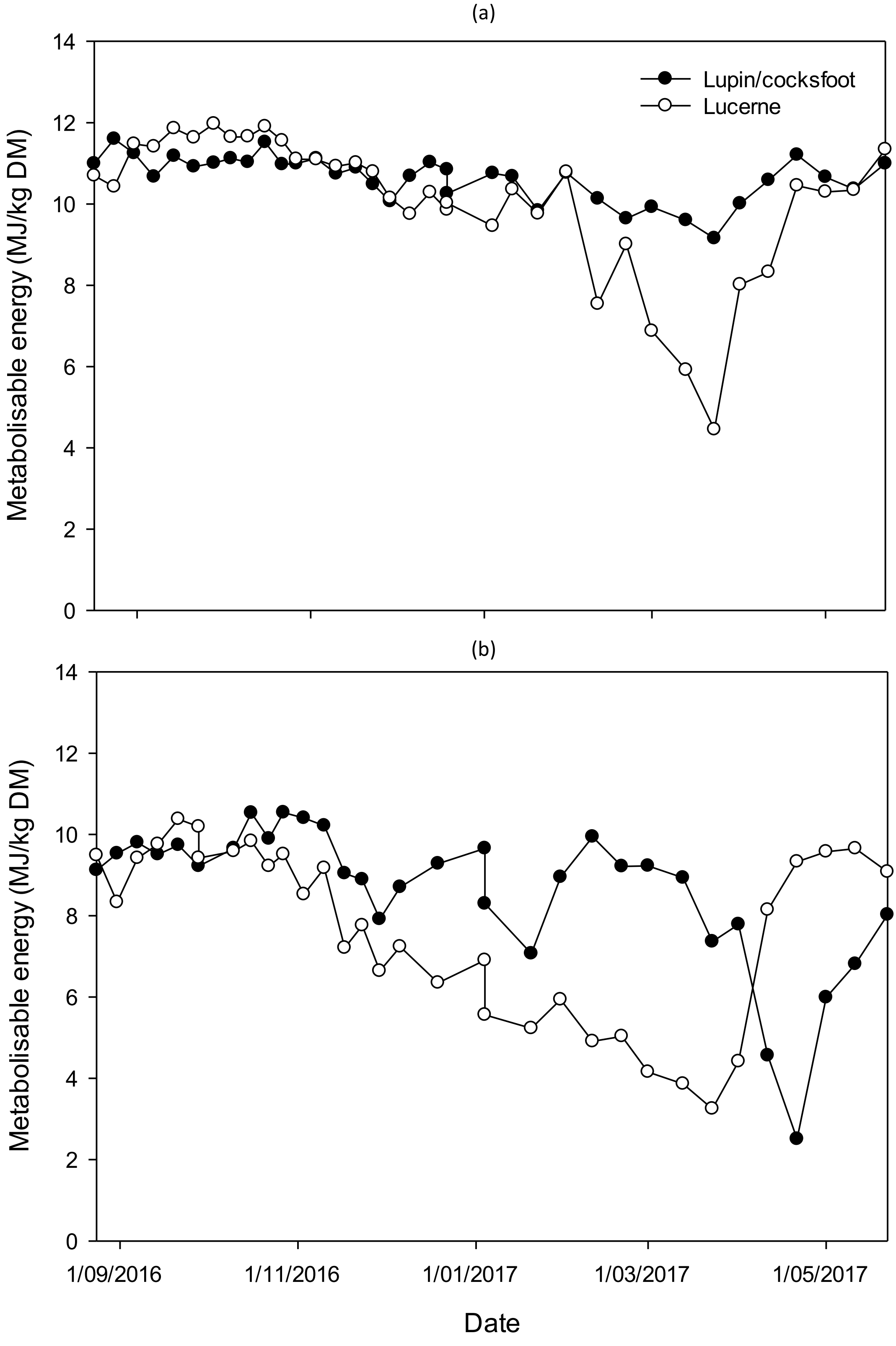


Figure 4.20 ME of (a) pre-graze and (b) post-graze of cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

Pre-grazing CP was higher in lucerne throughout the growing period ($P<0.001$). Both pasture types followed a similar pre-grazing CP pattern, with slight increase through to November, a decline through summer to the end of February, and then a rapid increase to pre-summer CP levels (Figure 4.21). Post grazing CP followed a similar pattern to pre-grazing CP, with a summer decline and autumn increase. Lucerne CP was higher than cocksfoot/lupin CP, but the gap between the two was smaller.

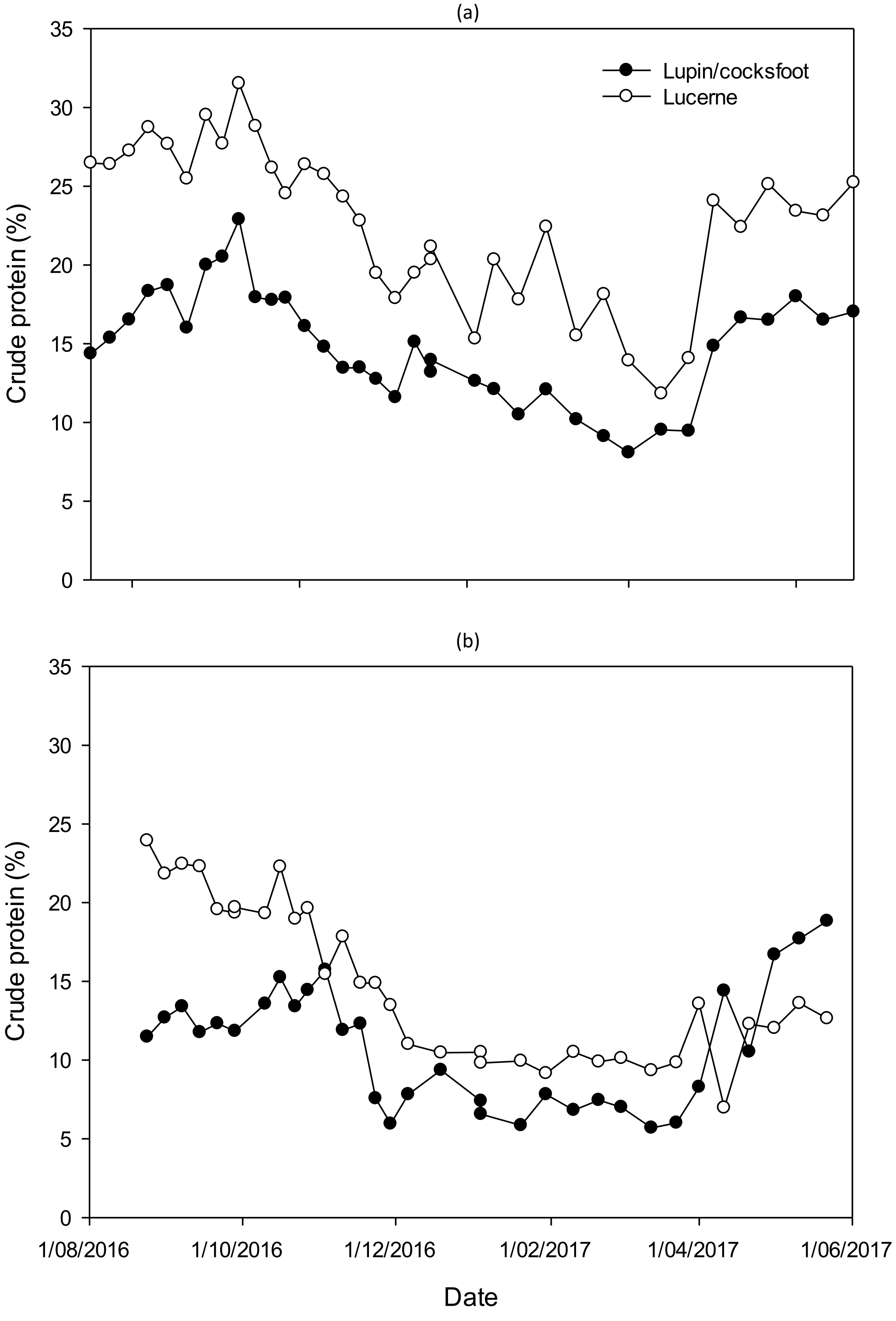


Figure 4.21 CP (%) of (a) pre-graze and (b) post-graze of cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

There was no significant difference between lupin, cocksfoot and lucerne in the average ME of leaf plus petiole/pseudostem (P=0.129) and stem (P=0.438) (Table 4.8). Lupin flowers contained more ME than lucerne flowers (P=0.009), and cocksfoot/lupin dead material on average contained 3.2 MJ ME more than lucerne pasture (P<0.001).

Table 4.8 Mean ME (MJ/kg DM) of lupin, cocksfoot and lucerne leaf + petiole/pseudostem, stem, flower and dead material from cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

	Lucerne	Cocksfoot	Lupin	P Value	SED
Leaf + petiole/pseudostem	11.8	11.5	11.6	0.129	0.128
Stem	10.1	9.9	-	0.438	0.415
Flower	11.7	-	12.2	0.009	0.127
Dead	5.0	8.2		<0.001	0.447

The CP content of lucerne was greater than the CP content of cocksfoot for all analysed components, including leaf plus petiole/pseudo stem (P<0.001), stem (P<0.001) and dead material (P<0.001) (Table 4.9).

Table 4.9 Mean CP (%) of cocksfoot and lucerne leaf + petiole/pseudostem, stem, and dead material from cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

	Lucerne	Cocksfoot	P Value	SED
Leaf + petiole/pseudostem	29.9	17.5	<0.001	0.884
Stem	18.1	9.9	<0.001	1.71
Dead	13.2	7.6	<0.001	0.654

The average ME of leaves and petiole/pseudostem of the main pasture species (lupin, cocksfoot, and lucerne) was not significantly different (P=0.128) and was within a tight range (10.4 - 13.4 MJ ME) throughout the grazing trial (Figure 4.22). Lupin ME dropped through summer (November – April), but at the beginning and ending of the growing season it contained the highest ME of the three species. Like lupin cocksfoot ME also dropped over summer, beginning earlier in August and increasing in February to pre summer levels. Lucerne ME was the highest and least variable throughout the grazing period, with slight declines occurring in September and May. CP content in leaves and petiole/pseudostem followed a similar seasonal pattern for both pasture types. Both pastures declined in CP through the summer (October – March), and increased to pre summer levels around March. Lucerne contained more CP than cocksfoot/lupin pasture.

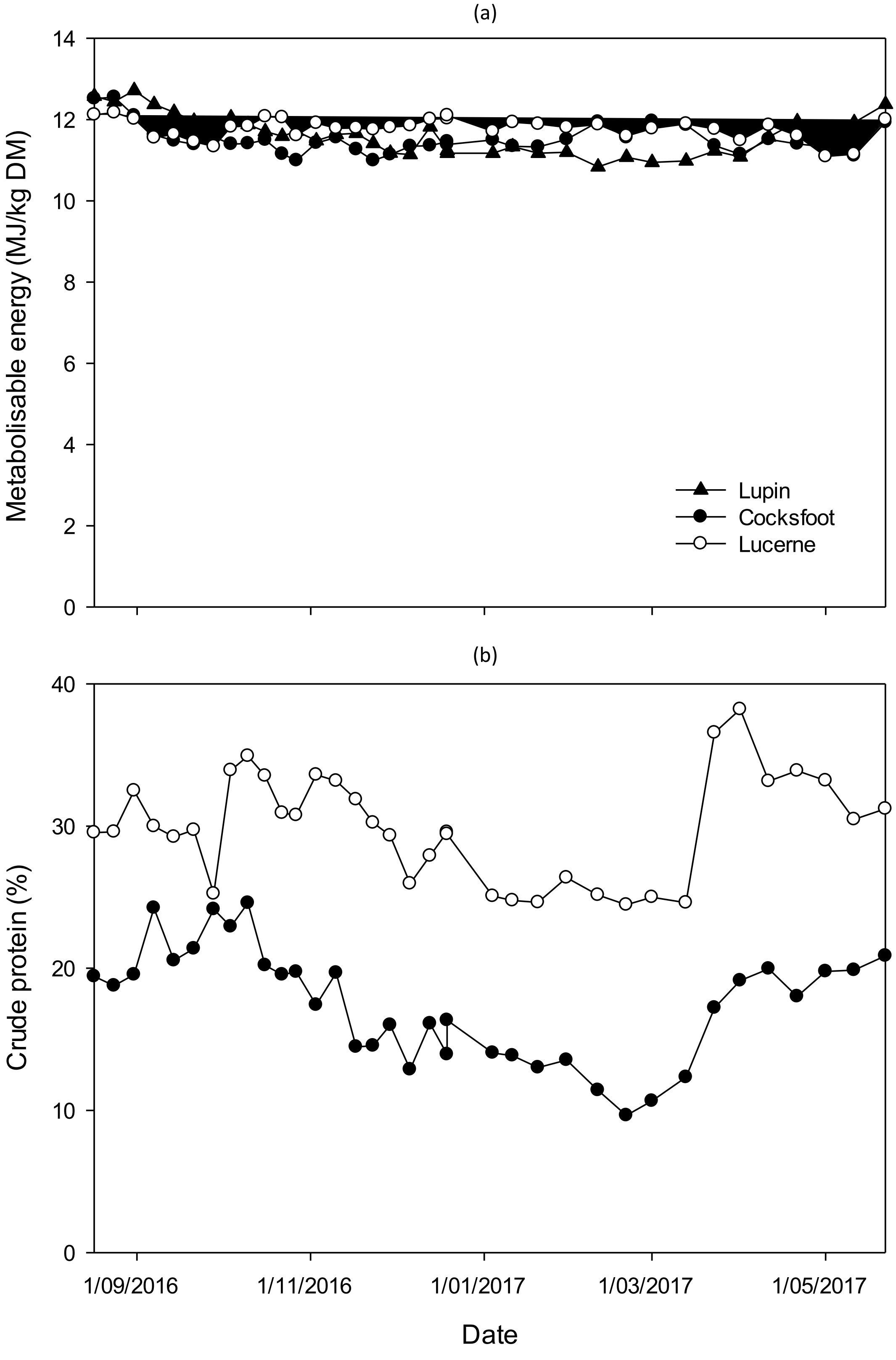


Figure 4.22(a) ME and (b) CP (%) of lupin leaf plus petiole, cocksfoot leaf plus pseudostem and lucerne leaf plus petiole of cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

Stem was only produced in a cocksfoot/lupin pasture over the reproductive period (November – January), and was produced by lucerne year round (Figure 4.23). Average ME of both pasture types was not significantly different ($P=0.438$), and they both trended downwards into summer. CP in lucerne stem was higher than that in cocksfoot/lupin stem ($P<0.001$). CP in cocksfoot/lupin stem declined slightly into summer, while lucerne CP content was considerably more variable, but still showed a summer decline

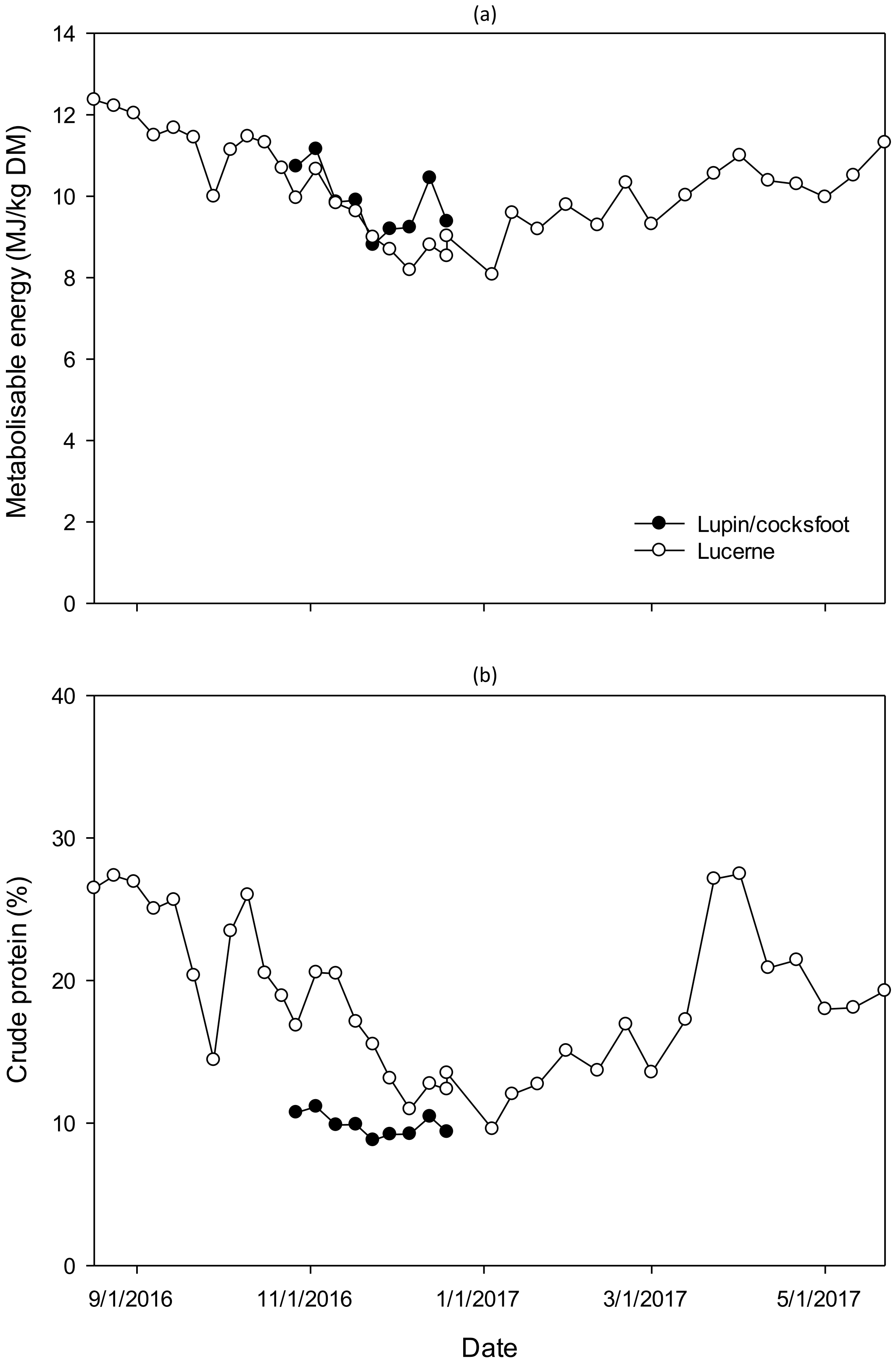


Figure 4.23(a) ME and (b) CP (%) of cocksfoot/lupin stem and lucerne stem of cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

The ME content of dead material was lower in lucerne than in cocksfoot/lupin pasture (P=0.001). Dead material in cocksfoot/lupin pasture had some weekly variation, but generally trended level, with a slight downward slope toward the end of the growing season Figure 4.24). Lucerne dead material had a low initial ME until November – December where it peaked rapidly. ME of dead lucerne then declined toward the end of the growing season at a quicker rate than that of lucerne. CP was higher in lucerne dead material than cocksfoot/lupin dead material (P<0.001). Both pasture types followed the same seasonal pattern, lowering slightly through the growing season.

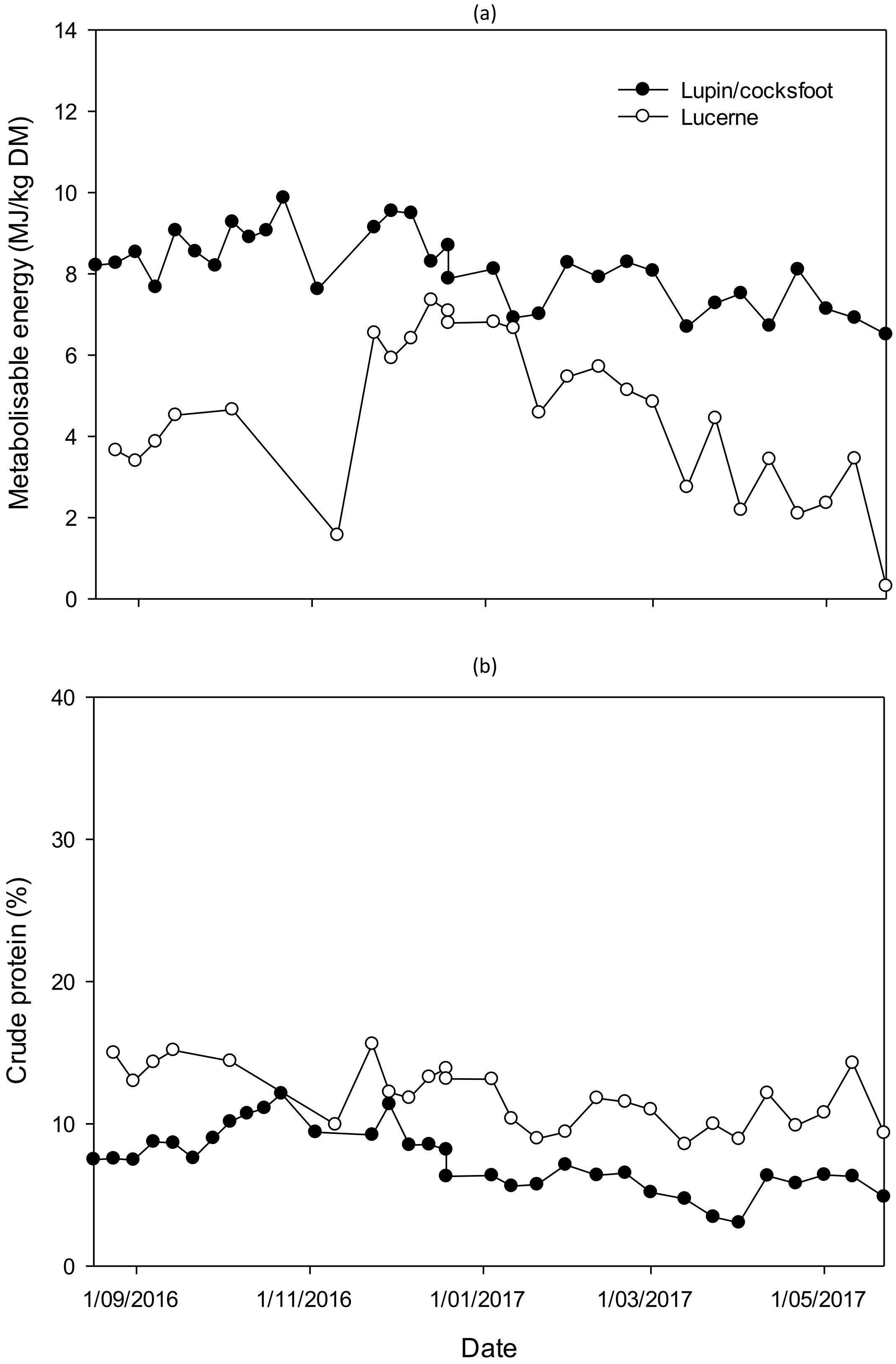


Figure 4.24(a) ME and (b) CP (%) of cocksfoot/lupin dead material and lucerne dead material of cocksfoot/lupin pasture and lucerne pasture under dryland conditions over the 2016/2017 growing season at Lincoln University, Canterbury.

5 DISCUSSION

The aim of this experiment was to determine the feeding value of a perennial cocksfoot/lupin mix pasture in relation to a lucerne pasture by comparing the liveweight gain and feed intake of young sheep grazing on the two pasture types under dryland conditions. The dataset used in this study included results obtained from the full 2016/17 growing season. This allowed comparisons of the two pasture types during spring and summer as well as during autumn, when the more intensive measurements of feed intake occurred. The literature review concluded that perennial lupin was well adapted to the challenge of surviving in high country pasture, including growing in low soil fertility and with high soil Al (Scott 1989). Perennial lupins have been recognised in several on farm studies as a viable high country legume option for sheep liveweight gain (Black *et al.* 2014; Black & Ryan-Salter 2016; Pollock & Moot 2016). However, the scale of on-farm trials limits the ability to explain differences in sheep performance. In this trial the liveweight gain of sheep grazing lucerne pasture was higher than that of sheep grazing cocksfoot/lupin pasture (P<0.001). This was primarily a result of higher FCE for DM and ME consumed in lucerne pasture than cocksfoot/lupin pasture.

5.1 Liveweight gain

The accumulated liveweight gain over the duration of the grazing trial was lower on cocksfoot/lupin pasture than lucerne pasture, with sheep gaining 60% of the 1193 kg/ha liveweight achieved on lucerne (Figure 4.14). This difference was caused by a lower stocking rate, with cocksfoot/lupin at 65% of that of lucerne, and lower daily liveweight gain, with cocksfoot/lupin at 52% of the liveweight gained by lucerne.

The higher stocking rate on the lucerne pasture was associated with greater pre-grazing herbage mass on offer to the sheep (Figure 4.14), which meant that more sheep had to be carried for the same grazing duration (288 days) to achieve similar herbage allowances between the two pastures (Figure 4.7). Average cocksfoot/lupin pre-grazing herbage mass was 66% of the 2279 kg DM/ha herbage mass of lucerne pasture. Pre-grazing herbage mass is influenced by the regrowth period following grazing, however grazing rotation, and therefore regrowth periods were the same for both pasture types. Botanical composition was clearly different between pasture types (Figure 4.18), with cocksfoot legume pasture containing only 13.94% legume compared with 96.54% legume in lucerne pasture. This results in a high level of nitrogen available for plant growth in lucerne, while cocksfoot/lupin pastures were potentially nitrogen deficient. This trial took place in a dryland environment, indicating water use efficiency (WUE) has an influence on pre-grazing herbage mass. Black & Ryan-Salter (2016) found WUE for herbage yield on cocksfoot/lupin pasture to be 71% of the of lucerne's 17.9 kg/DM/ha/mm during Year 2 of the trial, and 41% of lucerne's 19.4 kg/DM/ha/mm over Year 3. Lucerne pre-grazing herbage mass is also affected by partitioning of assimilates, causing lower shoot production in autumn, and re-mobilisation of root reserves, causing rapid shoot production in spring (Moot *et al.* 2003).

The higher daily liveweight gain of sheep grazing lucerne pasture (0.217 kg/head/day) compared to sheep grazing cocksfoot/lupin pasture (0.112 kg/head/day) was likely due to higher feed intake of sheep on lucerne. Sheep on cocksfoot/lupin pasture consumed 65% of the 1.496 kg DM/head/day consumed by sheep grazing lucerne pasture. The difference in feed intake could not have been due to different allowances as feed allowance was the same for both pastures (Table 4.4) and post-grazing herbage mass was the same (Table 4.5). However, the difference in feed intake was potentially the result of different composition of feed offered to sheep. There was no significant difference in annual DM composition of the two pasture types (Table 4.6), so DM composition is unlikely to have affected daily liveweight gain. Cocksfoot/lupin pasture contained a lower proportion of live material than lucerne pasture, with 70.86% compared to lucerne with 81.93% (Figure 4.17), contributing to lower liveweight gain compared to lucerne. Cocksfoot/lupin pasture and lucerne pasture had different botanical compositions (Figure 4.18). While the proportion of sown species present in both pastures was similar, legume content was significantly different, with cocksfoot/lupin pasture contained 14% of the legume present in lucerne pasture. Legumes are recognised as preferred over grass species (Parsons *et al.* 1994), potentially leading to higher herbage intake. The two pasture types have different morphological compositions (Figure 4.19). More stem was present in the lucerne fraction of lucerne pasture than in cocksfoot and lupin in the lupin/cocksfoot pasture, and more leaf plus petiole/pseudostem was present in cocksfoot and lupin than in lucerne. Morphological composition influences herbage intake as sheep select components for consumption. The composition of feed offered to sheep was different to what they actually consumed. During each grazing period sheep selected more live material than dead material (Figure 4.12 and Figure 4.13), with the proportion of dead material either remaining the same or increasing through the 10 day period. Of the live material sheep showed a preference for legume, with the lupin fraction of cocksfoot/lupin pasture consumed within the first 4 days of grazing. Sheep also showed preference for leaf over petiole/pseudostem and stem of lucerne and cocksfoot. Herbage mass declined more in lucerne than cocksfoot/lupin pasture over a grazing period (Figure 4.9), however the pattern of component consumption was not constant over the 10 day grazing period (Figure 4.12 and Figure 4.13). Sheep tended to be more selective in the first days than in the later stages of the grazing period, as more herbage mass meant more components to select from. The preferred pasture components selected first contained a higher nutritive value than those consumed later in the grazing period (Table 4.8 and Table 4.9), indicating pasture with a high herbage mass could lead to higher liveweight gain as sheep select a diet with a high nutritive value.

Liveweight gain is influenced by the ME consumed by sheep (Figure 4.5), with FCE greater on lucerne, at 2.69 kg/ha/GJ ME, than cocksfoot at 1.79 kg/ha/GJ ME. CP intake has minimal influence on liveweight gain (Figure 4.6) and no significant difference in feed conversion efficiency (Table 4.3) between the two pastures. Sheep grazing lucerne pasture had both a higher feed intake and higher FCE, but did not have higher total pasture feed quality. The ME of the cocksfoot/lupin pasture mix and lucerne pasture mix was not significantly different (P=0.224) (Table 4.7), but pasture morphological components contained differences in ME and CP (Table 4.8 and Table 4.9). For both lucerne and cocksfoot/lupin pasture leaf plus petiole/pseudostem contained the highest level of ME and CP, at 11.8 MJ ME/kg DM and 19.9% CP for lucerne, and 11.5 MJ ME/kg DM and 17.5% for the cocksfoot component of cocksfoot/lupin pasture. Stem contained lower ME and CP than leaf plus petiole/pseudostem in both pasture types, and dead material has a lower nutritive value again at 5.0 MJ ME/kg DM in lucerne and 8.2 MJ ME/kg DM in cocksfoot/lupin pasture. Flowers in lucerne and lupin contain a high level of ME, with lupin significantly higher at 12.2 MJ ME/kg DM than lucerne at 11.7 MJ ME/kg DM. Lupin flower and stem was a minor constitute of feed on offer in the cocksfoot pasture, therefore having little influence on overall feed quality and feed intake by sheep on that pasture type. The higher nutritive value components were consumed first by sheep grazing both pasture types (Figure 4.12 and Figure 4.13). This indicates sheep were likely consuming a higher quality pasture than anticipated from the nutritive value of the pasture mix, as sheep did not consume the entirety of the allocated herbage allowance (Figure 4.14). The higher pre-grazing herbage in the lucerne pasture allowed greater selection of botanical and morphological component, contributing to greater herbage intake and FCE, and therefore greater liveweight gain on lucerne pasture compared with cocksfoot/lupin pasture.

5.2 Seasonal changes

Liveweight gain had distinct points of accumulation change throughout the duration of the grazing experiment that align with the season. Liveweight gain per hectare is influenced by stocking rate and daily liveweight gain per sheep (Figure 4.1). Stocking rate was subject to seasonal variation as pre-grazing herbage mass changes. Daily liveweight gain per sheep was split into three periods of liveweight accumulation per pasture, spring, summer and autumn (Table 4.2). These seasonal changes were also apparent when comparing liveweight gain in response to DM intake of both pasture types (Figure 4.4).

Liveweight gain in spring was influenced by stocking rate and daily liveweight gain (Figure 4.1). Stocking rate through spring was higher on lucerne pasture than cocksfoot/lupin pasture (Figure 4.2). This was caused by a higher pre-grazing herbage mass on lucerne over this period (Figure 4.14) as herbage allowance was the same for both pasture types. The higher herbage mass of lucerne than cocksfoot/lupin over this period was likely due to nitrogen availability, re-mobilisation of root reserves, and better WUE (Black & Ryan-Salter 2016). The daily liveweight gain of sheep over the spring was higher on lucerne at 0.250 kg/sheep/day, compared with 0.161 kg/sheep/day on cocksfoot/lupin pasture. This was likely due to differences in the composition of herbage offered to sheep. Both pastures offered a high proportion of live material to sheep, with lucerne offering a higher proportion through the spring period than cocksfoot/lupin pasture (Figure 4.17). More legume was available on lucerne pasture than cocksfoot/lupin pasture through the spring (Figure 4.18), and a high proportion of leaf was also available in both pasture types Figure 4.19). Throughout spring more live components and leaf material was offered to sheep than in the other two seasons. This meant sheep had more high quality, preferred components to select a diet from than seasons, and more high quality, preferred components to select from in lucerne than in cocksfoot/lupin pasture. ME content between lupin/cocksfoot and lucerne pasture wasn't substantially different in spring (Figure 4.20), and CP content was higher in lucerne than cocksfoot/lupin pasture in all seasons (Figure 4.21). The higher ME consumed gained by sheep grazing lucerne compared to cocksfoot/lupin pasture (Figure 4.5) was more likely the result of diet selection. The higher liveweight gain in spring in comparison to other seasons should be maximised for higher annual liveweight gain.

Liveweight gain per hectare was lower in summer than spring (Figure 4.1). The stocking rate declines for both pasture types, as water availability limits pre-grazing herbage mass (Figure 4.2). The stocking rate of lucerne and cocksfoot/lupin pasture were similar over this period, as without water lucerne lost its herbage growth advantage (Figure 4.14). Toward the end of the summer period liveweight gain per hectare on lucerne was similar to liveweight gain on cocksfoot/lupin pasture as lucerne stocking rate dropped below that of cocksfoot/lupin (Figure 4.1).Daily liveweight gain over this period was lower on cocksfoot/lupin pasture at 0.0934 kg/sheep/day than lucerne pasture at 0.202 kg/sheep/day (Table 4.2). The drop in daily liveweight gain from spring to summer was influenced by lower DM intake (Figure 4.8) as botanical and morphological composition of pasture changed due to water stress. Over summer more dead material was present in both pasture types as water stress limited the growth of live material (Figure 4.17). Dead material contains less ME and CP than live pasture components (Table 4.8 and Table 4.9), and quality also declines compared to spring (Figure 4.24), meaning less high quality components were available for sheep to select. Reproductive components of both pasture types were present through summer (Figure 4.15 and Figure 4.19). Lupin and lucerne flowers contained a high level of ME (Table 4.8), while stem components of all three main pasture species contained a low level of ME. More stem was present in pasture than flower, and the flower component was not present for a large period of time, so stem contributed more herbage mass to pasture than flower. Sheep preferred not to consume stem (Figure 4.12 and Figure 4.13), which also contains low ME compared to other pasture components (Table 4.8). In studies from Black & Ryan-Salter (2014) and Pollock & Moot (2016) sheep showed a preference for lupin flowers, which reportedly contained high ME, however as the flower component of lupin had minimal contribution to cocksfoot/lupin pasture its effect on liveweight gain is negligible. The summer dry period caused a decline in ME of the total pasture in both pasture types (Figure 4.20), but more so in lucerne as the proportion of dead material increased. Despite the lower ME of lucerne compared to lupin/cocksfoot pasture sheep were still able to select components that gave them a higher ME than what was on offer in pasture mix, as indicated by considerably lower post-grazing levels of ME in comparison to pre-grazing ME (Figure 4.20). The primary limitation to lucerne growth through summer was water availability. While lucerne has a deep tap root giving it access to a greater volume of water than cocksfoot/lupin pasture (Evans 1977) it, like cocksfoot/lupin pasture, utilises all available water in spring , preventing it from producing herbage mass, and therefore liveweight gain, in summer. It is crucial to maximise spring production with high FCE for maximum total annual liveweight gain.

Liveweight gain per hectare in lucerne recovered in autumn as water availability increased with the arrival of autumn rain (Figure 4.1). Liveweight gain per hectare remained constant in cocksfoot/lupin pasture, with no visible change between summer and autumn liveweight accumulation. The stocking rate of both pastures increased in autumn as herbage mass increased response to water availably (Figure 4.2). Herbage mass increased more in lucerne than cocksfoot/lupin pasture through this period due to higher available nitrogen (Figure 4.20). Herbage mass in autumn did not reach the same level as herbage mass in spring. This was potentially due to lower temperatures, with lucerne optimum temperature 24 ^{o}C (Mills *et al.* 2006) and cocksfoot optimum temperature 30 ^{o}C (Brown *et al.* 2005). Lower herbage mass in lucerne is also potentially the result of allocation of assimilates to roots instead of shoots (Moot *et al*. 2003). Daily liveweight gain increased in autumn relative to summer in both pasture types, with 0.0784 kg/sheep/day on cocksfoot/lupin pasture and 0.183 kg/sheep/day on lucerne pasture. This was due to an increase in herbage intake, with herbage mass in pasture grazed in late autumn (Figure 4.11) decreasing more in both pasture types than late summer/early autumn herbage mass (Figure 4.10). Autumn pasture composition contained less dead material than summer in both pasture types, and less stem in cocksfoot/lupin pasture (Figure 4.17 and Figure 4.19). The consumption of pasture components within a grazing period was intensively measured over autumn, and showed that very little dead material was consumed, and stem material was only consumed at later stages of the grazing period for both pasture types (Figure 4.12 and Figure 4.13). Leaf was the preferred component and was consumed rapidly from beginning to end of the grazing period, unaffected by the seasonal change in growth rate from summer to autumn. The ME value of leaf was consistent for all pasture species throughout the experiment duration, but CP content increased following autumn rain as plants were able to utilise N (Figure 4.22).

5.3 Lupin in cocksfoot/lupin pasture

Lupin was a minor component of the herbage offered to sheep in the cocksfoot/lupin pasture (Figure 4.18). While sheep ate it, with lupin present in pasture consumed by Day 4 of the 10 day grazing rotation, it probably did not contribute much to their feed intake and therefore liveweight gain. The presence of lupin in this trial was variable through different paddocks (Figure 4.12 and Figure 4.13). This variation is potentially caused by intensive grazing, as lupin prefers lax grazing and require a long regrowth period when intensively grazed (Scott *et al.* 1995). In the years preceding this trial the plots were more intensively fenced and had a higher grazing intensity. This likely led to intensive grazing of lupin that it potentially could not tolerate over a long period of time, causing variation of lupin within paddocks. Over the previous 3 years of this trial Black & Ryan-Salter (2016) found lupin content consistently halved from one year to the next. While not confirmed Kitessa (1992) suggested the disappearance of lupin at Lincoln University was due to crown and root rot caused by *Fusarium heterosporum Nees*. As outlined in the literature review lupin re-seeds well, and mature high country stands are frequently let set seed to allow this. Lupin grown in this trial at Lincoln University didn’t mature and set seed before grazing, limiting re-generation. As lupin is not found in wild populations in the immediate vicinity of Lincoln University and lupin in pasture did not have the opportunity to re-seed no reserve of hard seed would have been present in pasture soil, further limiting potential regeneration of lupin. Lupin is not suited to this environment, and may not be suited to the grazing method used in this trial.

5.4 General discussion

Lucerne pasture was the better of the two dryland pasture options. Therefore is should be grown over cocksfoot/lupin pasture wherever possible to maximise liveweight gain and feed conversion efficiency on dryland farms before the system runs out of water in summer. Once this is achieved grazing pressure could be taken off of the lucerne over the dry period by grazing more resilient but lower quality pasture options, such as cocksfoot-based pastures. Lucerne may recover better than cocksfoot-based pastures in the autumn but emphasis should then be on conditioning the lucerne for the following spring rather than for liveweight gain. The better autumn production of lucerne could however be utilised for flushing ewes on prior to mating, particularly in environments where other sources of high quality feed suitable for flushing are scarce at that time of year. Flushing on lucerne carries a risk of possible reductions in ovulation rate compared to lush grass-based pasture, but not compared to drought affected poor quality pasture. Lucerne could be grazed for short period say 1-2 weeks of flushing to minimise negative effects on ewe reproductive performance. A fibre supplement might also help. Lucerne cannot be grazed over winter while cocksfoot dominant pastures can, so a farm system combining lucerne and cocksfoot dominate pastures has the potential to offer high feed value year round (Brown *et al*. 2006).

Lupin is not a suitable legume component in dryland pasture at Lincoln University as it lacked persistence. However sheep grazing cocksfoot/lupin pasture did gain acceptable live weight, and under dryland high Al conditions this liveweight gain may be more than other legume options. Obtaining lupin seed can be difficult as seed yields are highly variable and seed production is predominately for the ornamental market (Monks *et al*. 2016). The current domestic market is too small to justify investment, and as a result seed coasts are high. Lupin should be considered as an alternative legume only where environmental conditions limit the growth of other more productive legume species.

Further research should consider the improvement of lucerne production in spring in order to maximise high FCE. A better understanding of lupin disappearance at Lincoln University would be beneficial for improving lupin persistence in the high country, and grazing strategies for persistence and improved feed quality should be explored

5.5 Conclusions

- Sheep grazing cocksfoot/lupin pasture gained 60% as much liveweight per hectare as sheep grazing lucerne pasture over the trial duration. This was influenced by a higher stocking rate and herbage intake on lucerne than cocksfoot/lupin pasture
- Pre-grazing herbage mass was higher on lucerne pasture than cocksfoot/lupin pasture, allowing for a higher stocking rate on lucerne pasture at 20.8 head/ha compared with 13.6 head/ha on cocksfoot/lupin pasture.
- The consumption of morphological pasture species components is similar between cocksfoot/lupin pasture and lucerne pasture. In both cases leaf is the most rapidly consumed component, followed by petiole/pseudostem and stem. The lupin fraction of cocksfoot/lupin pasture was consumed within the first 4 days. Dead material was avoided by sheep grazing both pasture types.
- FCE of ME is greater on lucerne on cocksfoot/lupin pasture, contributing to greater liveweight gain.
- With adequate soil moisture lucerne pasture has the potential for high liveweight gain per hectare, making it a better pasture option for sheep than cocksfoot/lupin pasture. However, the feeding value of cocksfoot/lupin pasture is adequate for liveweight gain in young sheep. In the high country environment where the rooting depth of lucerne is restricted by high Al soils, limiting lucerne growth, Cocksfoot/lupin pasture can be used as an alternative forage crop.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr Alistair Black, for his support and dedicated guidance throughout the year, particularly with his help through the final few weeks of writing.

I would also like to thank:

My parents, for all the love and support they have given me that has allowed me to be where I am today

The team at the FRC, for their help and advice. Special thanks to Malcom for going above and beyond to ensuring I had working clipper when I needed them!

The other honours student, for your constant motivation and help throughout this year. Special thanks to Hannah for the company while sorting, Brenna for being an ideal person to work alongside, and Sonja, for chocolate coins, good company, and teaching me how to do press-ups

REFERENCES

Black, A.D.; Loxton, G.; Ryan-Salter, T.P.; Moot, D.J. 2014. Sheep performance on perennial lupins over three years at Sawdon Station, Tekapo. *Proceedings of the New Zealand Grassland Association 76*: 35-40.

Black, A. D.; Ryan-Salter, T. P. (2016). Evaluation of perennial lupin/cocksfoot pasture relative to lucerne pasture under summer dry conditions. *Journal of New Zealand Grasslands 78*: 123-132.

Brown, H. E.; Moot, D. J.; Lucas, R. J.; Smith, M. (2006). Sub clover, cocksfoot and lucerne combine to improve dryland stock production. *Proceedings of the New Zealand Grassland Association 68*: 109-115.

Brown, H. E.; Moot, D. J.; Teixeira, E. I. 2005. The components of lucerne (*Medicago sativa*) leaf area index respond to temperature and photoperiod in a temperate environment. *European Journal of Agronomy 23*: 348-358.

Burtt, E. S. 1981. The potential of *Lupinus angustifolius* cv. Uniharvest, in Canterbury, as a summer greenfeed for lambs. Doctoral dissertation. Lincoln College, New Zealand

Davis, M. R. 1981. Growth and nutrition of legumes on a high country yellow-brown earth subsoil. *New Zealand Journal of Agricultural Research 24*: 321-332.

Davis, M.R. 1991. The comparative phosphorus requirements of some temperate perennial legumes. *Plant and soil 133*: 17-30.

Department of Conservation. 2012. Weeds: Plant pests. Accessed 5/7/2017. http://www.doc.govt.nz

Evans, P. S. 1977. Plant root distribution and water use patterns of some pasture and crop species. *New Zealand Journal of Agricultural Research 21*: 261-265.

Gladstones, J. 1970. Lupins as crop plants. *Field Crop Abstracts 23*: 123-148.

Gibbs, H. M. 1988: Variation in alkaloid content of Russell lupins and *L. arboreus.* Dissertation. Lincoln College, New Zealand.

Harvey, I.C.; Seyb, A.M.; Warren, A.F.J.; Van Den Ende, H. 1996. The biological control of Russell lupin in riverbeds with endemic plant pathogens. pp. 119-125. *In*: Proceedings 49th New Zealand Plant Protection Conference.

Jarvis, P.; Lucas, R. J.; White, J. G. 1997. Sulphur and phosphorus responses of Russell lupin in rangeland. *Proceedings of the 18th International Grasslands* Congress: 21-22.

Jiang, S.; Keaney, D.; Ryan-Salter, T.P.; Black, A.D. 2014. Developing NIRS calibrations to predict the nutritional value of Russell lupin (*Lupinus polyphyllus*). *16th Australian Near Infrared Spectroscopy Group Conference, Coffs Harbour, NSW.*

Kitessa, S. M. 1992. The nutritional value of Russell lupin (*Lupinis polyphyllus x Lupinus arboreus*) for sheep. Doctoral dissertation. Lincoln University, New Zealand.

Mills, A.; Moot, D. J.; McKenzie, B. A. 2006. Cocksfoot pasture production in relation to environmental variables. *Proceedings of the New Zealand Grassland Association 68*: 89-94.

Moir, J. L.; Moot, D. J. 2014. Medium-term soil pH and exchangeable aluminium response to liming at three high country locations. *Proceedings of the New Zealand Grassland Association 76*: 41-46.

Monk, S.; Moot, D. J.; Belgrave, B.; Rolston, M. P.; Caradus, J. R. 2016. Availability of seed for hill country adapted forage legume. *Hill Country Symposium. Grassland Research and Practice Series 16*: 257-267.

Moot, D.J.; Pollock, K.M. 2014. Perennial lupin establishment and yield when sown at five different rates at Glenmore Station, Lake Tekapo. Proceedings of the New Zealand Grassland Association 76: 53-59.

Parsons, A. J.; Newman, J. A.; Penning, P. D.; Harvey, A.; Orr, R. J. 1994. Diet preference of sheep: effects of recent diet, physiological state and species abundance. *Journal of Animal Ecology*: 465-478.

Pollock, K. M.; Moot, D. J. 2016. Productivity and composition of perennial lupin pastures in response to six sowing rates, lime application and lupin type at Glenmore Station, Lake Tekapo. *Journal of New Zealand Grasslands 78*: 139-148.

Ryan-Salter, T.P.; Black, A.D.; Andrews, M.; Moot, D.J. 2014. Identification and effectiveness of rhizobial strains that nodulate *Lupinus polyphyllus*. *Proceedings of the New Zealand Grassland Association 76*: 61-65.

Scott, D. 1989. Perennial or Russell lupin: A potential high country pasture legume. *Proceedings of the New Zealand Grassland Association 50*: 203-206.

Scott, D. 2001. Sustainability of New Zealand high-country pastures under contrasting development inputs. 7. Environmental gradients, plant species selection, and diversity. *New Zealand Journal of Agricultural Research 44*: 59-90.

Scott, D. 2008. Sustainability of high-country pastures under contrasting development inputs. *Proceedings New Zealand Grasslands Association 70*: 19-23.

Scott, D. 2014. The rise to dominance over two decades of *Lupinus polyphyllus* among pasture mixtures in tussock grassland trials. *Proceedings of the New Zealand Grassland Association 76*: 47-52.

Scott, D.; Keoghan, J.M.; Cossens, G.G.; Maunsell, L.A.; Float, M.J.S. 1985. Limitations to pasture production and choice of species. pp. 9-15. *In*: Using herbage cultivars. Eds.

Burgess, R.E.; Brock, J.L. Grassland Research and Practise Series No. 3. New Zealand Grasslands Association Palmerston North, New Zealand.

Scott, D.; Maunsell, L. A.; Hunt, L. M. 1994. Relative sheep liveweight gain on perennial lupin, red clover and alsike. *Proceedings of the New Zealand Grassland Association 56*: 115-157.

Seed Force New Zealand. SF Force 4 - Lucerne. Accessed 2/7/2017. http://www.seedforce.co.nz

Smit, H. J.; Taweel, H. Z.; Tas, B. M.; Tamminga, S.; Elgersma, A. 2005. Comparison of techniques for estimating herbage intake of grazing dairy cows. *Journal of Dairy Science 88*: 1827-1836.

Stevens, D.R.; Baxter, G.S.; A., S.; Casey, M.J.; Miller, K.B. 1992. Grasslands Kara cocksfoot: a productive cultivar under lax grazing. *Proceedings of the New Zealand Grassland Association 54*: 143-146.

Wangdi, K. (1990). Studies on the field establishment of Russell lupin (*Lupinus polyphyllus x Lupinus arboreus*). Doctoral dissertation. Lincoln University, New Zealand.

White, J.G.H. 1995. A review of legume introduction in tussock grasslands with particular reference to species tolerant of low nutrient inputs. *Proceedings of the Agronomy Society of New Zealand 25*: 7785.

Woodman, R. F.; Keoghan, J. M.; Allan, B. E. 1992. Pasture species for drought-prone lower slopes in the South Island high country. *Proceedings of the New Zealand Grassland Association 54*: 115-120.

Woodman, R. F.; Keoghan, J. M.; Allan, B. E. 1996. Pasture legumes for the drought-prone, outwash soils of the southern Mackenzie Basin. *Proceedings of the New Zealand Grassland Association 58*: 247-252.