Sheep live-weight gain on cocksfoot-lupin compared with lucerne pastures in the first year (2014-2015) after establishment

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By

Blair Mark Hamill

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While 30 years of literature shows that lupins will thrive in the high country, there is little data on livestock performance of sheep fed lupin. Black *et al.* (2014) recently showed sheep performance on lupin was similar to that on control pastures but due to on farm conditions could not relate the differences to the feed type. This study aimed to identify any differences in livestock performance between animals on cocksfoot-lupin and lucerne pastures with respect to apparent intake, pasture composition and nutritional value. This dissertation reports the results from the first year of the grazing experiment (5 August 2014 – 28 May 2015) after the establishment period. Over the experimental period live-weight gain was 768 kg/ha for cocksfoot-lupin pastures and 1126 kg/ha for lucerne pastures. The difference in live-weight gain per hectare occurred in response to the higher mean live-weight gains per animal and the higher mean stocking rate over the year on lucerne. There was no significant difference in grazing days for cocksfoot-lupin and lucerne pastures due to cocksfoot-lupin grazing occurring earlier, indicating similar numbers of animals could be sustained over the year. Live-weight gains of 23.7 kg and 23.6 kg per animal was observed during the spring period for cocksfoot-lupin and lucerne fed animals respectively. However lucerne fed sheep grazed for 41 days less due to the lack of feed wedge. The higher intakes, rate of weight gain and stocking rate on lucerne pastures allowed lucerne to surpass the live-weight gain per hectare of cocksfoot-lupin a shorter period. Live-weight gain was 468 kg/ha and 614 kg/ha for cocksfoot-lupin and lucerne pastures respectively in spring. Cocksfoot-lupin pastures had a higher DMD and ME, but protein content was higher in lucerne. The higher protein would have aided live-weight gains. ME intake may have been higher due to increased pasture intake on lucerne. Over the spring summer period (28 November 2014 – 16 February 2015) live-weight gain was 171 kg/ha for cocksfoot-lupin pastures and 381 kg/ha for lucerne pastures. The difference in performance was linked to increased individual intake resulting in increased weight gains per animal on lucerne. Weight gain over the period was 14.5 kg/animal and 25.4 kg/animal for cocksfoot-lupin pastures and lucerne pastures respectively. In the autumn period (18 February 2015 – 28 May 2015) live-weight gain was 129 kg/ha for cocksfoot-lupin pastures and 131 kg/ha for lucerne pastures. Animal growth on lucerne stopped after 57 days but the increased stocking rate on lucerne prevented changes in the difference of cumulated growth between the pastures. A high proportion of dead material on offer and lack of leaf material in the autumn may be responsible for the reduced performance on lucerne at this time. There is evidence to suggest that sheep will graze lupin with particular preference to the leaves. The cocksfoot-lupin pastures produced forage of comparable quality to lucerne. Cocksfoot-lupin pastures show an advantage over lucerne as they may be able to be grazed earlier in spring possibly due to the high proportion of cocksfoot in the pasture. Overall production on cocksfoot lupin pastures was 70% of lucerne in the first year after establishment suggesting cocksfoot-lupin as an alternative forage in areas unsuitable for lucerne.

Keywords: *Dactylis glomerata*, dryland, high country, legumes, *Lupinus polyphyllus*, *Medicago sativa*, nutritional value

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1 Introduction

Agricultural production in the Canterbury high country is challenged by many factors. These include long cold winters resulting in short growing seasons (Wangdi 1990) and vast variation in high country soils. High country soils vary from semi desert to alpine and reflect the parent material, degree of losses, vegetation and climate (Float *et al.* 1994). Many high country soils are deficient in nitrogen (N), phosphorus (P), sulphur (S) and molybdenum (Mo) (Wangdi 1990). Altitude variation in the high country of 200 m to more than 2000 m affects rainfall patterns, temperature and soil development (Float *et al.* 1994). Moir *et al.* (2013) described the soils of the Mackenzie District as 'pallic' where rainfall was <700 mm or 'brown' where rainfall was >1000 mm. Each were formed from glacial till or outwash and loess of greywacke or schist and are typically shallow and stony (Moir *et al.* 2013). Patterns of natural vegetation in the high country reflect the soil distribution, climate and aspect; however human impact has modified the distribution of species in the last 1000 years (Float *et al.* 1994).

The influence of the surroundings has caused high country farming operations to be based around tussock grasslands and semi-improved pasture where possible (Dynes *et al.* 2010). The term 'semi-improved' defines pastures which have been modified by fertilisers and grazing management resulting in fewer, but better grazing species in the sward (Joint Nature Conservation Committee 1990). Reflecting the nature of high country pastures, the stocking rate is low often only 1.1 SU/ha (Moot *et al.* 2009). The development of irrigation and subsequent shift to dairying on the lowland Canterbury plains has restricted the availability of traditional finishing areas. High country farmers are facing increasing pressure to be able to finish lambs on their own properties (Dynes *et al.* 2010). This pressure emphasises the need for a high yielding resilient pasture legume which not only survives, but thrives on the limited area of cultivatable high country land.

Lucerne (*Medicago sativa*) is one plant that is capable of surviving in dry environments and has become adopted by many high country farmers (Anderson *et al.* 2014). The deep tap root of lucerne gives it the ability to extract deep soil water over 2 m down the soil profile (Moot *et al.* 2008). Lucerne is also well known for yielding high quality and highly palatable pasture. For example, Brown and Moot (2004) found that sheep fed lucerne had 30 % greater crude protein (CP) and metabolisable energy (ME) intakes than sheep fed red clover (*Trifolium pratense*) or chicory (*Cichorium intybus*). This was due to the similar herbage quality of lucerne and a greater feed intake compared to red clover or chicory. Lucerne yields of 17-27t DM/ha/yr were 3-9 t DM/ha/yr greater than red clover or chicory over six seasons (Brown & Moot 2004).

While lucerne is an excellent forage, unfortunately many Canterbury high country soils have high aluminium (Al) concentrations (>3.0 mg/kg) and acidic soils (pH <5.5) restricting the root growth and nodulation of lucerne (Moir & Moot 2010; Moot & Pollock 2014). In the search for a suitable high country legume the perennial 'Russell' lupin (*Lupinus polyphyllus*) has come into consideration for its tolerance to Al and acid soils. Lupin, like lucerne is a perennial tap rooted legume which displays winter dormancy (Scott 1989). The ability of 'Russell' lupin to survive in acidic and dry soils has been well documented and supported over the past 30 years of research at Mt John research station, Tekapo (Scott 2014). Even in the UK lupins have been noted as having agronomic potential in marginal areas (Dickie *et al.* 1985).

For many years only one study investigated animal performance on lupins in which Scott *et al.* (1994) reported that Merino wethers grew faster on red clover and alsike clover (*Trifolium hybridum*) than on lupins, perhaps due to the nutritional value of the different forages or the alkaloids present in lupins. In the only study on the nutritive value of 'Russell' lupin across an entire growth season, Kitessa (1992) found that 'Russell' lupins produce good quality forage across most of the growth period however changes in the proportion of plant components, their chemical composition and digestibility caused total herbage quality to decline with plant maturity.

To clarify the lack of knowledge surrounding sheep production on 'Russell' lupins, Black *et al.* (2014) compared the performance of Merino ewes and lambs grazing 10 ha of lupin pasture to a control flock fed predominantly lucerne over a 3 year period. Black *et al.* (2014) found at tailing in December, lambing percentage averaged 111 % for lupins and 105 % for the control flock. At this time the ewes averaged 58 kg and 62 kg for the lupins and control mobs respectively whereas the lambs averaged 19 kg under both treatments. At weaning in February lambs grazing on lupins averaged 28 kg whereas the control averaged 31 kg. For the ewes at this time the weights were 58 kg and 61 kg for the lupin and control respectively. Wool production in September was 4.62 kg/ewe for the lupins and 4.92 kg/ewe for the control. While Black *et al.* (2014) believed the data supported the potential for perennial lupins to be used in place of lucerne, the experiment was limited by on farm conditions. In particular, with limited information on the amount and nutritive value of the forages offered to the lupin and control flocks meant Black *et al.* (2014) had limited ability to explain the differences in sheep performance. They believed the reason ewes on lupins lost weight during lambing and did not gain as much weight leading into autumn was due to the lack of lupin leaf material but there was no data on grazing preference to explain this.

In recent years there has been a strong push to evaluate the potential of lupins as a high country forage when sown in conjunction with cocksfoot (*Dactylis glomerata*). Cocksfoot is a highly regarded grass species for being persistent and productive during dry summers and with low soil fertility (Black *et al.* 2015). With this and the limitations of Black *et al.* (2014) in mind a controlled experiment was established at Lincoln University in December 2013 to compare sheep production from cocksfoot-lupin and lucerne pastures. These pastures were grazed by Merino hoggets in autumn 2014 and by Coopworth sheep in the following year between August 2014 and May 2015.

The objective of this honours study was to evaluate the feeding value of cocksfoot-lupin pastures relative to lucerne for sheep under dryland conditions. This dissertation builds on the previous analysis of the first autumn's data from this experiment (Hight 2014) and reports the results from the first complete grazing season after establishment (2014-2015). Pasture production was quantified as the accumulation of live-weight gain per hectare which is a function of the average daily live-weight gain and stocking rate of the Coopworth sheep. Sward data measurements of herbage mass, botanical composition and nutritive value were used to help explain any differences in animal production between the two pastures.

Plate 1.1 Coopworth lambs grazing cocksfoot-lupin pasture, 1 March 2015 at Lincoln University, Canterbury

2 Literature review

The objective of this section was to review the published scientific literature which has evaluated the suitability of perennial lupin as an alternative forage for sheep production in New Zealand. This review assessed the ability of lupin to survive the conditions imposed by the high country environment compared to other legumes and compare the nutritional value of lupin to lucerne. The literature on current lupin grazing management and grazing studies were reviewed.

2.1 Persistence of legumes in the high country

Traditionally in high country areas pasture improvement has been based on over-sowing or over-drilling with white (*Trifolium repens*), red or alsike clovers and cocksfoot. However these clovers are often intolerant to drought and low soil fertility (Woodman *et al.* 1996).

Lupins were noted as being the dominant legume of an experiment by Woodman *et al.* (1996) at Omarama Station, Otago in regards to survival, distribution and reseeding. The Woodman *et al.* (1996) experiment involved lupin, red clover, lucerne and four birdsfoot trefoil (*Lotus corniculatus*) cultivars (cv. 'Goldie', 'Dryland', 'Granger' and 'Empire'). At the end of the 9 year experiment the lupin and 'Goldie' birdsfoot trefoil showed the greatest persistence. A few yellowed, spindly lucerne plants survived and no red clover survived. (Figure 2.1). The lupins developed healthy stands and spread across the landscape whereas the survival of birdsfoot trefoil and lucerne was limited to old stream channels which provided more favourable soil conditions (Woodman *et al.* 1996).

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Figure 2.1 Sown legume plant numbers (/m^2) for the period 1989-1995 at Omarama Station, Otago, New Zealand (Woodman et al. 1996).

The reseeding of lupins in the Woodman *et al.* (1996) experiment was more successful than birdsfoot trefoil which aided the longevity of the pasture (Table 2.1). In many years there was no reseeding of birdsfoot trefoil and in 1995 and 1996 no birdsfoot trefoil seedlings survived. Birdsfoot trefoil requires a full 16 hr photoperiod in order to flower. Due to the latitudes of the southern Mackenzie Basin, Otago-Canterbury, New Zealand (44° S) this could not occur until late December or January. Other indeterminate flowering occurred throughout summer. Once the seeding occurs a further 30-34 days is required in order to achieve satisfactory seed viability. The soil moisture deficits which often occur from November onwards restrain the likelihood of a successful reproductive sequence and explains the poor performance observed. In comparison to birdsfoot trefoil, lupins have a shorter photoperiod requirement to reach full flowering. In the Mackenzie Basin, lupin flowering can start in early to mid-November and finish in late November to early December when subsoil moisture is adequate. Lupin in the Mackenzie Basin can also germinate earlier than other legume species with germination and emergence occurring in late winter-early spring. Germination of lupin can occur at temperatures cooler than 5°C. Lupins can rapidly establish due to its large seed of 30 g/1000 seed (Ryan-Salter *et al.* 2012) which allows for a greater supply of seed reserves (Woodman *et al.* 1996).

Table 2.1 Re-seeded seedling numbers (/m^2) of 'Goldie', 'Dryland', 'Granger', 'Empire' birdsfoot trefoils, and perennial lupin from 1993-1996 at Omarama Station, Otago, New Zealand (Woodman *et al.* 1996).

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Scott (2008) reported the results of two 26 year grazing experiments which involved the sowing of 25 different species (11 legumes, 13 grasses and one herb) under 35 different rates of P and S fertilisers, under three sheep stocking rates and two grazing methods at Mt John, Lake Tekapo. Irrigation was supplied to the high fertiliser (500 kg/ha of superphosphate) treatment only. The pastures were established in spring 1982 by over drilling into mouse-ear hawkweed (*Heiracium pilosella*) - fescue tussock (*Festuca novae-zelandiae*) grassland. Alsike clover and white clover was dominant in the first period (2-4 years) of the experiment when provided with the high fertilisers and irrigation treatments. Lupins were dominant under the moderate fertiliser and grazing treatments. Lupins were increasingly dominant at the lowest fertiliser application treatments. Several plots remained lupin dominant after 21-24 years (Table 2.2, Figure 2.2).

Table 2.2 Change 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 (*Festuca rubra* subsp. *commutate*), D = cocksfoot, H = Hieracium, K = Caucasian clover (Trifolium ambiguum), L = lupin, o = tall oat grass (*Arrhenatherum elatius*), W = white clover, and Z = fescue tussock from 1982 – 2007 at Mt. John, Lake Tekapo, New Zeeland (Scott 2008).

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Figure 2.2 Changes in relative ranking of species over 19 years (1983-2000) of lupin, lotus, caucasian clover, cocksfoot and fescue tussock at Mt. John, Lake Tekapo, New Zeeland. Left-hand vertical scale mean ranking contribution of species to pasture bulk. Right-hand scale estimated percentage contribution to pasture bulk (Scott 2001).

Lupin has also been a highly regarded legume for low soil fertility in several other papers (Fitzgerald 1981; Hampton *et al.* 1990; Scott 1989; Wills *et al.* 2003). Scott *et al.* (1985) described lupin as being suitable for areas with moderate temperatures and altitudes. Lupin has a moderate tolerance to short term water stress and a medium tolerance to long term moisture stress however no ranges have ever been quantified. Lupins have a moderate suitability for low fertility soils and therefore is most suitable to sites with a moderate soil fertility (Figure 2.3). This paper, in contrast to others, regarded the 'Russell' lupin to have poor suitability to wet, acidic and infertile soils. In comparison, Scott *et al.* (1985) summarised lucerne as best suited for moderate to high temperatures and low to moderate altitudes with sunny faces, but again the ranges were not quantified to support these claims. Lucerne has a high tolerance to drought and prolonged periods of moisture stress and has a low to medium adaption to moderate soil fertility. Lucerne is poorly to moderately suitable to soils which are wet, acidic or infertile.

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Figure 2.3 The most suitable role of some pasture legumes in relation to the environmental factors of temperature, soil moisture and soil fertility. Names of species more suited to lax grazing are given in capital letters whereas lowercase denotes species more suitable to intensive grazing. Arrows indicate the conditions in which some species become more suitable (Scott *et al.* 1985).

2.2 Soil fertility and soil conditions for ''Russell'' lupins

Lupin is very tolerant to soils which would be considered unsuitable to most other plants. Despite their tolerance to acidic soil conditions, Kitessa (1992) reported that in early experiments in the 1930s lupin would not persist in heavy wet Southland soils, or the pumice soils of the central North Island. Lupin prefers rocky, sandy, or loose textured soils of low to moderate soil fertility and moderate moisture levels (Scott 1989). While lupin was reported to be tolerant and suited to acidic conditions (pH 5-5.5)

(Kitessa 1992; Scott 1989, 2008), no papers have tested where the low pH limit is. Studies on lupin have used pH values shown on Table 2.3, all of which but one shows lupin sown in low pH conditions

Table 2.3 Soil pH and concentrations of soluble aluminium in field and pot studies involving lupin.

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Davis (1981) in a pot experiment found when the soil exchangeable Al was 3-3.5 milliequivalents (m.e) lupin had the lowest concentration of Al in the roots which indicated that lupins are more tolerant of soil aluminium than white clover, *L. pedunculatus x L. corniculatus* and lotus (Table 2.4). Soil exchangeable Al higher that 1.0 m.e can cause toxicity in some plants (Davis 1981). Plant uptake of Al was also increased by low P.

Table 2.4 Shoot aluminium concentrations in white clover, lupin, *L. pedunculatus x L. corniculatus* and lotus. Letters denote Duncan's test significance (Davis 1981).

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White *et al.* (1995) demonstrated that 'Russell' lupin cannot be grown successfully in soils deficient in S without S fertiliser application at Mesopotamia Station, Canterbury. In their experiment the soil had a sulphate concentration of 2 ppm and an Olsen P of 6. By applying 40 kg S/ha in the form of sulphate at sowing (September 10, 1990) and an additional 20 kg S/ha in the form of gypsum on 2 October 1991 the yield of lupin after 2 years was increased from two DM score points to five to seven DM score points when comparing the 50 kg P/ha treatments (Figure 2.4). White *et al.* (1995) scored as follows: 1-very small red/yellow seedlings 30-40 mm high, 2-larger seedlings still chlorotic, up to 150mm high, 3- not specified, 4- green lupins low mass 700 kg DM/ha, 5- not specified, 6-2100 kg DM/ha, 7- not specified, 8-3500 kg DM/ha.

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Figure 2.4 Phosphorus and sulphur increases dry matter scores of lupin in the second growing season, December 1991, Mesopotamia Station, Canterbury. Circles = Triple phosphate (21% P); Squares = Carolina rock phosphate (13% P); solid symbols = +S (60 kg S/ha); open symbols =-S (White *et al.* 1995).

Scott (2008) reported lupin as the most efficient user of fertiliser in terms of fertiliser and sheep production costs and returns. 50 kg/ha/yr of elemental S was deemed to be the most efficient application in terms of 'dollars returned from dollars spent' in regards to grazing capacity gained as a result of fertiliser input.

Davis (1991) found that in Pukaki silt loam with a Olsen P of 5 mg/kg, 'Russell' lupin yielded significantly greater than white clover and birdsfoot trefoil with a P input of only 6.25 kg P/ha (Figure 2.5). However as P application increased up to 800 kg P/ha the yield of lupin decreased possibly due to increasing competition from resident clovers and grasses which were stunted when P inputs were low. Lupin benefit from S imputs, while the soil S levels were not reported S was applied in the superphosphate application and the 125 kg/ha of magnesium sulphate application after drilling. This may have stimulated the growth of lupin to produce greater yields than the white clover or birdsfoot trefoil.

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Figure 2.5 The effect of phosphorus on the yield of three legume species: white clover, lotus and lupin in a Pukaki silt loam soil at Hakatere, Canterbury in January 1984. Total yield included sown legume, grasses and weeds. The letters above each column indicate significant differences ($P<0.05$) by Duncan's range test. (Davis 1991).

Davis (1991) concluded the results suggested that lupin was capable of extracting P from the soil which other species were unable to access. Three factors were purposed which may have helped lupin extract P not available to other plants:

1. The geometry and extension of the roots – The long and wide roots of lupin give the plant the ability to explore the soil with greater efficiency (Borie 1994). Hill and Miller (1994) also reported the high root DM of lupins allows improved soil exploration for nutrient uptake by increasing the rhizosphere volume compared to *L. pedunculatus*.
2. Enhancement of acid and chelating substances excreted by the roots and enhancement of extracellular root P activity – This is related to root phosphatase excretion. Root phosphatase is important in the mineral nutrition of plants. It can hydrolyse some forms of organic P present in the soil solution or organic phosphates close to the roots. Lupin may be able to enhance P uptake by acidifying the rhizosphere through the excretion of H^+ and/or releasing chelating substances. The organic exudates can solubilise otherwise insoluble phosphate compounds (Borie 1994). Lupin roots have a high root cation exchange capacity which gives the plant the ability to extract P from sparingly

soluble fertilisers such as phosphate rock more effectively than other plants such as *L. pedunculatus*. (Hill & Miller 1994).

3. Root associations with free living or symbiotic microorganisms – To aid P availability and uptake an association would have to form with a microorganism involved in the P cycle. In the rhizosphere surrounding most plants there is a large number of fungi and bacteria strains with the ability to solubilises or mineralise insoluble P (Borie 1994).

Davis (1991) also found that nitrate and total mineralisable N levels were higher in the soil under 'Russell' lupins than under white clover or birdsfoot trefoil at the nil and low P application rates. This suggests increased rates of N fixation was occurring. The addition of P increased the soil nitrate and total mineralisable N under white clover and birdsfoot trefoil but not under the lupin.

2.3 Morphology of perennial lupin

L. polyphyllus, like lucerne, is a legume with a tap root system. Stems of lupin are erect and can grow 50-150 cm in height (Lambrechtsen 1986). The leaves of lupin are clearly distinguishable. The stalked palmate leaves feature 9-13 leaflets 4-10 x 1-1.25cm in size (Plate 2.1) (Lambrechtsen 1986). Generally the upper side of the leaf is hairless, however the underside of the leaf ranges from sparsely to densely hairy (Lambrechtsen 1986). Racemes, 15-40 cm long and bluish to purple in colour, develop sparsely hairy dark pods. These pods are 2.5-4 cm long containing 5-9 dark grey to brown spotted seeds (Lambrechtsen 1986). Lupin dies back each year allowing it to survive winter frosts (Horn & Hill 1985). The flowering of 'Russell' lupins is indeterminate. It is not considered to be affected by day length or vernalisation however this has not been tested. The current hypothesis is that lupin will flower under any conditions good for growth. Typically flowering occurs in November or December but could occur in any season (Ryan-Salter *et al.* 2012).

Plate 2.1 Lupin has palmated leaves featuring 9-13 leaflets 4-10 x 1-1.25cm in size. 26 March 2015, Lincoln University, Lincoln.

2.4 Sheep performance when fed perennial lupin

Scott *et al.* (1994) set stocked Merino wethers (6-22 sheep/ha) on 500 m^2 plots sown in either 'Grasslands Pawera' red clover, alsike clover or perennial lupin from November to April each year for 5 years. The experimental animals were weighed monthly over the grazing period after overnight fasting. The stocking rate of each plot was based on the total amount of feed which could be offered to achieve similar allowances. For the first 2 years the sheep were re-randomised on to new plots at weighing but for the next 3 years the sheep were restricted to particular species treatments and re-randomised to another plot of same species at each monthly weighing. The mean sheep live weight gain increased from 29 kg to 40 kg by the end of the grazing period. However there was high variability in the live weight gain data caused by the variation in forage growth both within and between years. Of any period, the summer growth caused the most variation. Scott *et al.* (1994) found the highest animal growth rates occurred in the late spring and tapered off through the summer and autumn (Figure 2.6). When all monthly measurements where combined the un-weighed mean daily weight gains were 58 g/day on perennial lupin, 77 g/day on alsike clover and 110 g/day on red clover (LSD 5% = 10.4 g/day). Therefore the growth rate of lambs on lupin and alsike clover was 53% and 70% of that of red clover repetitively, Scott *et al.* (1994) believed the results of the experiment supported their view of perennial lupin as a superior high country forage in regard to growth and feed on offer in low fertility soils but there was a downside in the lower sheep growth rate. However, an established lupin field would have a large carrying capacity (Scott *et al.* 1994), but no reference was given to what is a 'large' carrying capacity. In the first 3 years, red clover grazing resulted in the highest gain/ha but was overtaken by lupins in the last two years due to the increasing stocking rate on the lupin pastures as the experiment progressed.

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Figure 2.6 Daily live weight gain (g/day) of young Merino wethers set stocked on perennial lupin, red clover and alsike clover. Means of 5 years (1989-1994) at Mt John, Lake Tekapo. Least significant difference assumes independence of measurement in each period (Scott *et al.* 1994).

Sheep performance on perennial lupin over a three year period at Sawdon Station, Lake Tekapo was also investigated by Black *et al.* (2014). At this experiment, lupin was sown in a mix with oats (*Avena sativa*), barley (*Hordeum vulgare* L.), Italian ryegrass (*Lolium multiflorum*) and white clover. In December 2011, 143 two tooth Merino ewes and their 114 lambs were introduced onto the lupin plots. They were rotationally grazed around five plots shifted every 2 weeks. A second group of two-tooth's (800-900) with their lambs rotationally grazed lucerne and sometimes clover based pasture as a control nearby. On 10 February 2012, at weaning, the stock were taken off the lupin to allow a recovery period. 120 ewes grazed lupin again 6 weeks later (March 10, 2012). This grazing period was to determine if the lupin were able to be used for flushing and mating. This group was moved between plots every two weeks as before. The lupin pastutes were destocked on June 20. Black *et al.* (2014) found that at weaning 2012 the 114 lambs on the lupin pasture had an average weight of 28 kg. This meant that the lambs had grown 150 g/day since tailing. The lambs in the control mob averaged 31 kg which translated to a growth rate of 217 g/day. Black *et al.* (2014) found the lupin fed ewes lost 3 kg on average over the two month summer period whereas the control ewes gained 5kg (Figure 2.7) The loss in ewe live weight over the lambing/lactation period was predicted to be due to the lack of leaf material at that time or could have been due to stocking rate, feed allowance and grazing preference. During the autumn period (March, 23-May, 18) the lupin feed ewes gained 7 kg at 125 g/day whereas the control mob gained 9 kg at 161 g/day.

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Figure 2.7 Live weight changes of Merino ewes and lambs grazing on perennial lupins compared with lucerne and clover-based pastures (control) from October 2011 to August 2014 at Sawdon Station, Lake Tekapo. Maximum standard errors of means are given (Black et al. 2014).

The lambing percentage of the lupin fed ewes was higher than that of the control mob with 103% and 93% respectfully in 2012. Lamb weight averaged 20 kg on lupins and 21 kg on the control pasture at tailing (Figure 2.7). The ewes on the lupin pasture lost 8 kg over lambing whereas the lucerne fed ewes lost 2 kg. At weaning the 128 lupin fed lambs averaged 28 kg with a mean growth rate of 121 g/day, the control lambs averaged 31 kg with a mean growth rate of 151 g/day. The lupin fed ewes held their weight over the summer period whereas the control ewes gained 2 kg. The lupin ewes gained 2.6 kg (64 g/day) compared to 4.9 kg (120 g/day) for the control between 11 April, and 26 May 2013.

At tailing in 2013, the lambing percentage for both treatments had increased to 120% and 117% for lupins and the control respectively. The average weight of the lupin lambs was 19 kg and 17 kg for the control lambs. During the lambing period the lupin fed ewes lost 4.3 kg, however the control ewes had gained 4 kg. The weaning weight of the lambs was 30 kg for both treatments. The live weight gain from tailing was 166 g/day and 194 g/day for lupins and the control mob respectively. The lupin ewes had gained 1.3kg whereas the control ewes lost 3.6 kg. Over the autumn period (24 April to 19 May 2013), the lupin ewes gained 1.7 kg (63 g/day) and the control ewes gained 2.6 kg (96 g/day).

At shearing on 19 September 2013 the fleece weight of the ewes, which had for the previous two seasons grazed lupin, was lower than that of the control ewes. The average weight was 4.64 kg and 4.92 kg for the lupin and control ewes respectfully. The staple length and the mean fibre diameter were found to be statistically similar (Table 2.5).

Table 2.5 Wool characteristics at shearing in September, 2013, of ewes that had been grazing on perennial lupin 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).

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Black et al. (2014) concluded that Merinos will perform on lupin almost as well as on lucerne and other improved pastures. The nature of the on-farm experiment was reported to have limitations such as the little information regarding pastures offered to the control flock resulting in little ability to compare the lupin flock to the control flock and explain any differences in performance. However Black *et al.* (2014) showed lupins to be a successful lambing forage which also had the added advantage provided shelter for new-born lambs.

2.5 Nutritional value of perennial lupin

Kitessa (1992) quantified dry matter digestibility (DMD) of lupin components throughout the season at Lincoln University, Canterbury. By using the organic matter data from Kitessa (1992) and the formula in section 3.6.5 this was converted to metabolisable energy (ME). The ME of the lupin leaf material was consistent throughout the summer whereas the ME declined in the stem, leaf and pod components. The ME of the dead material was inconsistent throughout the period ranging from 2.6-7.5 MJ /kg DM (Table 2.6). The ME of the stem and petiole components decreased quickly falling from 13.2 and 10.1 MJ /kg DM at 5 October 1989 to 3.8 and 5.8 MJ /kg DM at 18 January 1990 for the two components respectfully. Plant breeding and grazing technique should aim to maximise leaf material which had a ME ranging from 12.2-12.8 MJ /kg DM over the same period. Brown *et al.* (2005) reported lucerne leaf ME around 11 MJ /kg DM indicating lupin leaf would provide high quality forage for sheep.

Table 2.6 Within-harvest comparison of the mean metabolisable energy (ME) content (MJ /kg DM) of different plant parts of ''Russell'' lupin at various growth stages from the 5th of October 1989 to 18th of January 1990 at Lincoln University, Canterbury (Kitessa 1992).

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Kitessa (1992) showed that as the lupins matured the N content of the whole plant decreased falling from 4.2% to 2.4 % N (Figure 2.8). There were two periods in which the significant reductions in N concentration occurred: in the 3 weeks before flowering, which began in October and three weeks before the last sampling at the dry pod stage which was reached on 18 January 1990. The greatest reduction in N concentration occurred during the first three weeks of sampling representing about 73% of the total decrease in N concentration. However even at the lowest plant concentration of N the lupin DM still contained 15% crude protein (CP). N content was highest in the leaves, pods stems and showed a linear decline over time whereas the N% of the petiole showed a quadratic decline. No quantification was given on the N concentration of the individual lupin components.

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Figure 2.8 Variation in the nitrogen % in the dry matter of 'Russell' lupin harvested at different growth stages (1989-90) at Lincoln University Canterbury (Kitessa 1992).

Kitessa (1992) found the neutral detergent (NDF) fibre concentration of all the whole plant increased over time in a linear fashion in all plant parts at 0.21% /day reaching 46% at the final cut, although the rate of change was varied between the plant components. The rate of NDF increase in the stems and pods was twice that of the whole plant rate. The lowest NDF plant components were the leaves followed by the flowers. In these components the NDF increased by less than 5% over the experimental period.

Black *et al.* (2014), like Kitessa (1992), found N content was highest in the leaves, flowers and pods and lowest in the stems and petioles. Over the season leaf N decreased from 5.4% to 3.8%, petiole N decreased from 3.1% to 1.5%, stem N was reduced 4.3% to a minimum of 0.7% and then increased to 1.8% and the N content of the dead material ranged from 0.6 to 1.7% (Figure 2.9). Bailey *et al.* (1970) reported in comparison that lucerne leaves had a 3-5% N content and the stems contained 1.5-4% N.

The DMD of the leaves, petioles and stems was over 80% in October. The leaf DMD stayed over 80% for the remainder of the season whereas the DMD of all other components decreased in accordance with Kitessa (1992). Terry and Tilley (1964) reported lucerne leaf DMD ranged from 81-83% over April to June 1957 in England indicating lupin leaf is comparable to lucerne.

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Figure 2.9 Nitrogen concentrations of perennial lupin from October 2012 to June 2013 at Sawdon Station, Lake Tekapo. Error bars indicate the standard errors of means (Black *et al.* 2014).

Data on the nutritional information on lupin is limited to the two studies discussed warranting further study into the nutritional value of lupin. However the comparable nutritive value to lucerne suggest lupin show potential as a livestock forage.

2.6 Lupin alkaloids

All lupin plant components are grazed in spring, but as summer draws closer preference to the leaves is reduced. Lupin leaves are not particularly palatable during the summer due to the bitter alkaloids produced so the young buds are often the first part to be grazed at this time (Scott 1989). It is possible to breed lupin plants with reduced alkaloid content, but this may make the plants more susceptible to insect attack (Gladstones 1970). Stock refusing to graze lupin due to the alkaloid content could place pressure on other species in the sward and may increase the dominance of the lupins. All plant parts are palatable to sheep again in the winter (Scott 1989). However Kitessa (1992) found that at the full bloom stage (27 November – 3 December 1990) sheep grazed all lupin components with an apparent initial preference for the leaves, however the sheep did not graze the lupin straight away (Figure 2.10).

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Figure 2.10 The pattern of disappearance of lupin plant components over successive days of grazing by sheep at full bloom stage (27 November - 3 December 1990) in 1990 at Lincoln University, Canterbury (Kitessa 1992).

Overseas reports suggest poisoning and death of livestock grazing on perennial lupin due to alkaloids, however as of 1989 this had not yet been reported in New Zealand (Scott 1989). This may be due to the alkaloid profile being different for New Zealand perennial lupin (A.D. Black, personal communication, 10 November 2015). Unlike red clover (another commonly sown legume species) lupin contain no phytoestrogens (Sirtori *et al.* 2005).

2.7 Sheep acceptance of perennial lupin

Kitessa (1992) found when grazing of lupin occurred at the full bloom stage (27 November – 3 December 1990) sheep initially would eat the weeds growing between and within lupin rows. As a result defoliation of lupin was very slow but increased to a rapid removal rate. The rate of removal followed a highly significant ($P<0.001$) quadratic relationship over time spent grazing (Figure 2.11). After 6 days of grazing, Kitessa (1992) found 89% of the lupin DM on offer had disappeared with a very low residual of 250 kg/ha remaining. The leaves were the first component to be grazed by the sheep as they disappeared faster and earlier than any of the other lupin components (Figure 2.10). The sheep began to consume the lupin petiole after day 2. There was no decline in the quantity of the stem and flowers until after four days of grazing. The proportion of the plant parts in the DM residual was reported to clearly show the preference of sheep to the leaf material.

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Figure 2.11 The disappearance of lupin foliage over successive days of grazing by sheep at the full bloom stage (27 November – 3 December 1990) at Lincoln University, Canterbury (Kitessa 1992).

At the green pod stage (17 – 24 December 1990), Kitessa (1992) reported that all lupin plants had produced pods on the main stems but there was still some flowers present. Like at full bloom, the sheep removed all of the weeds in the first few days and then began to graze the lupin. Sheep which had already grazed lupin showed a greater preference to lupin than those that had never eaten lupin however the difference was not significant. With successive grazing at the green pod stage there was a rapid linear reduction in the quantity of residual DM. Sheep removed about 5.8 g DM/plant/day (Figure 2.12A). The rate of DM disappearance was significantly faster at the green pod stage than at the full bloom stage ($P<0.01$). The leaves were the first component to disappear which occurred rapidly and before any other plant component (Figure 2.12B). All plant components other than the stems showed decline after the second day of grazing whereas the stems did not decline until after 4 days.

By this stage almost all of the other components had disappeared. It was estimated that by the end of the grazing period 80% of the lupin DM on offer had disappeared.

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Figure 2.12 The disappearance of lupin plants (A) and components (B) over successive days of grazing by sheep at the green pod stage (17 – 24 December 1990), at Lincoln University, Canterbury (Kitessa 1992)

By the dry pod stage (21 – 26 January 1991) some of the pods had already shattered (Kitessa 1992). At this stage sheep which were accustomed and unaccustomed to lupin did not consume significantly different lupin intakes. At this stage, there was a linear decline in DM across the grazing period (Figure 2.13A). When grazing had completed, 75% of the DM on offer had disappeared. At this stage most of the material on offer was pods (Figure 2.13B). All plant parts were rapidly removed except the stems. There was a significant consumption of pods which decreased from 32 g/plant to 5 g/plant over the grazing period. Unlike at the full bloom and green pod stages, at the dry pod stage, the lupin leaves were not the major contributor to the disappeared DM. The pods made up 50% of the disappeared DM.

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Figure 2.13 The disappearance of lupin plants (A) and components (B) over successive days of grazing by sheep at the dry pod stage (21 – 26 January 1991) at Lincoln University, Canterbury (Kitessa 1992)

2.8 Lupin pasture composition

Black *et al.* (2014) reported in October 2012, the herbage mass on offer consisted of 41% leaf and petiole, 1% stem, 51% dead material (the majority of which was dead stem from the previous year) and 7% other species. By December 2012, the composition of the herbage mass had changed to 42% leaf and petiole, 35% stem, 7% lupin flower, 8% dead material and 9% other species (Figure 2.14). In February 2013, the composition had changed to 24% leaf and petiole, 36% stem, 1% flower, 10% dead material and 29% other species. At the start of the new season in September 2013, the herbage on offer consisted of 40 % leaf and petiole, 58% dead stem material and 2% other species. By December 2013 this had changed to 37% leaf and petiole, 35% stem, 12% flower, 13% dead material and 3% other species. The composition continued to change, by April 2014 the sward consisted of 37% leaf and petiole, 35% stem, 1% green stem and 73% dead material (Figure 2.14).

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Figure 2.14 Seasonal pattern of standing biomass and composition of a perennial lupin stand grazed by Merinos from October 2012 to May 2014 at Sawdon Station, Lake Tekapo. Error bars are standard errors of means for total herbage mass (Black *et al*. 2014).

Kitessa (1992) found the distribution of plant parts varied in there yield and proportion as did Black *et al.* (2014) (Figure 2.15). The DM of the stems increased from 0.5 g/plant to 26 g/plant at the green pod stage (17 - 24 December 1990). Petiole and leaf material reached their maximum weight at the flowering stage (16 November 1989). Kitessa (1992) reported the contribution of flowers to the DM yield was negligible and at its highest point only represented 5 % of the total DM per plant. Maximum yield occurred at the dry pod stage (21 – 26 January 1991). This was when dead and pod material was at its greatest weight and 9 weeks later than the maximum leaf yield.

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Figure 2.15 The dry matter yield (g) of vegetative and reproductive parts of 'Russell' lupin harvested at different growth stages (1989-90) at Lincoln University, Canterbury (Kitessa 1992).

2.9 Complimentary species for perennial lupin

Lupin is a winter dormant plant. Previously it has not been recommended to sow lupin with any other species (Scott 1989). More recently experiments with lupin sown with cocksfoot have shown success. Moot and Pollock (2014) reported that the use of cocksfoot sown as a companion species for lupin worked effectively when sown at a rate of 2 kg/ha in the high country soils of Glenmore Station, Lake Tekapo. In this experiment the cocksfoot was shown to benefit from lime application but in each year of the experiment (2013 & 2014) cocksfoot still produced 20% of the total yield when lupins where sown at a rate of 8 kg/ha or less. The lupins where not affected by the application of lime therefore the use of lime would aid in maintaining the yield and quality of the companion species (Moot & Pollock 2014).

But why use cocksfoot? Scott (2011) assessed the effect of the biennial spelling of pastures at Mt. John, Lake Tekapo. Grass species used in this experiment were cocksfoot, tall fescue (*Schedonourus phoenix*), timothy (*Phleum pratense*), brown top (*Agrostis capillaris*), chewing fescue and phalaris (*Festuca arundinacea*). Cocksfoot was the dominant grass species. Cocksfoot was found to produce more pasture in the following year after early summer grazing. Cocksfoot pastures persisted the longest of any of the grass species. With periodic spelling cocksfoot grew more tussock like and the dead leaf bases gave greater protection to the growing points in subsequent grazing.

Fraser (1994) over a 5 year experiment at Lincoln found that cocksfoot did not decline in density as other pastures did even when moderate numbers of grass grub (*Costefytra zealandica*) where present. Cocksfoot at year 3 was the dominant pasture despite being sown at only 25% of the total seed mix.

Scott *et al.* (1985) compared grasses for their suitability in different environments. It was reported that cocksfoot was suited to regions with cool temperatures, high altitudes and southerly aspects. Cocksfoot has a moderate to high tolerance to moisture stress for both long and short periods. Cocksfoot has a moderate suitability for low fertility sites but is of greatest value in low to medium fertility sites (Figure 2.16).

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Figure 2.16 The most suitable role of some grass species in relation to the 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.* 1985).

Compared to 'Grasslands Apanui' and 'Saborato', 'Grasslands Kara' cocksfoot is significantly more productive in the spring, however in spring 'Grasslands Apanui' yield 380 kg DM more than 'Grasslands Kara' in Gore, Southland (Stevens *et al.* 1992). 'Grasslands Kara' cocksfoot is less susceptible to leaf rust (*Puccinia striifomis*) and stem rust (*P. graminis*) than other cocksfoot cultivars (Rumball 1982). Stevens *et al.* (1992) reported digestibility of 71.9%, 72.1% and 69.3% for Kara cocksfoot over spring summer and autumn respectfully. Over those seasons protein was 27.2%, 23.0% and 22.0%.

2.10 Grazing management of lupin

Scott (1989) reported that lupin should be left 1-2 years to establish or to a height of 30-40 cm. At Sawdon Station, Lake Tekapo, Black *et al.* (2014) allowed the lupin to flower and set seed before the first grazing in the first year. The long term vigour of legumes relies on good root development during establishment (Scott 1989). Lax grazing of lupin is preferred (Scott *et al.* 1985), but Black *et al.* (2014) successfully rotationally grazed lupin pastures. Scott (1989) reported that lupins can be grazed to ground level and recover, although the recovery period would be considerably longer (Scott 1989)

2.11 Regrowth of lupins after grazing

Kitessa (1992) reported autumn regrowth of 'Russell' lupin. When Coopworth sheep grazed a crop 'Russell' lupin at the full bloom stage (27 November – 3 December 1990, 265 days after sowing), the greatest amount of regrowth was observed (70 g DM/plant) (Figure 2.17). When grazed at the full bloom stage, the lupin was able to complete a second lifecycle reaching the dry pod stage again on 29 April 1991. The combined yield from the two harvests when grazed at the full bloom stage was 9.5 t DM/ha. When grazed at the green pod stage (17 – 24 December 1990, 285 days after sowing) lupins yielded a regrowth of 37.7 g DM/plant with a combined harvest yield of 8.6 t DM/ha. Lupins which were grazed at the dry pod stage (21 – 26 January 1991, 313 days after sowing) showed the least amount of regrowth where the DM yield increased by only 3.6 g DM/plant over three extra months. The total yield was 8.2 t DM/ha which wasn't much different to the plants grazed at the green pod stage. Of all of the growth stages at which the lupins were grazed the smallest residual was left when grazing occurred at full bloom. This means that time of grazing relative to reproductive maturity determines the degree of regrowth, not the residual remaining after grazing (Kitessa 1992). While total annual DM yield was greatest when the lupins were grazed at the dry pod stage (Table 2.7), grazing at full bloom will increase the scope in which 'Russell' lupins could be utilised in New Zealand as it would provide a second grazing or autumn feed for flushing ewes (Kitessa 1992).

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Figure 2.17 The amount of residual DM remaining for regrowth and the amount of regrowth obtained from perennial lupin grazed at three different growth stages (full bloom: 27 Nov -3 Dec 1990, green pod: 17 Dec -24 Dec 1990 and dry pod stage: 21 Jan -26 Jan 1991), 1990-1991 at Lincoln University, Canterbury (Kitessa 1992).

Table 2.7 Regrowth of 'Russell' lupin grazed at three growth stages and calculated total harvestable yield after grazing at one of three stages (full bloom: 27 Nov -3 Dec 1990, green pod: 17 Dec -24 Dec 1990 and dry pod stage: 21 Jan -26 Jan 1991) over 1990-1991, at Lincoln University, Canterbury (Kitessa 1992).

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2.12 Conclusions

To conclude, this literature review has shown:

- Lupin shows the ability to thrive in soils with low pH, low Olsen P, and high Al which are unsuitable for conventional species but benefit from applications of sulphur.
- Recent razing trials on suggest that lupin have potential as a high country forage. However detailed information on the livestock performance on lupin is lacking.
- The nutritional value of lupin is similar to that of lucerne indicating the potential of lupin as a forage from a nutritional perspective.
- Lupin alkaloids have not appeared to be responsible for any livestock deaths in New Zealand. A study has shown that sheep will still graze lupin over the summer despite reports of high alkaloid content in the leaves.
- The proportion of leaf and petiole does not change considerably over the growth season however dead material accumulates from summer into autumn.
- Animals appear to graze all components of the lupin with an apparent preference to the leaves.
- Cocksfoot shows good potential as a complement species for lupin due to its ability to produce quality forage in drought conditions. Its use as a complementing species for lupins has already been supported by one study.
- While in the past lax grazing of lupin has been recommended, more resent research suggests that lupins can by successfully rotationally grazed.
- Lupin have the greatest re-growth when grazed prior to reaching the dry pod stage.

3 Materials and methods

3.1 Site and preparation

This experiment was conducted at the Lincoln University Horticultural Research Area (Paddock H12, 90 x 174m, 43°38’53.788” S, 172°27’23.95” E, and 9 masl) on a Templeton slit loam soil. The climate can be described as temperate and sub humid, characterised by cool, moist winters and warm, dry summers. The prevailing wind is a cool sea breeze from the north east. The experimental field is exposed to cold, moist south westerly winds and warm, dry north west Föhn winds. Temperature and rainfall data at the Broadfields metrological station was collected monthly. The Broadfields meteorological station is about 2 km north of the experimental site (43°62' S, 172°47' E). The annual rainfall is 632 mm, average air temperature is 11.4 °C and annual average potential evapotranspiration (PET) is 1015.7 mm. Temperature and rainfall data specific to the experimental period is show on Table 3.1.

Table 3.1 Mean monthly air temperature and rainfall during the experimental period compared to long term means (LTM) from 1975 – 2014 at the Broadfields meteorological station, Canterbury, 2 km from the experimental site.

	Temperature (°C)	LTM temperature (°C)	Rainfall (mm)	LTM rainfall (mm)
Jul. 14	7	6.1	48	61
Aug. 14	7.5	7.5	14	65
Sep. 14	9.6	9.4	25	40
Oct. 14	11.5	11.3	20	53
Nov. 14	13.5	13	48	50
Dec. 14	15.2	15.1	22	53
Jan. 15	17.7	16.6	8	45
Feb. 15	16.2	16.2	19	42
Mar. 15	15.4	14.7	39	51
Apr. 15	13.2	12	79	51
May. 15	9.9	9.2	6	58
Jun.15	7.1	6.5	75	64
Jul. 15	6.5	6.1	37	61
Aug. 15	7	7.5	31	65
Average/Total	11.2	10.8	472	758

The field grew perennial ryegrass (*Lolium perenne*) and white clover for 4 years (2008-2012) for a grassland experiment previous to this experiment. The field was sown in forage oats in March 2013. The purpose of this treatment was to reduce the likelihood of previous experiments affecting future experiments. Balege was cut in October 2013 and was exported off the field. The remaining stubble was ploughed and cultivated into a seed bed in before starting this experiment.

3.2 Experimental design

The experimental site was subdivided into three blocks, 0.52 ha in size. Perennial lupin ('Blue' and 'Russell') and cocksfoot ('Kara') was randomly sown together in half of each of the blocks, the other half of each block was sown with lucerne ('Force 4') (Figure 3.1, Plate 3.1). Sowing occurred on 5 December 2013 into a cultivated seed bed. All six 0.26 ha plots were permanently fenced and supplied with stock water. Each plot was then divided further into five 'breaks' of equal size using temporary electric fences to allow rotational grazing within each plot.

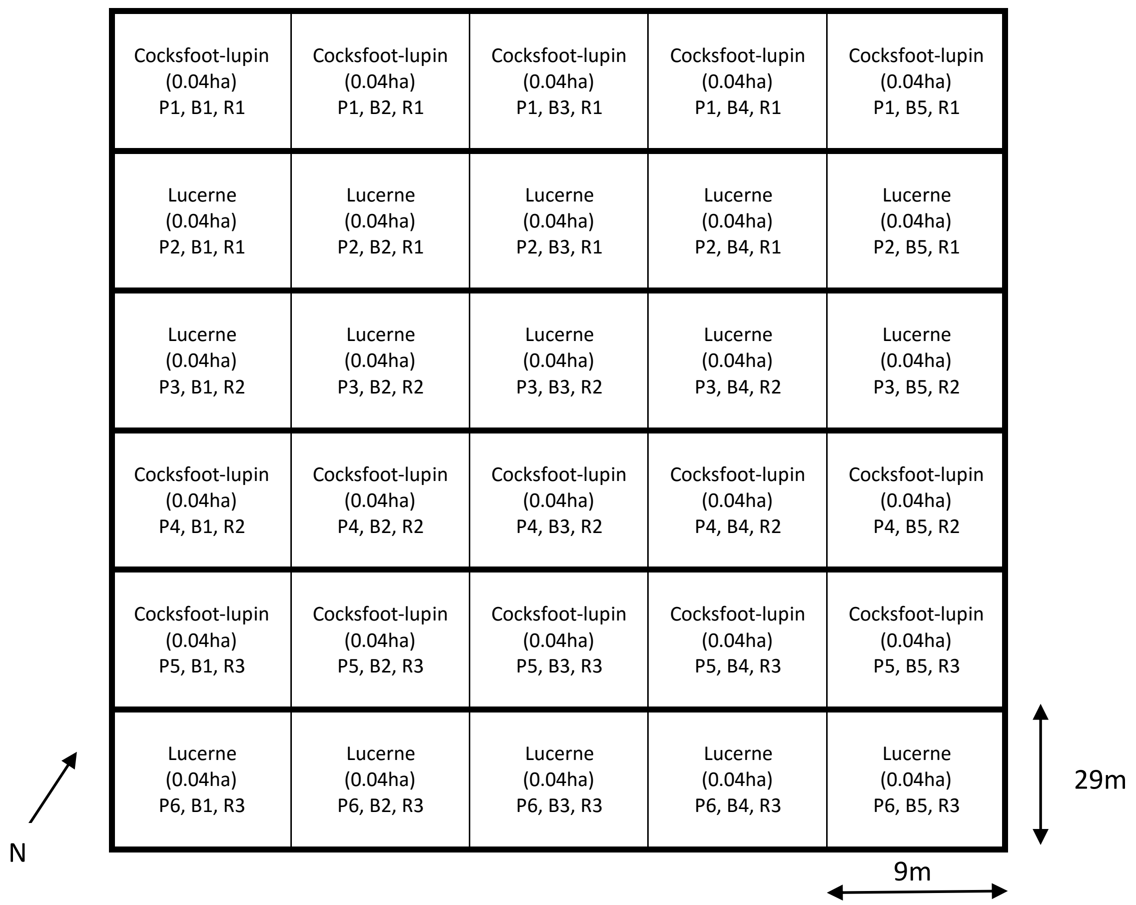

Figure 3.1 Lupin grazing experiment design at Lincoln University, Canterbury. 'P' represents the plot, 'B' represents the 'break' and 'R' represents the replicate.

Plate 3.1 Sheep grazing in ‘break 5’ at Lincoln University, Lincoln on 5 May 2015. Image taken from the north corner of the experimental site (plot 1, ‘break 5’) facing south. Note the fence with black warratahs separating the plots and the temporary fences with red standards separating the ‘breaks’.

3.3 Plant varieties

‘Force 4’ lucerne was bred in Europe and supplied by Seed Force Ltd, Christchurch. On the international winter dormancy scale of 1-10 (1 = highly winter dormant, 10 = highly winter active) ‘Force 4’ Lucerne scores a 4. Most of the New Zealand sown pastures rank 4-5. The seed was supplied inoculated with rhizobia .

The lupin seed was supplied by the commercial grower Rosevear & Co. Ltd, Ashburton. The two lupin varieties used were ‘blue’ and ‘Russell’. The ‘blue’ lupin is a perennial species and should not be confused with the annual blue lupin species (*L. angustifolius*). The ‘Russell’ lupin seed was likely to have come from the roadside populations of the hybrid of *L. polyphyllyus* and *L. arboreous* (Edward 2003). The day before sowing the lupin seed was inoculated with the recommended ‘Group G’ inoculant (Becker Underwood, Australia). This may not have been required as found recently by Ryan-Salter *et al.* (2014).

The cocksfoot, ‘Grasslands Kara’ was bred and supplied by Agricom. ‘Grasslands Kara’ is noted to have an upright growth habit, mid-season heading date and better winter growth and disease resistance compared to other cocksfoot cultivars.

3.4 Establishment

The pastures were sown using a Flexiseeder precision drill. The outside drill round sowed ‘‘Russell’ Lupin and the inner drill round sowed ‘Blue’ Lupin. The rows were spaced 150 mm apart. A sowing rate of 30 kg/ha was used for the lupin. The cocksfoot was sown with the lupin at 10 kg/ha. The lucerne was sown at 15kg/ha.

Adequate rainfall over the Christmas period meant that the use of irrigation was unnecessary but irrigation was used in January and February to help establish the pastures. No fertilisers were applied. In March the plots were individually fenced off. Each ‘break’ was fenced off with 3 electrified wires. Soil tests in March 2014 showed an Olsen P of 17 mg/L, sulphate sulphur of 1 mg/kg and pH 6 (Table 3.2).

Table 3.2 Soil test results for the experimental site at a depth of 0 - 7.5 cm on 14 March 2014, Lincoln University, Canterbury.

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

3.5 Animals and grazing management

In spring 2014, Coopworth hoggets were placed on the plots once the pasture cover reached 2000 kg DM/ha. For the cocksfoot-lupin plots this occurred on 5 August 2014 and for lucerne plots on 15 September 2014. The average weight of the animals when they were put on the pastures was 38.9 kg and 46.6 kg for cocksfoot-lupin and lucerne fed animals respectively. Based on the pasture growth rate and herbage mass several factors were adjusted such as the stocking rate, duration of grazing and the interval between the grazing of each break in the rotational system. All animals were shorn on 28 November 2014 and the initial hoggets were replaced by Coopworth lambs with an average live weight of 33.7 kg on 16 February 2015.

3.6 Measurements

3.6.1 Live-weight gain

Each time the stock were shifted into the next break in the grazing rotation (4-12 days) they were weighed. Live weight gain was calculated as the change in the mean live weight of two or three core animals (animals which never left or entered the experiment due to reduced or excess feed supply) in each group since the last shift multiplied by the stocking rate. The animals were weighed using a Pratley (Tumuka, New Zealand) weigh crate with Gallagher (Hamilton, New Zealand) scales.

3.6.2 Herbage mass

Herbage mass was measured in each break every 2 weeks during the winter period (1 July - 5 August 2015) and each time the sheep were shifted using an sward stick (Jenquip, Fielding, New Zealand). The sward stick was calibrated by cutting bulk 0.5 m^2 quadrat samples (cut at 1 cm above ground level) before being used to assess botanical composition during the grazing period. Quadrat cuts were made at the time of each break shift in the plot which had just been grazed (post-grazing) and the break about to be grazed (pre-grazing). One cut was made in each 'break' except for in 'break 2' where two quadrates where taken.

3.6.3 Botanical composition

Botanical composition was determined in each break prior to grazing and post-grazing. A subsample was removed from the fresh 0.5 m^2 quadrat sample, the components were separated and dried in a drying oven at 65°C for 48 hours and weighed to give an indication percentage of each component on offer. The cocksfoot-lupin pastures were separated into: legume leaf, legume petiole, legume flower, cocksfoot, weeds and dead material. The lucerne pasture was separated into: legume leaf, legume stem, legume flower, weeds and dead material. The leaf was not separated from the petiole in lucerne as it is small and assumed to be undistinguishable to grazing livestock. Weeds present were: white clover, perennial ryegrass, dock (*Rumex obtusifolius*), and fathen (*Chenopodium album*).

3.6.4 Apparent intake

Using the quadrat harvests pre and post grazing the apparent intake (kg DM/day) was calculated as the difference in the pre and post grazing mass divided by the stocking rate and the number of days the sheep had spent in the 'break'.

Apparent intake was assessed in greater detail when the stock grazed one of the five 'breaks' ('break 2') with quadrat harvests occurring every 2-3 days during the period the 'break' was grazed. These quadrats were separated to provide data to show apparent preference as well as intake.

3.6.5 Pre-grazing nutritional analysis

The herbage pre-grazing samples which were separated and dried from 'break 2' were retained for the purpose of conducting a nutritional analysis. Samples of like components were mixed into a bulk sample in order to have sufficient material for grinding. A mixed bulk sample was also measured with a representative proportion of all the plant components. The samples where ground using a Cyclone Mill with a 1 mm sieve and then further ground using a Retsch ZM 200 grinder (Haan, Germany) with a 1 mm sieve. The samples where then analysed using near inferred reflectance spectroscopy (NIRS) at the Riddols Analytical Laboratory at Lincoln University for protein content and DMD. ME was calculated using the formula:

$$\mathrm{MJ\ ME\ /kg\ DM} = \frac{((\mathrm{DMD\ \%} + 3)\times \mathrm{OM\ \%})}{100} \times 0.16$$

3.7 Statistical analysis

All statistical analyses were conducted using GenStat 16 Ed (VSN International, 2014). One way ANOVA was used to test for any significant differences between the cocksfoot-lupin and lucerne treatments. All figures were generated using the Sigma Plot 13 (Systat Software Inc, 2014) software package. To aid comparison the standard error of the means (SEM) has been added to each figure and standard error of difference (SED) to each table.

4 Results

4.1 Apparent intake

Over the spring period once the cocksfoot-lupin and lucerne grazing coincided (15 September - 28 November 2014), apparent feed intake was 2.36 kg DM/ head/ day and 1.61 kg DM/ head/ day for lucerne and cocksfoot-lupin fed sheep respectively ($P<0.001$). Apparent intake was significantly different ($P<0.05$) on 15 September 2014, 13 October 2014 and 10 November 2014 where apparent intakes were higher on lucerne pastures by 1.63, 1.08 and 1.52 kg DM/ head/ day respectively (Figure 4.1).

During the spring-summer period (28 November – 16 February 2015), apparent pasture intake on lucerne was 2.21 kg DM/head/day and 1.41 kg DM/head/day on cocksfoot-lupin pastures. The difference in apparent intake between the two pastures over the spring-summer period was significant ($P<0.001$). Apparent intakes were significantly different on 18 December 2014 and 19 January 2015 ($P<0.01$). Apparent intake at these times were 1.30 and 1.37 kg DM/head/day greater on lucerne pastures. There were negative values on 5 February 2015, perhaps due to the nature of quadrat method. With these removed apparent intake on cocksfoot-lupin pastures was 1.57 kg DM/head/day and 2.28 kg DM/head/day ($P<0.001$) for lucerne pastures over the spring summer period.

In the autumn, apparent intake on cocksfoot lupin pastures was 0.79 kg DM/head/day and on lucerne 0.90 kg DM/head/day, however the difference between these means was not significantly different ($P=0.722$). There was a significant difference in intake on 9 March 2015 ($P<0.05$) which was caused by all cocksfoot-lupin apparent intake values being negative, again this was possibly due to the nature of the quadrat method. By removing these and other negative values the average apparent intake on cocksfoot lupin pasture was 1.26 kg DM/head/day compared to 1.11 kg DM/head/day on lucerne. The difference between the pastures with negative values removed was not significant ($P=0.613$).

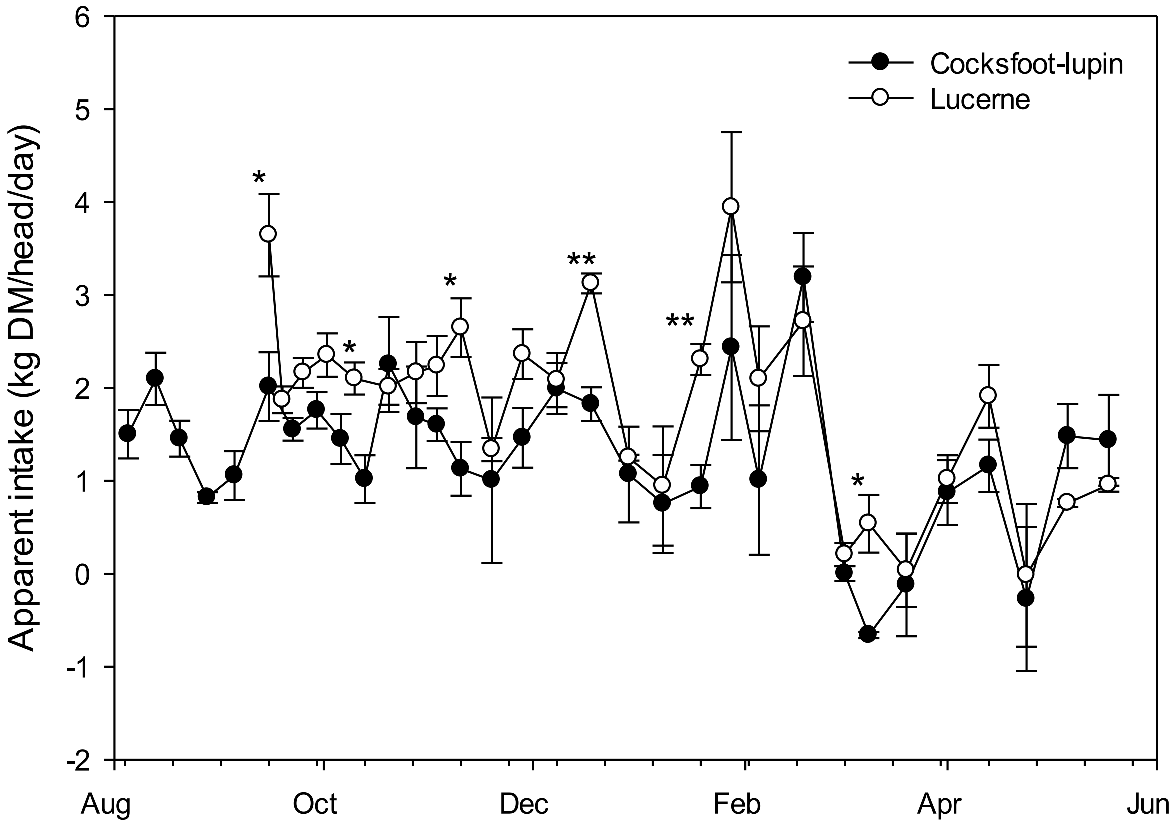

Figure 4.1 Apparent herbage intake of young growing sheep on cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 - 28 May 2015) at Lincoln University, Canterbury, New Zealand. Error bars indicate SEM. *P<0.05, **P<0.01, ***P<0.001, ns = not significant.

4.2 Live-weight gain

Grazing of the lucerne pastures began 41 days later than the cocksfoot-lupin pastures in spring. Live-weight gain per hectare increased linearly through the spring period when cocksfoot-lupin fed hoggets grew at 210 g/day and lucerne fed hoggets grew at 298 g/day (Figure 4.2). Over the spring period the cocksfoot-lupin fed hoggets gained 23.7 kg/animal and the lucerne fed hoggets gained 23.6 kg/animal. The difference in live-weight gain was not significant (P=0.921) but the lucerne feed animals grazed for 41 days less. When the cocksfoot-lupin and lucerne animals were both grazing their respective pastures during the same period (15 September - 28 November 2014) live-weight gain was 17.0 kg/animal on cocksfoot-lupin and 23.6 kg/animal on lucerne (P<0.01).

The same animals where used in the spring period as in the spring-summer period. During this period, hoggets grazing lucerne gained more weight (25.4 kg/animal) than the cocksfoot-lupin fed hoggets (14.5 kg/animal). The difference in live weight gain of 10.9 kg/animal was significant (P<0.001).

For the entire autumn period the cocksfoot-lupin fed lambs consistently gained weight at 140 g/day on average. Over the first half of the autumn period the cocksfoot-lupin lambs grew at a slower rate than those on lucerne which grew at 193 g/day. However after 57 days (16 April 2015) with an average live weight of 44.8 kg, live-weight gain on the lucerne pasture ceased. By the end of the autumn period the lambs fed cocksfoot-lupin pasture had put on more weight in total (14.1 kg) than the lucerne fed lambs (12.0 kg). The difference in live-weight gain was 2.1 kg at the end of the autumn period, however this difference was not significantly different (P=0.341).

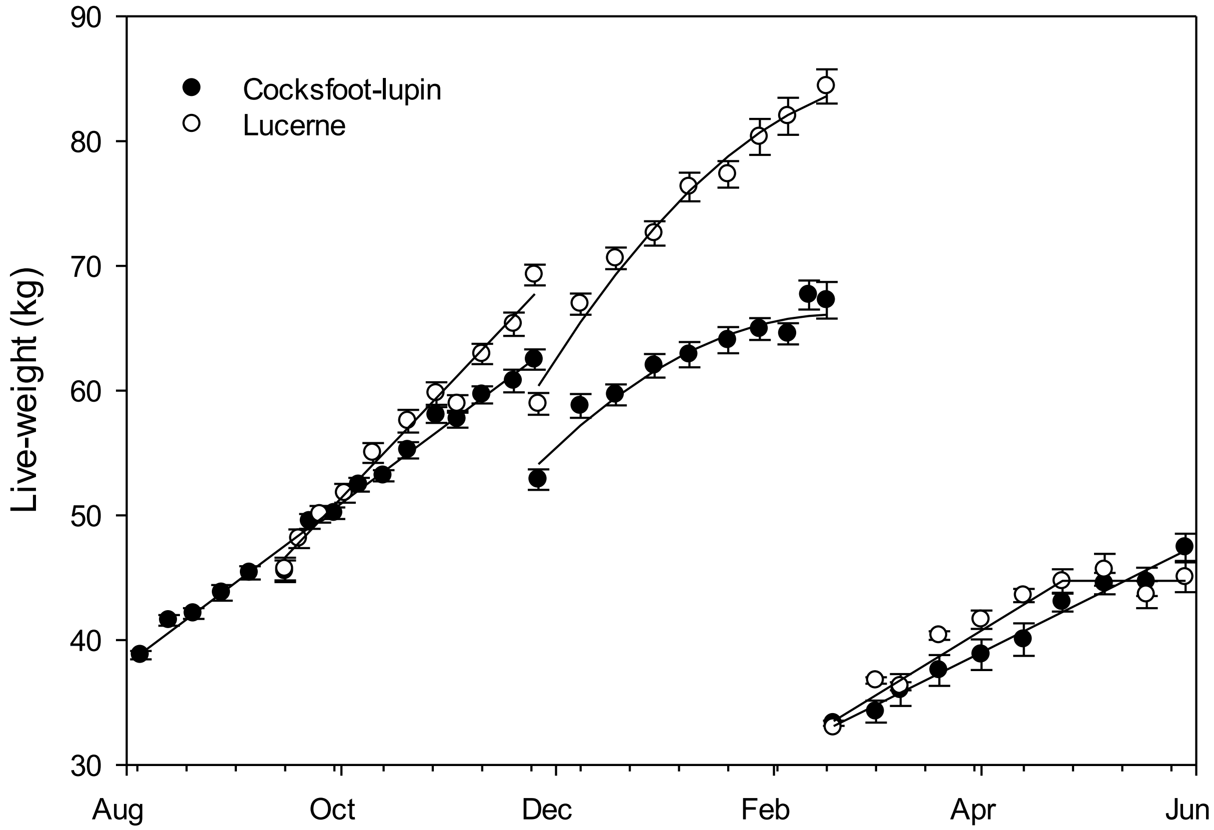

Figure 4.2 Seasonal changes in live weight gain of young growing sheep on cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury. Error bars indicate SEM.

The cumulative live-weight gain was higher on the cocksfoot-lupin pasture until 20 October 2014 where it was over taken by the lucerne pasture (Figure 4.3). The cumulative live-weight gain per hectare remained greatest on the lucerne pasture for the remainder of the experimental period. Total cumulative live-weight gain was 768 kg/ha and 1126 kg/ha for cocksfoot lupin and lucerne pastures respectively. In spring, accumulation of live-weight was 468 kg/ha and 614 kg/ha for cocksfoot-lupin and lucerne pastures. In the spring-summer period, accumulation of live-weight was 171 kg/ha and 381 kg/ha for cocksfoot-lupin and lucerne pastures. In autumn accumulation of live-weight was 129 kg/ha and 131 kg/ha for cocksfoot-lupin and lucerne pastures. At the end of the spring, spring-summer and autumn periods the difference in cumulative live-weight gain per hectare was 146 (P<0.001), 356 (P<0.001) and 358 (P<0.001) kg/ha higher on lucerne. While the lucerne feed animals gained the most weight across each period, the rate of live-weight gain was less consistent compared to the cocksfoot-lupin pastures (Figure 4.3). At the time of each weight measurement the cocksfoot-lupin fed animals showed less variation.

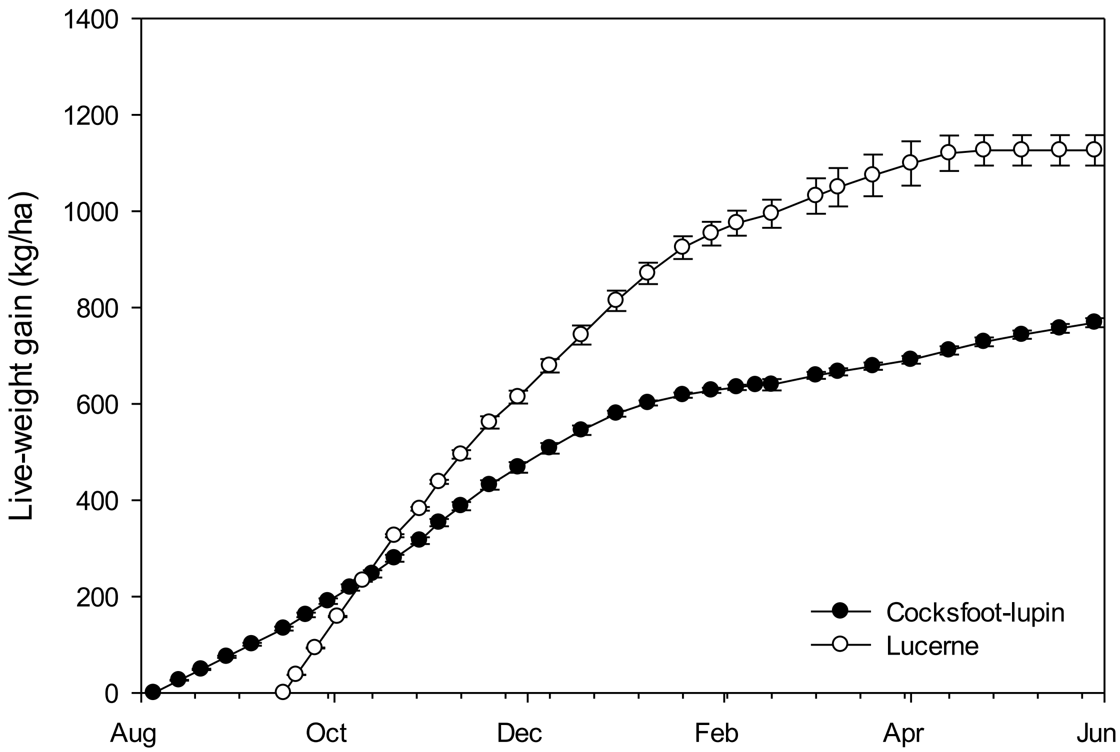

Figure 4.3 Seasonal changes in cumulative live-weight gain of cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury. Error bars indicate SEM.

4.3 Grazing days

The total number of grazing days provided by the cocksfoot-lupin pasture was greater than that of the lucerne pasture until 8 January 2015 (Figure 4.4). After 20 March 2015 lucerne pastures provided a greater number of total grazing days. By the end of the experiment lucerne provided 4528 grazing days/ha which was 318 grazing days/ha more than cocksfoot-lupin pastures which provided 4210 grazing days/ha, however this was not statistically different (P=0.186).

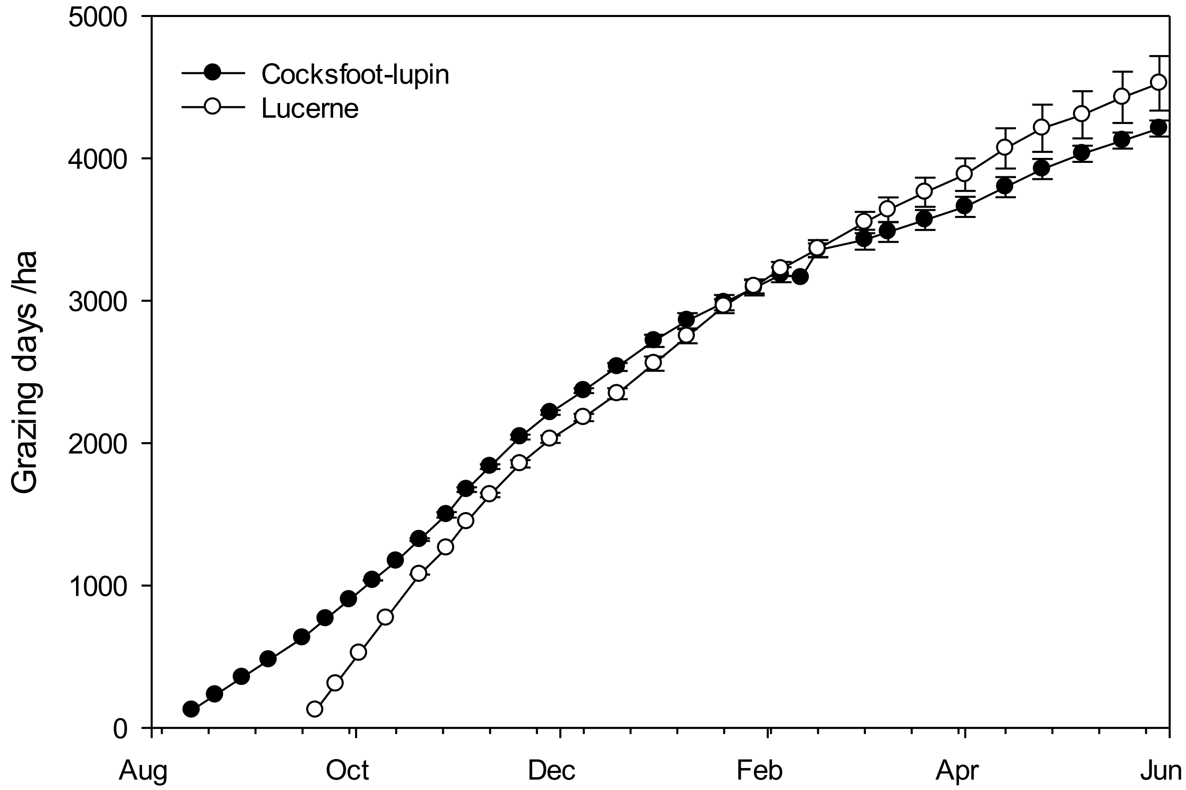

Figure 4.4 Seasonal changes in the cumulative grazing days per hectare of cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury. Error bars indicate SEM.

4.4 Pre-grazing herbage mass

Across the experimental period, the average herbage mass at the start of grazing in the 'break' to be grazed was 2601 kg DM/ha for lucerne and 1861 kg DM/ha for cocksfoot-lupin pastures respectively (P<0.01) (Figure 4.5).

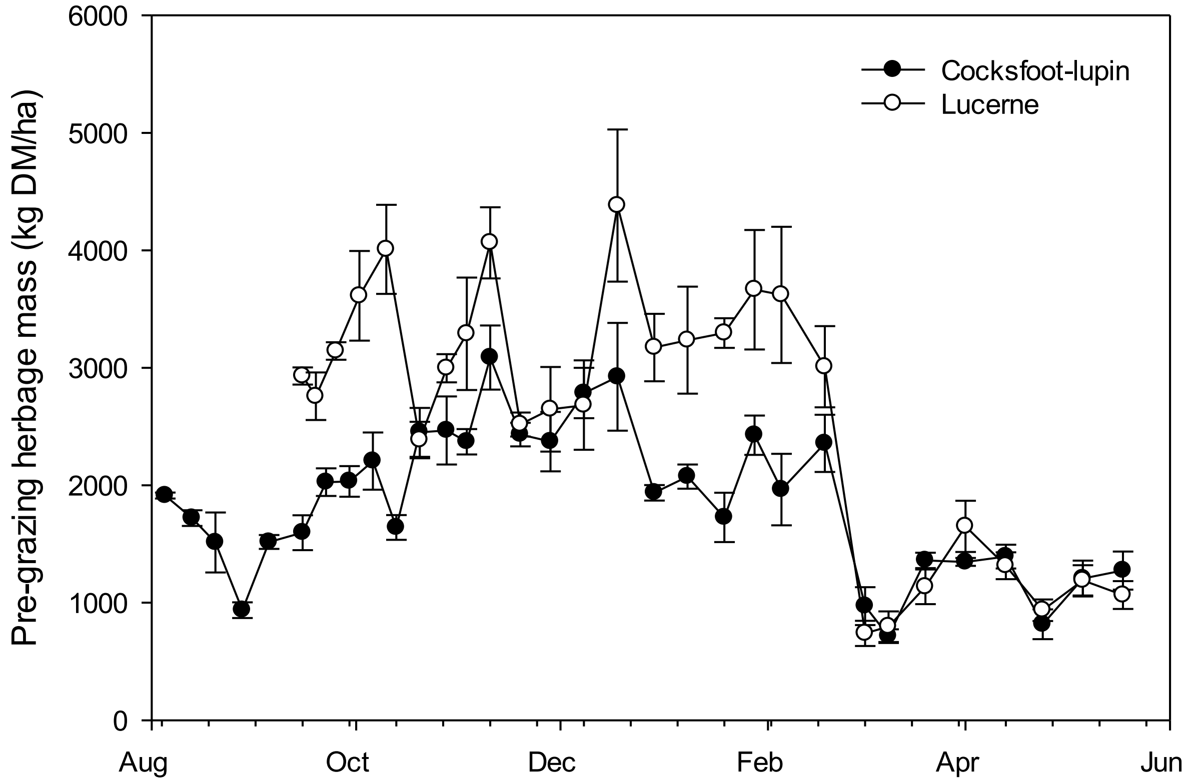

Figure 4.5 Pre-grazing herbage mass of cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury, New Zealand. Error bars indicate SEM.

4.5 Post-grazing herbage mass

Across the experimental period, the average residual in the 'break' which had just been grazed was 1024 kg DM/ha for lucerne and 1129 kg DM/ha for cocksfoot-lupin pastures respectively although this was not statistically significantly (P=0.389) (Figure 4.6).

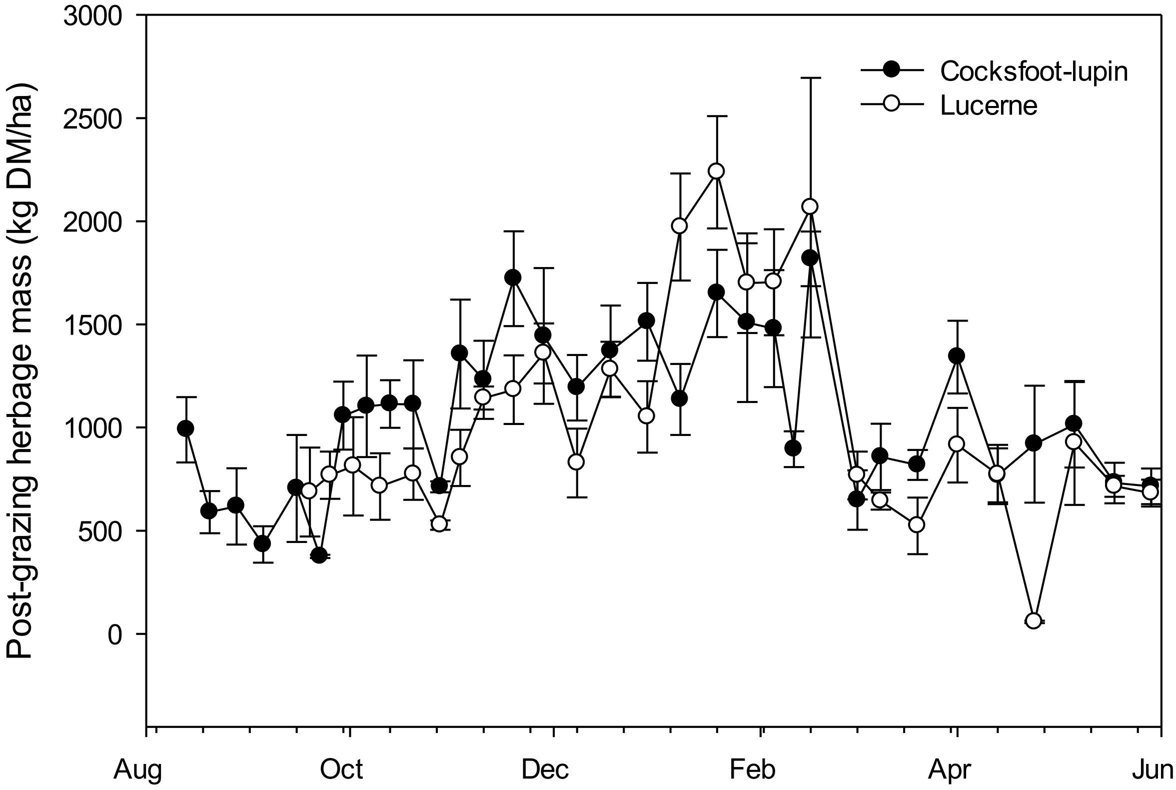

Figure 4.6 Post-grazing herbage mass of cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury, New Zealand. Error bars indicate SEM.

4.6 Stocking rate

Stocking rate on the cocksfoot-lupin pasture at the beginning of spring was 15.4 animals/ha. When the hoggets first grazed the lucerne a much higher stocking rate of 30.8 animals/ha was able to be supported (Figure 4.7). From the start of the spring to 3 November 2014 the stocking rate of the cocksfoot-lupin pasture increased up to 29.5 animals/ha. The lucerne had a drop in stocking rate after the initial grazing but increased to 30.8 animals/ha at the same time the cocksfoot-lupin stocking rate peaked. From late November until February the stocking rate on both forages was reduced at each shift. After this the stocking rate on the lucerne increased, but the stocking rate of the cocksfoot-lupin pastures continued to decrease apart from a small rise in April. The stocking rate across each plot was more variable for the lucerne than it was for the cocksfoot lupin. Only during one grazing period (ending 6 May 2015) did the stocking rate on the cocksfoot-lupin pasture exceed that of the lucerne pastures. Over the experimental period, the stocking rate on the cocksfoot-lupin pasture was 15.1 sheep/ha whereas on the lucerne pasture it was 19.1 sheep/ha ($P<0.01$). Average seasonal stocking rates are shown on Table 4.1.

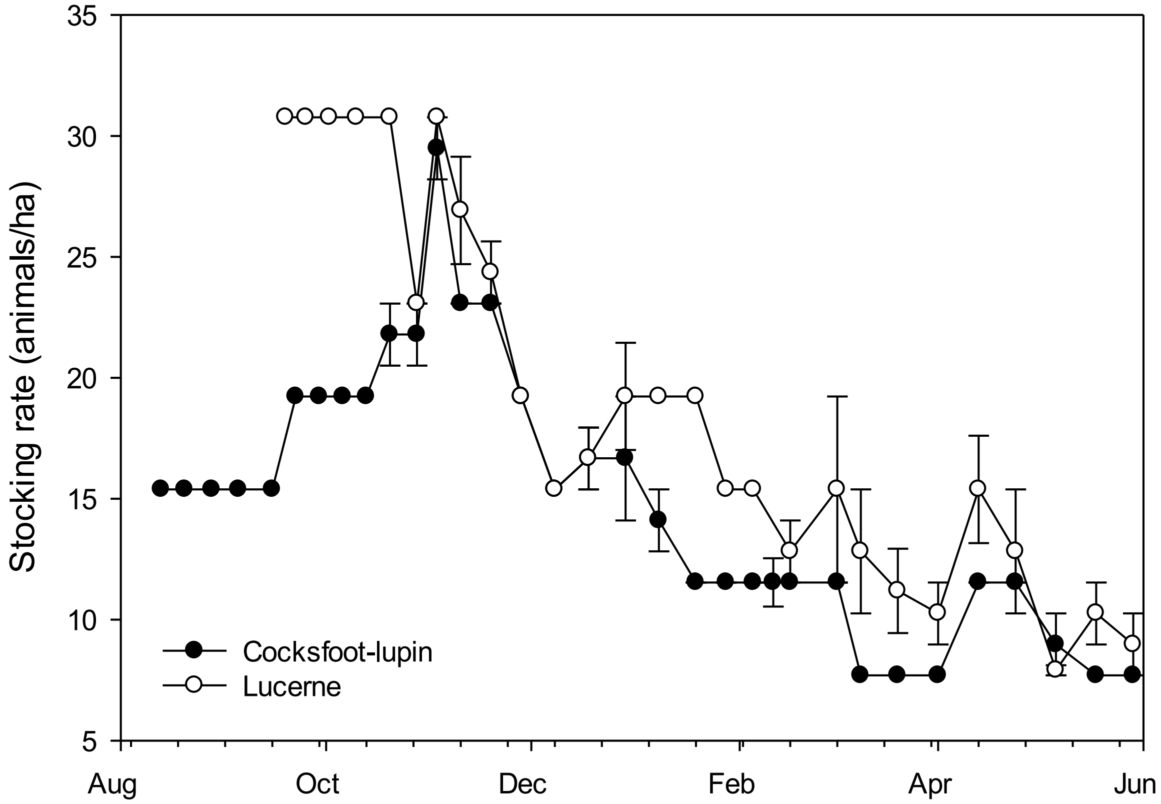

Figure 4.7 Seasonal changes in stocking rate of cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury. Error bars indicate SEM.

Table 4.1 Seasonal changes in stocking rate of cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury.

Period	Cocksfoot-lupin	Lucerne	SED	P value
Early Spring (5 Aug - 15 Sept 2014)	15.4			
Spring (15 Sept – 28 Nov 2014)	20.1	29.5	0.80	<0.01
Spring-summer (28 Nov 2014 – 16 Feb 2015)	17.0	19.6	1.32	0.055
Autumn (18 Feb -28 May 2015)	9.12	11.7	0.85	0.004
Year 1 (5 August 2014 – 28 May 2015)	15.1	19.1	1.10	<0.01

4.7 Herbage allowance

The allowance of feed (assuming that all of the feed in each break is on offer) was 2.9 kg DM/head/day and 3.1 kg DM/head/day on average across the entire year (5 August 2014 - 28 May 2015) for the cocksfoot-lupin and lucerne pastures respectively (Figure 4.8). This was not significantly different (P=0.557). There was a significant difference in allocation on five of the 27 grazing dates. On 15 September 2014 the difference between allocation was highly significant (P<0.01). On 19 January 2015, 20 March 2015 and 24 April 2015 there were significant differences (P<0.05) in feed allowance of 2.19, 1.5 and 0.50 kg DM/head/day respectively (Figure 4.8). At all significant times other 20 March 2015, the allowance was greater on the lucerne pastures. On 6 May 2015 there was a highly significant difference in allocation (P<0.001) where the cocksfoot-lupin fed animals received an allowance of 1.0 kg DM/head/day more than the lucerne fed animals. No significant difference in allocation across any season occurred (Table 4.2).

Table 4.2 Seasonal changes in pasture allowance for young growing sheep on cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury, New Zealand

	Allowance (kg DM/head/day)			
	Cocksfoot-lupin	Lucerne	SED	P
Spring	2.7	2.8	0.17	ns
Spring-summer	3.3	4.0	0.38	ns
Autumn	2.6	2.1	0.35	ns

ns = not significant

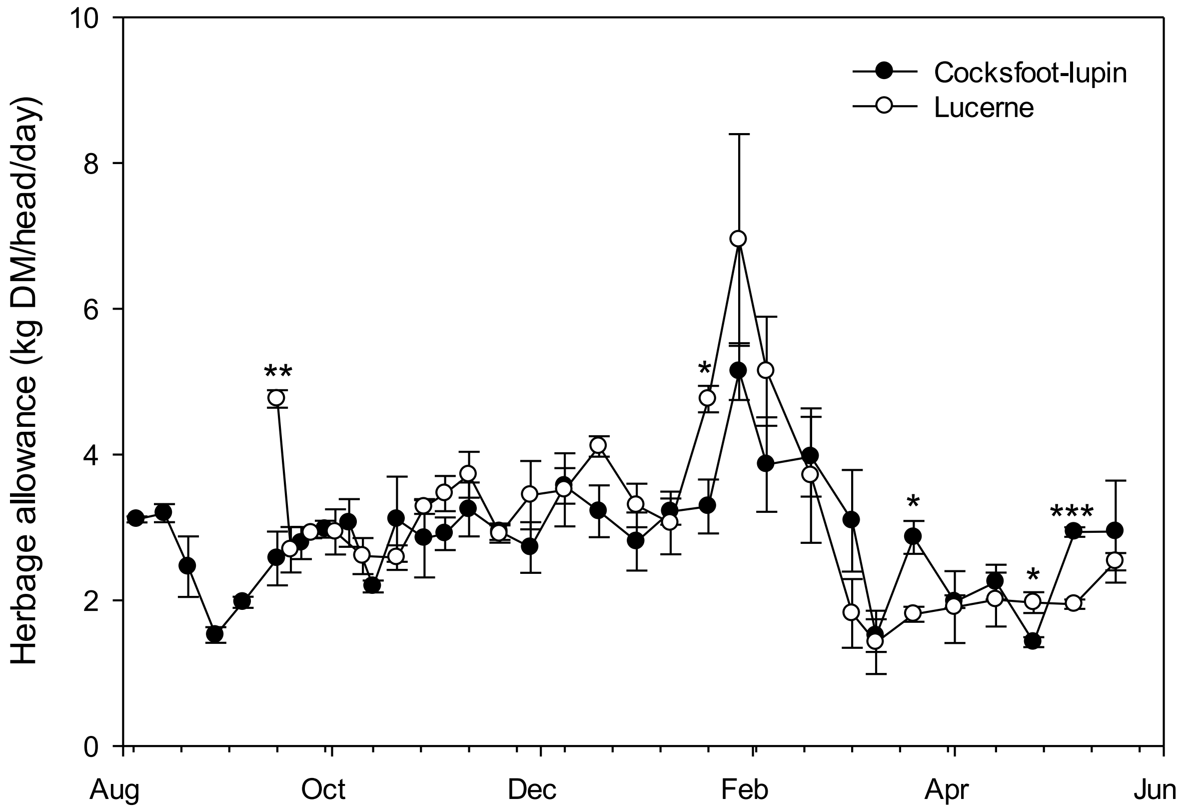

Figure 4.8 Pasture allowance for young growing sheep on cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury, New Zealand. Error bars indicate SEM. *P<0.05, **P<0.01, ***P<0.001, ns = not significant.

4.8 Pre-grazing herbage composition

During spring, weeds comprised 12% of the living plant material on offer in the lucerne pastures (Figure 4.9A). Over the experimental period the percentage of weeds decreased to make up 5% of the living forage on offer across the entire experimental period. Over the entire experimental period lucerne averaged 95% of the total living herbage on offer in the lucerne pastures.

In the cocksfoot lupin pastures (Figure 4.9B), cocksfoot was the dominant species over nearly the entire experimental period. Only on 28 January 2015 did the lupin make up a greater proportion of the overall living material on offer at 57% of the total living herbage on offer. Cocksfoot ranged from 41 to 99% of the total herbage on offer. Cocksfoot was very important in autumn where it provided 83% of the total living herbage on offer. Over the experimental period cocksfoot made up 70% of the herbage on offer on average (Table 4.3). The proportion of lupins in the sward varied across the period from 1 to 57%. Over the experimental period lupins represented 22% of the forage on offer. The weeds in the cocksfoot lupin pasture varied from 0 to 24% of the herbage on offer and across the experimental period averaged 8%.

Table 4.3 Seasonal changes in pre-grazing pasture composition on cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury, New Zealand

	Cocksfoot %	Legume %	Weed %
	Year (5 August 2014 - 28 May 2015)		
Cocksfoot-lupin	70.1	21.7	8.2
Lucerne		94.5	5.5
	Spring (5 August - 28 November 2014)		
Cocksfoot-lupin	65.0	24.1	10.9
Lucerne		87.8	12.2
	Spring-summer (28 November 2014 - 16 February 2015)		
Cocksfoot-lupin	65.6	25.5	8.9
Lucerne		97.3	2.7
	Autumn (18 February - 28 May 2015)		
Cocksfoot-lupin	82.7	14.5	2.8
Lucerne		99.5	0.5

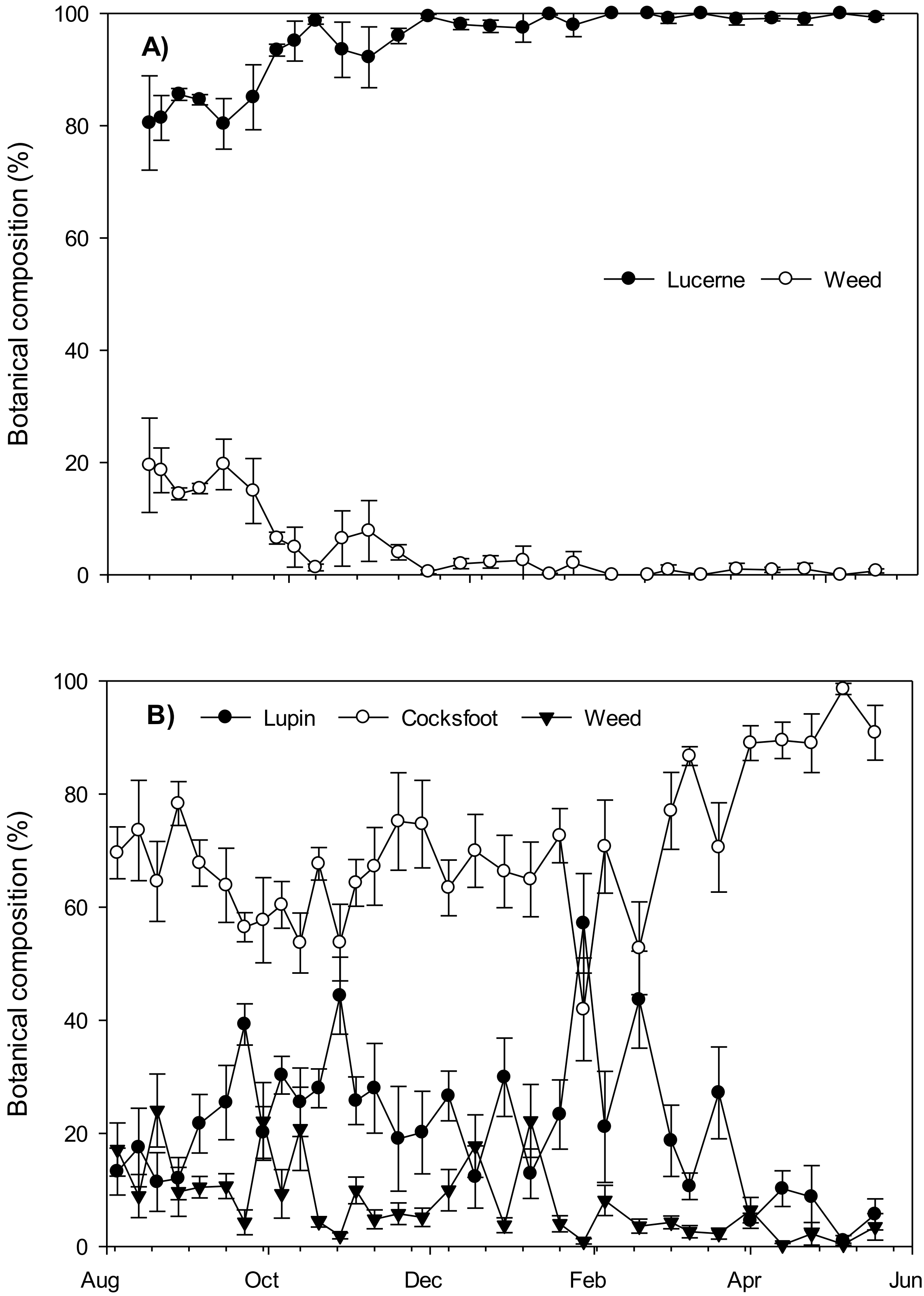

Figure 4.9 Changes in lucerne (A) and cocksfoot-lupin (B) pre-grazing pasture botanical composition in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury, New Zealand. Error bars indicate SEM.

4.9 Herbage disappearance

Herbage disappearance from the lucerne and cocksfoot pastures in 'break 2' has been summarised in Figures 4.10 to 4.16. The data shows that sheep showed preference for the lucerne leaf pasture component. The sheep did not appear to be interested in grazing the stem, weed or dead herbage components. The dead material in the lucerne pastures began to accumulate into autumn.

The sheep on the cocksfoot-lupin pastures ate both the lupin leaf and cocksfoot pasture components. The preference was for the cocksfoot as indicated by the steeper line gradients. There was a high proportion of dead material in the cocksfoot-lupin pastures over January which remained high for the remainder of the experiment. When lupin flower was present it was preferentially grazed by the sheep indicated by there being no lupin flower left when the sheep left the paddock. The proportion of weeds in 'break 2' remained stable across the experimental period. The lupin petiole component was generally only present in minor quantities and usually did not change considerably during grazing.

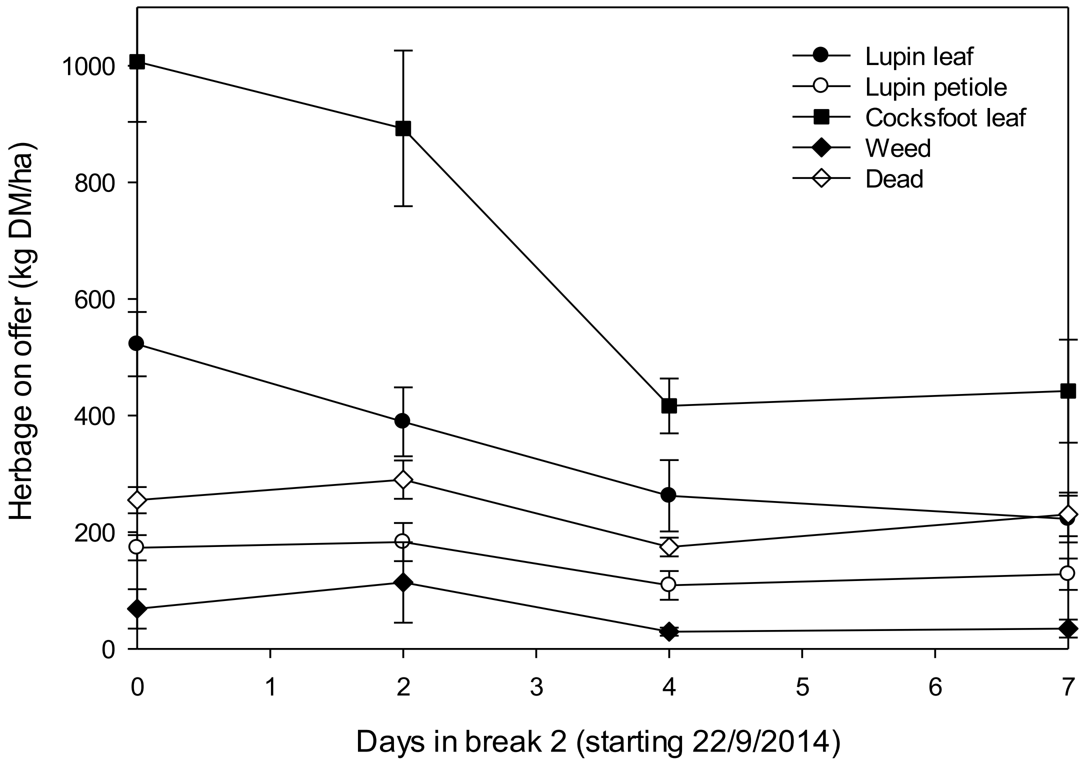

Figure 4.10 Herbage on offer in 'break 2' for cocksfoot-lupin pastures while the 'break' was grazed from 22 September - 29 September 2014 at Lincoln University, Canterbury. Error bars

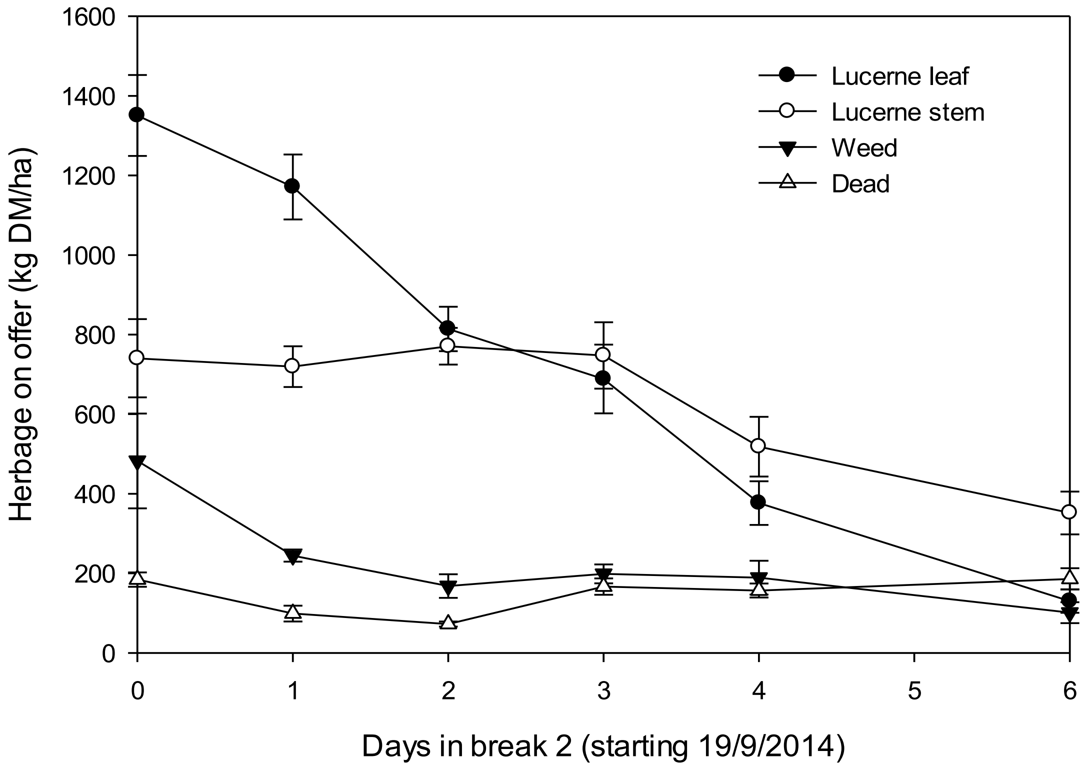

Figure 4.11 Herbage on offer in 'break 2' for lucerne pastures while the 'break' was grazed from 19 September - 25 September 2014 at Lincoln University, Canterbury. Error bars indicate SEM.

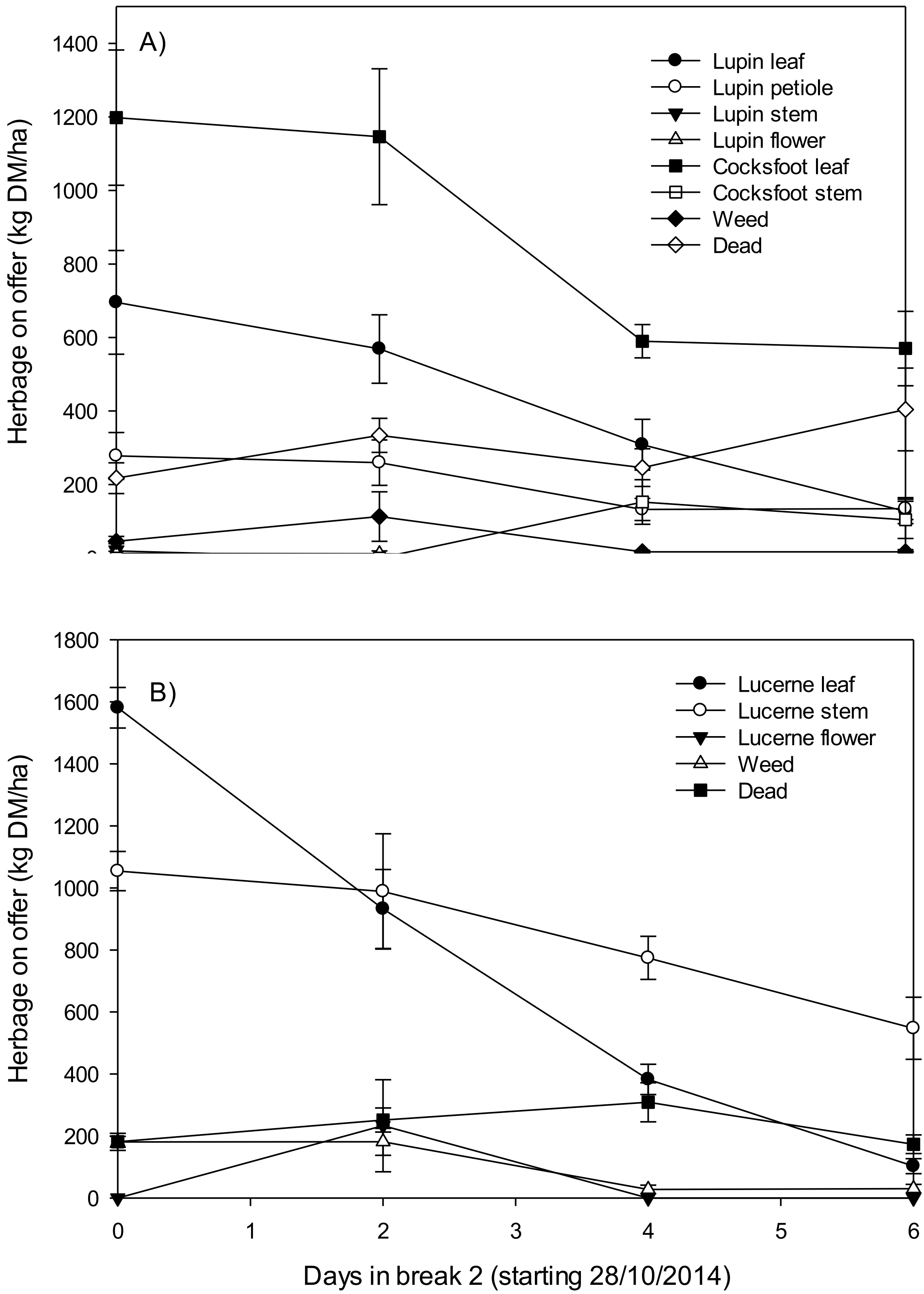

Figure 4.12 Herbage on offer in break 2 for cocksfoot-lupin (A) and lucerne (B) pastures while the 'break' was grazed from 28 October - 3 November 2014 at Lincoln University, Canterbury. Error bars indicate SEM.

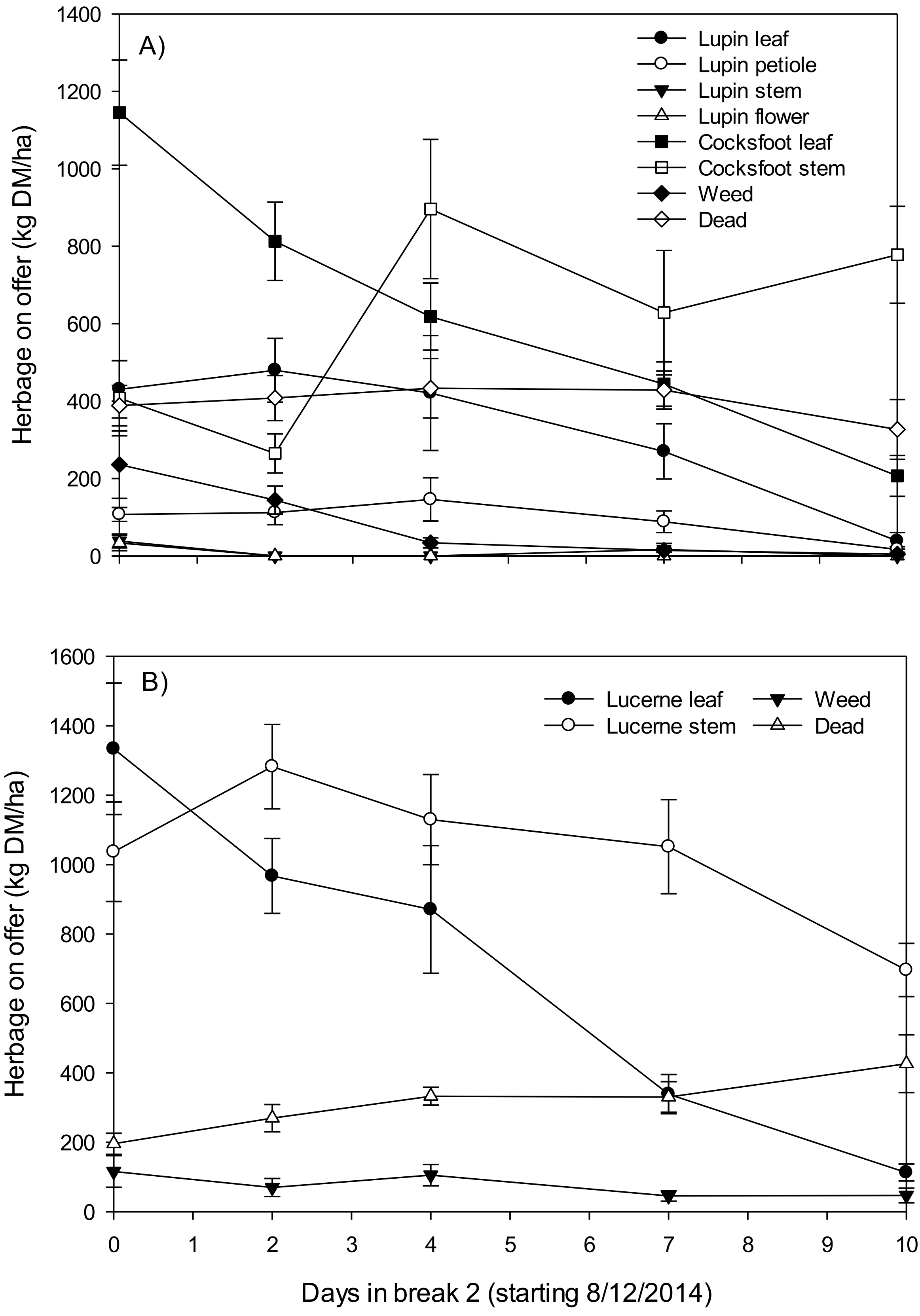

Figure 4.13 Herbage on offer in break 2 for cocksfoot-lupin (A) and lucerne (B) pastures while the 'break' was grazed from 8 December – 18 December 2014 at Lincoln University, Canterbury. Error bars indicate SEM.

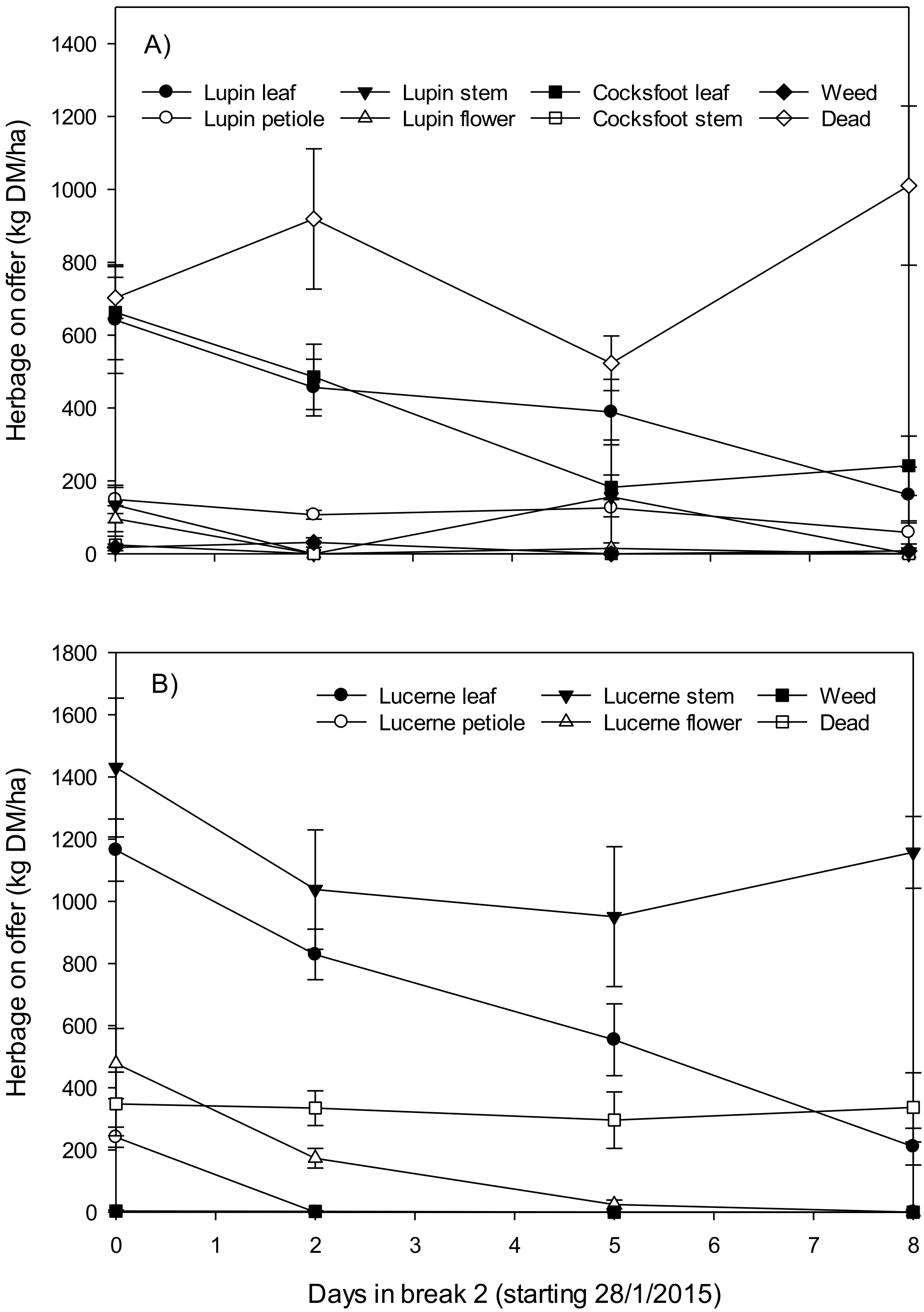

Figure 4.14 Herbage on offer in break 2 for cocksfoot-lupin (A) and lucerne (B) pastures while the 'break' was grazed from 28 January 2014 - 5 February 2015 at Lincoln University, Canterbury. Error bars indicate SEM

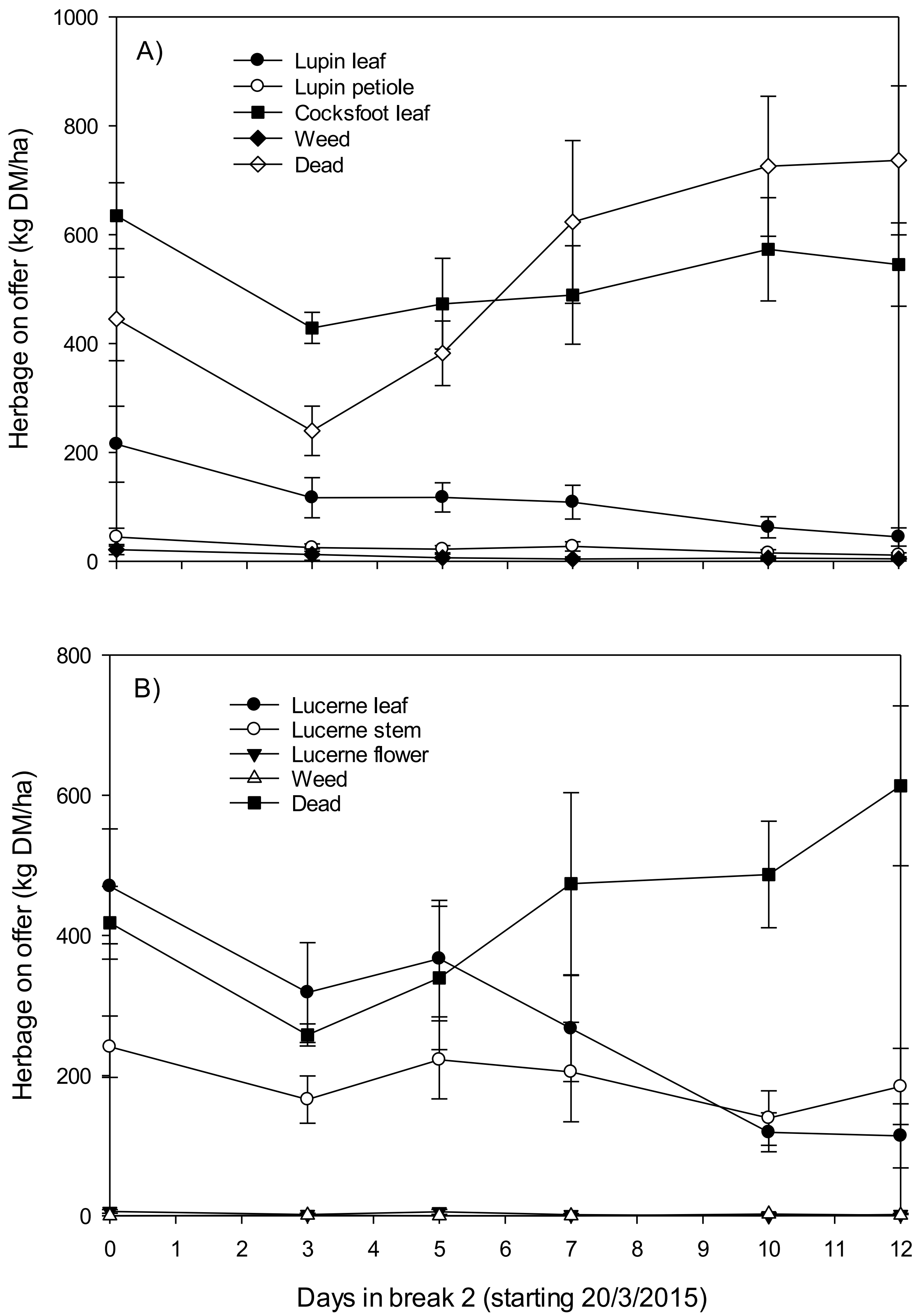

Figure 4.15 Herbage on offer in break 2 for cocksfoot-lupin (A) and lucerne (B) pastures while the 'break' was grazed from 20 March - 1 April 2015 at Lincoln University, Canterbury. Error bars indicate SEM.

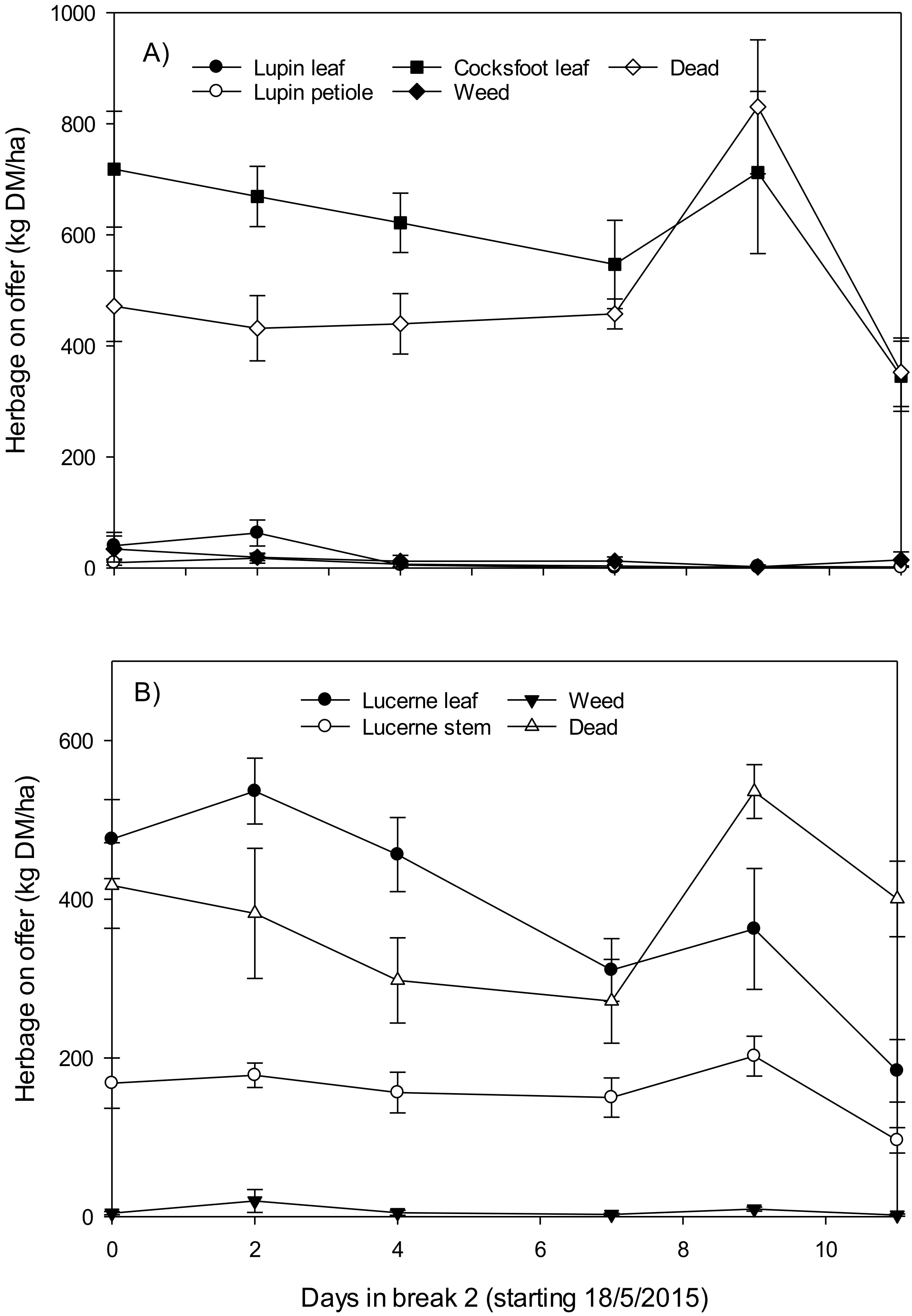

Figure 4.16 Herbage on offer in break 2 for cocksfoot-lupin (A) and lucerne (B) pastures while the 'break' was grazed from 18 May - 29 May 2015 at Lincoln University, Canterbury. Error bars indicate SEM.

4.10 Nutritional value

On average across the experimental period DMD and ME content of the mixed herbage on offer was significantly (P<0.001) greater for the cocksfoot-lupin pastures than in the lucerne pastures (Table 4.4). Protein content was significantly (P<0.001) greater in the lucerne across the experimental period.

Table 4.4 Average DMD %, protein % and ME of mixed herbage on offer for cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury.

	DMD (%)	Protein (%)	ME (MJ /kg DM)
Lucerne	55.2	17.7	8.7
Cocksfoot-lupin	66.8	13.5	10.3
SED	2.70	0.67	0.37
P	***	***	***

*P<0.05, **P<0.01, ***P<0.001, ns = not significant

The DMD of the cocksfoot-lupin pasture ranged from 58.4 to 72.8% (Figure 4.17). Throughout the year the DMD of the cocksfoot-lupin pastures was more consistent than the lucerne pasture. The DMD of the lucerne pasture ranged from 26 to 71% with an extreme decrease in DMD occurring in the autumn period.

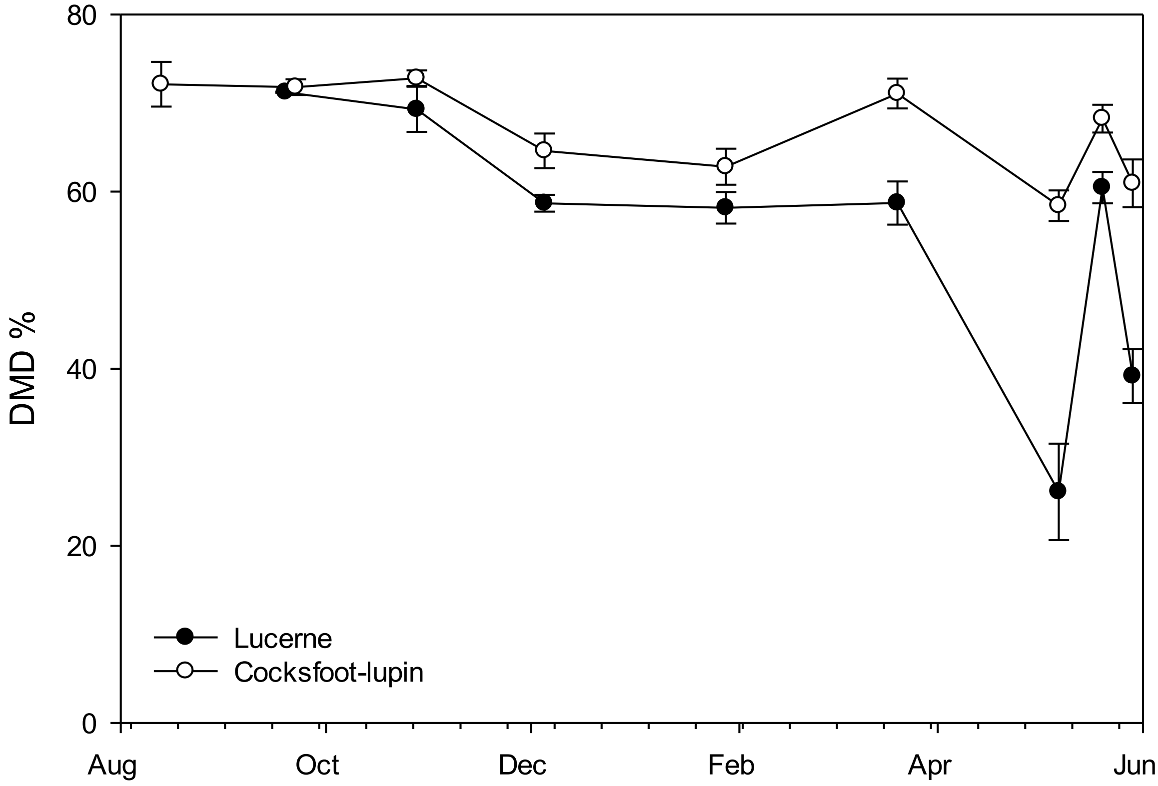

Figure 4.17 Average DMD % of cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 - 28 May 2015) at Lincoln University, Canterbury. Error bars indicate SEM.

The protein content of lucerne pasture was consistently higher than that of the cocksfoot-lupin pastures throughout the year (Figure 4.18). The protein content of lucerne varied from 14 to 23% in comparison to cocksfoot-lupin which varied from 11 to 18%. As with the DMD the variation in the protein content was greatest over the autumn period

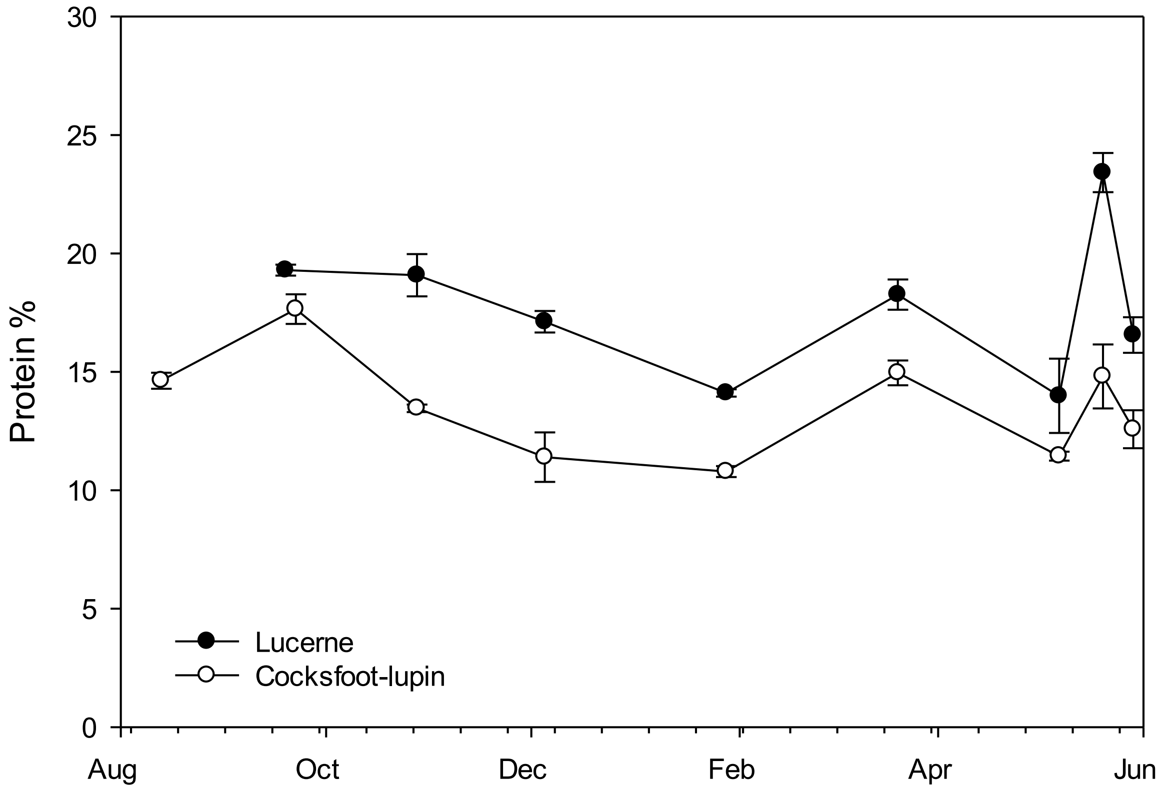

Figure 4.18 Average protein content of cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 - 28 May 2015) at Lincoln University, Canterbury. Error bars indicate SEM.

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The ME of the cocksfoot-lupin pasture was consistently higher than that of the lucerne pasture throughout the year (Figure 4.19). The variation in ME of cocksfoot-lupin was less than lucerne which varied from 9 to 11 MJ /kg DM and 5 to 11 MJ /kg DM for the two pastures respectively. Most of the v

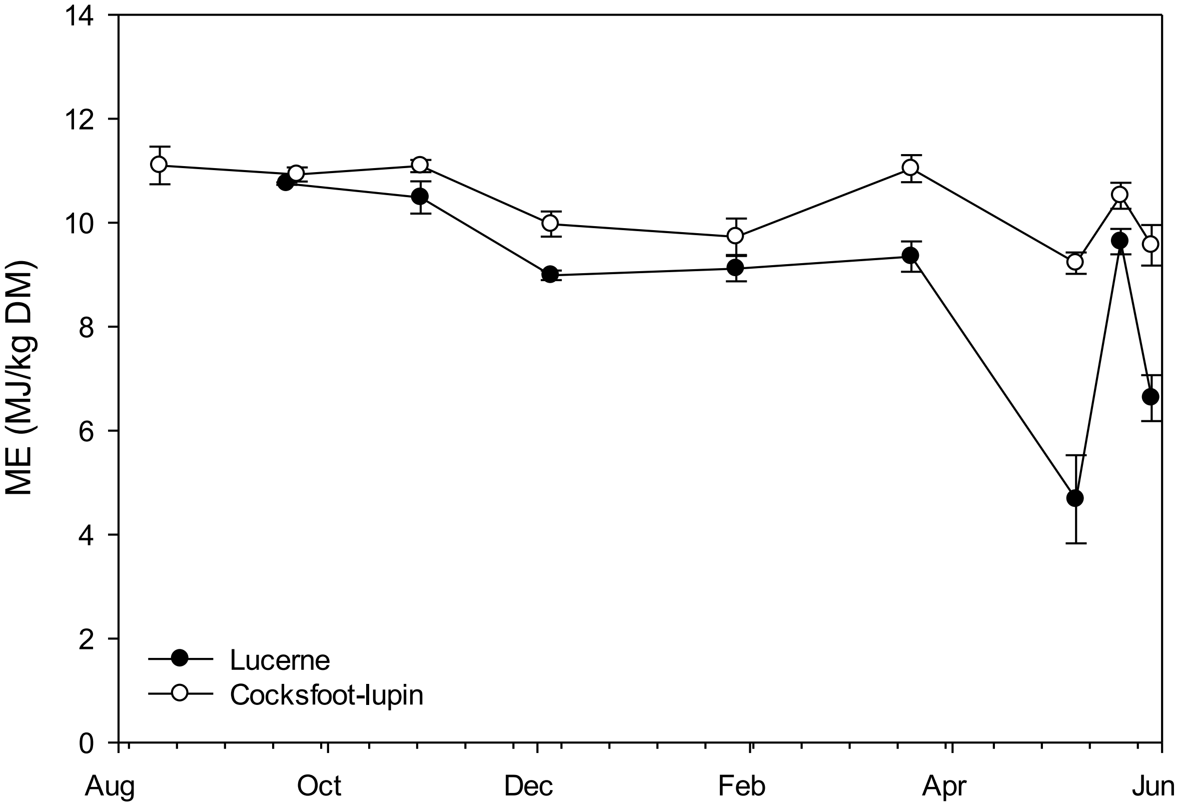

Figure 4.19 Average ME of cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury. Error bars indicate SEM

Table 4.5 shows the differences in DMD, protein and ME on average in each season. During the spring period there was no significant difference in DMD or ME between the pastures. There was a highly significant (P<0.001) difference between the protein of the two pastures where lucerne pastures contained 19.2% protein compared to 15.6% for cocksfoot-lupin pastures. During the spring-summer and autumn periods there were significant (P<0.001) differences in the DMD, protein content and ME of the pastures. DMD and ME was higher for cocksfoot-lupin pastures and protein was higher for lucerne pastures.

Table 4.5 Seasonal averages of DMD, protein content and ME in cocksfoot-lupin and lucerne pastures in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury, New Zealand.

Pasture	DMD (%)	Protein (%)	ME (MJ /kg DM)
	Spring (5 August - 28 November 2014)		
Lucerne	70.3	19.2	10.6
Cocksfoot-lupin	72.2	15.4	11.0
SED	1.09	0.73	0.15
P	ns	***	ns
	Spring-summer (28 November 2014 - 16 February 2015)		
Lucerne	58.4	15.6	9.1
Cocksfoot-lupin	63.7	11.1	9.9
SED	1.19	0.67	0.18
P	***	***	***
	Autumn (18 February – 28 May 2015)		
Lucerne	46.1	18.1	7.6
Cocksfoot-lupin	64.7	13.5	10.1
SED	4.10	1.04	0.59
P	***	***	***

*P<0.05, **P<0.01, ***P<0.001, ns = not significant

Over the experimental period there was no significant difference between the DMD and the ME of the cocksfoot leaf and the lucerne leaf/petiole (Table 4.6). There was a significant ($P<0.001$) difference in the protein content where lucerne leaf/petiole had a protein content of 24.5% compared to 16.5% in cocksfoot leaves. In all seasons there was no significant difference between the DMD and ME of lucerne leaf/petiole and cocksfoot leaf. In every season there was a significant difference in the protein content.

Table 4.6 Seasonal averages of DMD, protein and ME in cocksfoot leaf and lucerne leaf/petiole in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury, New Zealand.

	DMD (%)	Protein (%)	ME (MJ /kg DM)
	Year (5 August 2014 - 28 May 2015)		
Cocksfoot leaf	74.4	16.5	11.5
Lucerne leaf/petiole	76.0	24.5	11.5
SED	1.11	0.98	0.84
P	ns	***	ns
	Spring (5 August - 28 November 2014)		
Cocksfoot leaf	75.7	17.8	11.6
Lucerne leaf/petiole	76.0	25.9	11.4
SED	1.42	1.28	0.53
P	ns	***	ns
	Spring-Summer (28 November 2014 - 16 February 2015)		
Cocksfoot leaf	72.2	14.5	11.3
Lucerne leaf/petiole	74.1	21.7	11.2
SED	0.95	1.69	0.12
P	ns	**	ns
	Autumn (18 February - 28 May 2015)		
Cocksfoot leaf	75.1	17.0	11.8
Lucerne leaf/petiole	78.3	25.6	12.0
SED	2.85	1.37	0.39
P	ns	***	ns

*P<0.05, **P<0.01, ***P<0.001, ns = not significant

Over the experimental period there was no significant difference between the protein content of lupin leaf and lucerne leaf/petiole (Table 4.7). There was a significant difference ($P<0.01$) between the lupin leaf and lucerne leaf/petiole DMD and ME. Both of which were higher in the lupin leaf. During the spring period the DMD and the ME was significantly ($P<0.001$) different and both higher in the lupin leaf. The same trend occurred in the spring-summer period also, however this time the differences were highly significant ($P<0.01$). In the autumn DMD was significantly ($P<0.01$) greater in the lupin leaf. Protein content was significantly higher in the lucerne leaf/petiole and ME was significantly higher in lupin leaf ($P<0.05$).

Table 4.7 Seasonal averages of DMD, protein and ME in lupin leaf and lucence leaf/petiole in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury, New Zealand.

	DMD (%)	Protein (%)	ME (MJ /kg DM)
	Year (5 August 2014 - 28 May 2015		
Lupin leaf	81.2	23.9	12.1
Lucerne leaf/petiole	76.0	24.5	11.5
SED	0.88	1.27	0.11
P	***	ns	***
	Spring (5 August - 28 November 2014)		
Lupin leaf	78.9	26.6	11.9
Lucerne leaf/petiole	76.0	25.9	11.4
SED	0.96	1.06	0.13
P	**	ns	**
	Spring-Summer (28 November 2014 - 16 February 2015)		
Lupin leaf	83.3	21.8	12.2
Lucerne leaf/petiole	74.1	21.7	11.2
SED	0.99	2.52	0.13
P	***	ns	***
	Autumn (18 February - 28 May 2015)		
Lupin leaf	83.0	20.7	12.3
Lucerne leaf/petiole	78.3	25.6	12.0
SED	0.99	1.80	0.82
P	**	*	*

*P<0.05, **P<0.01, ***P<0.001, ns = not significant

The legume leaves contained the highest levels of DMD, protein and ME at most times of the year (Table 4.8). Over the spring summer period the legume flowers had the highest nutritional value of all the pasture components.

Table 4.8 Seasonal averages of DMD, protein and ME of apparent cocksfoot-lupin and lucerne pasture components in their first year after establishment (5 August 2014 -28 May 2015) at Lincoln University, Canterbury, New Zealand. Error bars indicate SEM.

Pasture component	DMD (%)	Protein (%)	ME (MJ /kgDM)
Lucerne		Spring (5 Aug – 28 Nov 2014)	
Leaf	76.0	25.9	11.4
Stem	66.5	15.8	10.1
Dead	47.1	10.5	7.6
Weed	74.0	18.2	11.0
Cocksfoot-lupin		Spring (5 Aug – 28 Nov 2014)	
Leaf	78.9	26.6	11.9
Petiole	76.4	13.9	11.8
Cocksfoot leaf	75.7	17.8	11.6
Dead	39.9	8.8	6.3
Weed	76.3	17.6	11.5
Lucerne		Spring-Summer (28 Nov 2014 – 16 Feb 2015)	
Leaf	76.9	24.0	11.6
Stem	48.6	9.8	7.8
Flower	76.7	19.5	11.6
Petiole	67.8	15.2	10.4
Dead	36.9	10.1	6.1
Weed	70.1	20.1	10.6
Cocksfoot-lupin		Spring-Summer (28 Nov 2014 – 16 Feb 2015)	
Leaf	83.3	21.8	12.2
Petiole	64.9	11.6	10.1
Flower	78.8	24.9	12.2
Stem	72.0	14.0	11.2
Cocksfoot leaf	72.2	14.5	11.3
Cocksfoot stem	54.6	7.9	8.7
Dead	52.2	8.6	8.1
Weed	71.1	16.6	10.9
Lucerne		Autumn (18 Feb – 28 May 2015)	
Leaf	78.3	25.6	12.0
Stem	64.8	16.5	10.2
Dead	20.0	10.6	3.7
Weed	74.4	25.9	11.6
Cocksfoot-lupin		Autumn (18 Feb – 28 May 2015)	
Leaf	83.0	20.7	12.3
Petiole	60.4	6.8	9.3
Cocksfoot leaf	75.1	17.0	11.8
Dead	55.8	10.6	8.8

5 Discussion

5.1 General Discussion

Total live-weight accumulation on cocksfoot-lupin pastures (768 kg/ha) was 358 kg/ha less than lucerne pastures (1126 kg/ha) (Figure 4.3). This was due to the higher stocking rates (Table 4.1, Figure 4.7) and greater live-weight gains on lucerne over the year. The number of grazing days provided from each pasture were similar at the end of the experiment (Figure 4.4). The stocking rate was significantly higher on average on lucerne than on cocksfoot-lupin when both pastures were being grazed, indicating more animals could be stocked per hectare in lucerne 'breaks' than lupin cocksfoot 'breaks' at any one time as there was more herbage mass on offer (Figure 4.5) at a similar herbage allowance (Figure 4.8).

One grazing day is defined as one animal on pasture for one day (Mills *et al.* 2015). The similar grazing days observed between cocksfoot-lupin and lucerne pastures shows that cocksfoot-lupin pastures can support similar numbers of sheep over the growing season. The reason there was a significant difference in stocking rate but not grazing days is due to cocksfoot-lupin pastures being grazed 41 days earlier than the lucerne pastures in spring. The high stocking rate on the lucerne pastures, which occurred in response to the high pre-grazing herbage mass (Figure 4.5) required more animals to be placed on the plots to achieve similar intakes to the cocksfoot-lupin pasture. This allowed lucerne to catch up to the cocksfoot lupin pastures which had accumulated 631 grazing days more than lucerne before lucerne grazing had begun (Figure 4.4). This is in contrast to Mills *et al.* (2015) who reported grazing days are lower for lucerne compared to grass based pastures, however like Mills *et al.* (2015) it was found that greater animal production occurs on lucerne pasture.

The pre-grazing herbage mass of lucerne was especially high over the spring and summer periods (Figure 4.5). The similar post-grazing herbage mass (Figure 4.6) and greater pre-grazing mass shows that dry matter production was greater for lucerne. However DM yield was not reported in this dissertation because live-weight gain per hectare was used as the pasture production variable. In the absence of water stress, lucerne growth and development is rapid. Further increase in growth rate occurred in response to high temperature and long photoperiods (Moot et al. 2003). The 2014-2015 summer however was drier than the long term rainfall mean (Table 3.1). Therefore the greater yield and regrowth rate from lucerne may have been associated with the ability of lucerne to extract soil water (>2 m) from greater depths than cocksfoot (1.4 m) (Evans 1978). This would have been aided by superior water use efficiency of lucerne over the summer compared to cocksfoot (Tonmukayakul 2009), the dominant species in the cocksfoot-lupin pasture over this period (Table 4.3 & Figure 4.9B). The lucerne pastures also had a greater supply of N due to being legume dominant. Over the summer the lucerne pastures were composed of 97% legume whereas the cocksfoot-lupin pastures had a legume content of 26% (Table 4.3, Figure 4.9 A&B) with no additional N fertiliser applied to either pasture.

There was no significant difference in the allowance of feed to sheep on the cocksfoot-lupin or lucerne pastures over the year (Figure 4.8 & Table 4.2). This is a crucial point. As there was no difference in the amount of feed offered to the sheep then any differences in animal performance can be more conclusively linked to differences in the forage intake, pastures composition or nutritional value.

Due to selective grazing the sheep would have consumed a diet of a different quality and composition than that of the overall pasture offered. Lucerne fed animals showed consistent preference for the leaves all year round (Figures 4.11 & 4.12B-4.16B). The leave/petiole had the greatest nutritive quality of all lucerne pasture components (Table 4.8). The stock on the cocksfoot lupin pasture ate cocksfoot leaf and lupin leaf in the greatest quantity (Figures 4.10 & 4.12A-4.16A). This diet selection occurs due to three key reasons: active preference for specific pasture components, accessibility of sward components relating to the swards vertical structure (Carrère *et al.* 2001) and the animals tendency to graze from the top of the sward down (Litherland & Lambert 2007).

While ME, protein and DMD varied throughout the year (Figures 4.17, 4.18 & 4.19) the ME and DMD was highest for cocksfoot-lupin pastures. Protein content was consistently higher in the lucerne pastures (Figure 4.18, Table 4.5). The average forage quality of the lucerne pastures over the experimental period (Table 4.4) would have been affect by the high proportion of dead material in the autumn period (Figure 4.16) which has poor nutritional value (Table 4.8).

The protein content of most pastures in New Zealand is 10 to 30% (Lambert & Litherland 2000) which both the cocksfoot-lupin and lucerne pastures were consistently within. In most situations protein intake is not the key limiting nutritional factor in pastures so the ME of the pasture largely determines its nutritive value (Litherland & Lambert 2007). However for growing sheep Fraser and Rowarth (1996) reported that high protein diets were associated with the highest lamb live-weight gains.

The following sections discusses seasonal differences in animal performance which aid to explain the differences in performance across the year. Hoggets were used from August 2014 to February 2015 where they were then replaced by lambs for the autumn period. As different animals were used, the autumn period was kept separate from the spring and spring-summer periods for determining average forage quality and live weight gain rates. The spring and spring-summer period data was separated as while the same animals were used the spring period was pre-shearing and the spring summer period was post-shearing.

5.2 Spring

Over the spring period (5 August – 28 November 2014) there was a live-weight accumulation of 133 kg/ha on the cocksfoot-lupin pastures before lucerne grazing began on 15 September 2014 (Figure 4.3). However by the end of the spring period the lucerne pastures had accumulated 146 kg/ha of live-weight more than the cocksfoot-lupin pastures. At the end of the spring period live-weight gain was 468 and 614 kg/ha for cocksfoot-lupin and lucerne pastures respectfully. The higher stocking rate (Figure 4.7 & Table 4.1) on the lucerne pastures in the spring also coincided with higher pasture intakes (Figure 4.1). Live-weight gain per animal was 298 g/day compared with 210 g/day for lucerne and cocksfoot-lupin pastures respectfully (Figure 4.2).

The grazing of the cocksfoot-lupin pastures occurred 41 days earlier (starting 5 August 2014) than the lucerne pastures (starting 15 September 2015). At 5 August 2015 the pre-grazing herbage mass of the cocksfoot-lupin pastures was 1913 kg DM/ha compared to 1373 kg DM/ha on the lucerne pastures warranting the lucerne pastures to be spelled longer. In high country pastures seasonal distribution is as important as annual DM production. In a survey, farmers have noted the spring period feed shortage as an important factor for not carrying any extra stock (Chapman & Macfarlane 1985). Spring is the most important period to maximise dryland production due to the moist soils and low evapotranspiration rates at that time of year. High animal growth rates are required in spring in order to maximise live-weight gain before the summer dry (Brown *et al.* 2006). Lupin died back for the winter and did not reappear in substantial volume until October 2014, so the cocksfoot component was likely responsible for the winter and early spring growth of the cocksfoot-lupin pasture due to is early dominance in the sward (Figure 4.9A).

The first grazing rotation of the cocksfoot-lupin pastures took 41 days ending on 15 September 2014. At this point the lucerne began its first grazing rotation in 'break 1' alongside the cocksfoot-lupin pasture. The beginning and ending of grazing on the cocksfoot-lupin and lucerne pastures did not coincide during the first grazing rotation. Stock on the cocksfoot-lupin pastures were shifted about every 7 days whereas the shifting frequency was more variable on the lucerne pastures. Shifting on the lucerne pastures occurred more frequently at the start of the rotation and slowed towards the end of the rotation. The purpose of this was to compensate for the lack of feed wedge (Hight 2014). Also, the pasture growth rate of lucerne pastures was accelerating resulting in higher herbage masses (Figure 4.5) and stocking rate variation (Figure 4.7)

Aside from the initial grazing of the first rotation of lucerne there was no significant differences in feed allowance between the pastures in spring (Figure 4.8). Apparent intakes were significantly different across the season driven by differences on three occasions: in 'break 1' and 'break 5' during the first rotation and ‘break 4’ during the second rotation (Figure 4.1). The difference in intake at these times was 1.63, 1.09 and 1.52 kg/head/day greater for lucerne. When lucerne was first grazed, a greater allocation was offered resulting in increased intake. Although it is very difficult to accurately gauge true animal intake. There was considerable variation in the intakes each at grazing period (Figure 4.1).

The higher intakes on lucerne pastures would be expected to be caused by poor stock acceptance of the lupin, but there is still evidence to suggest that sheep grazed the lupin leaf pasture component (Figures 4.10 & 4.12B). It must be emphasised that a pasture containing 22% legume and 70% cocksfoot is being compared to one containing 95% legume (Table 4.3) so sheep did have the option not to graze the lupin. A previous study also found apparent intakes to be higher on lucerne that cocksfoot dominate pasture (Peri *et al.* 2001). Legume fibre is arranged in short branching vascular bundles unlike grasses which have parallel vascular bundles which run the full length of the leaf. The implications of this is grass leaf material must be masticated and reduced to a smaller size to pass out and degrade in the rumen (Litherland & Lambert 2007). Therefore animals consuming legume can eat and digest faster. Although lucerne was not included in the study by Gong *et al.* (1996) it was found animals consuming legume had a higher bite intake and rate than animals consuming grass thus increasing overall intake. The lucerne may have also simply been more palatable.

Overall there was no difference in the DMD or ME of cocksfoot lupin and lucerne pasture over the spring period (Table 4.5), but the protein content of lucerne was significantly higher. The proportion of weeds was highest in the cocksfoot lupin pastures in spring. However with 8.2% weeds in the cocksfoot-lupin pasture (Table 4.3) the effects this would have on intake quality would be minimal as sheep are selective grazers and may avoid the weeds. Sheep showed preference for lucerne leaf/petiole and cocksfoot leaf (Figures 4.10 & 4.12B). In the spring there was no difference in DMD or ME of the cocksfoot leaf compared to the lucerne leaf/petiole however the protein content of the lucerne leaf/petiole was greater (Table 4.6). During the spring period there was no difference between the protein content of lupin leaf and lucerne leaf/petiole however the lupin leaf had a higher DMD and ME (Table 4.7)

The higher feed and protein intake on lucerne and potentially higher ME intake as a result of increased feed consumption may explain the observed difference in sheep live-weight gain per animal in spring. Lucerne animals may have eaten more due to faster intake and digestion rates. The lucerne pasture also may have been more palatable than both cocksfoot and lupin. Further, the increased stocking rate on lucerne allowed live-weight gain per hectare to exceed that of the cocksfoot-lupin pastures.

5.3 Spring-summer

By the end of the spring-summer period accumulated live weight gain was 995 kg/ha for lucerne and 639 kg/ha for cocksfoot-lupin pastures (Figure 4.3). During this period cocksfoot-lupin pastures contributed 171 kg/ha and lucerne pastures contributed 381 kg/ha. The different in performance per hectare was not related to stocking rate however the difference in stocking rate between the pastures was nearly significant (Table 4.1). The increased live-weight gain per hectare coincided with differences in individual animal live-weight gains (Figure 4.2) and fed intakes of lucerne fed sheep (Figure 4.1). Over the spring-summer period sheep on the lucerne pastures gained more weight, 25.4 kg/animal compared to 14.5 kg/animal on the cocksfoot lupin pastures (Figure 4.2). Hoggets did not gain weight linearly in the spring-summer period as they did in the spring period, instead the rate live weight gain decreased with time from 28 November 2014 to 16 February 2015 which may have indicated that the sheep were approaching their mature weight.

Over the spring-summer period there was no difference in the pasture allowance (Table 4.2 & Figure 4.8). Apparent intake was greater on lucerne pasture with intakes of 1.41 and 2.21 kg DM/head/day for cocksfoot-lupin and lucerne pastures respectively.

During the spring-summer period sometimes the cocksfoot-lupin pastures composed of large proportions of lupin ranging from 12% to 57% (Figure 4.9B). When the sheep grazed the cocksfoot lupin over spring-summer the herbage disappearance data suggests sheep consumed both the cocksfoot leaf and the lupin leaf although cocksfoot leaf was consumed faster (Figures 4.13A & 4.14A). This suggests that sheep may initially tried to avoid the alkaloids which reach their highest concentrations during the summer (Kitessa 1992; Scott 1989). Lucerne fed sheep showed preference for the leaf component. (Figures 4.13B & 4.14B) In the cocksfoot-lupin pastures there was a high proportion of cocksfoot stem and dead material on offer in December and was not particularly palatable indicated by its presence increasing throughout the grazing period in the case of the cocksfoot stem. In the case of the dead material it remained a constant 400 kg DM/ha. The nutritive value of the stem and dead material was poor compare to the cocksfoot leaf or lupin leaf (Table 4.8). This may have resulted in the sheep having a limited pasture selection potential reducing voluntary intake.

The proportion of dead material was high in the cocksfoot-lupin pastures in January. It was higher than any other component and was avoided by the sheep (Figure 4.14). In response the sheep grazed lupin and cocksfoot green material down to low residuals. This meant the sheep fed cocksfoot-lupin had less ability to selectively graze pastures resulting in the pasture consumed being of lower reduced quality or quantity. The nutritive quality of the cocksfoot leaf was not high as the lupin leaf in regard to DMD, protein and ME (Table 4.8). Legume flowers where particularly acceptable to the sheep as they had always completely disappeared by the end of grazing (Figures 4.13 & 4.14). The disappearance of lupin flower is in agreeance with Scott (1989) who reported sheep show preference to the lupin flowers. While the flowers have a high nutritive value (Table 4.8), the low mass of flowers would have meant little flower volume was consumed per animal. Therefore the flower would have had little influence on overall nutritive intake. During the spring-summer DMD and ME was higher in the cocksfoot-lupin pastures and protein was higher in the lucerne pastures (Table 4.5). This occurred despite there being a high proportion of dead material in the cocksfoot-lupin pastures in December and January (Figure 4.14A). There was no significant difference in the DMD or the ME of the cocksfoot leaf and lucerne leaf/petiole. Protein content was greater in lucerne leaf/petiole (Table 4.6). Over the spring summer period there was no significant difference in the protein content of the lupin leaf and lucerne leaf/petiole. There was a very highly significant difference between the DMD and the ME of the lucerne leaf/petiole and the lupin leaf. Both of which were higher in the lupin leaves (Table 4.7). However lupin leaf was not consumed to the same extent as the lucerne.

The increased livestock performance on lucerne in the spring-summer period was due to the higher pasture intake on lucerne. The higher intakes lead to higher protein intake and total ME intake due to increases in intake volume. Intake was increased on lucerne pastures possibly due to the increased palatability which increased voluntary intake and the reduced selection ability of sheep on cocksfoot-lupin pastures due to high proportions of dead material and cocksfoot stem.

5.4 Autumn

By the end of the autumn period total live-weight gain was 768 kg/ha and 1126 kg/ha for cocksfoot-lupin pastures and lucerne pastures respectfully across the year. The autumn period contributed 129 kg/ha for cocksfoot-lupin and 131 kg/ha for lucerne pastures (Figure 4.3). Initially autumn growth rates on lucerne pastures was higher than on cocksfoot lupin pastures, with growth rates of 190 and 140 g/day respectively but on 16 April 2015 the live-weight of the lambs on the lucerne pastures plateaued and their live-weight gains were subsequently equalled by the cocksfoot-lupin pastures (Figure 4.2). By the end of the autumn period the lambs on the cocksfoot-lupin pastures had gained 14.1 kg/animal and 12.0 kg/animal for the lucerne pastures. The higher stocking rate of 19.1 animals/ha on lucerne pastures compared to 15.1 animals/ha on cocksfoot-lupin pastures (Figure 4.7) meant that by the end of the grazing period the difference in the cumulative live-weight gain between the two pastures was no different to the spring-summer period.

The allocation of feed was not significantly different across the autumn period (Table 4.2), however on 20 March, 24 April and 6 May 2015 there were differences in feed allowance (Figure 4.8), however at these occasions there was no significant difference in apparent intake (Figure 4.1). Apparent intake was not significantly different across the autumn period and was only significantly different on 9 March 2015 where all cocksfoot-lupin paddocks showed negative intakes. This was likely due to the nature of the quadrat method used where a sample is taken based on an estimate of the best representative site in the 'break'.

There were very few weeds (0.5%) (Table 4.3) in the lucerne pastures during the autumn period however the herbage on offer data during the autumn period (Figures 4.15 & 4.16) suggested that dead material was accumulating in both pastures but lucerne in particular. The increase in dead material decreased the nutritive value of lucerne pastures in autumn compared to other seasons and to cocksfoot-lupin pastures in the autumn period. Over the autumn period DMD was 64.7% and 46.1%, protein was 18.1% and 13.5% and ME was 10.1 and 7.6 MJ/kg DM for the cocksfoot-lupin and lucerne pastures respectively (Table 4.5). The DMD, protein and ME of lucerne all decreased substantially in May (Figures 4.17, 4.18 & 4.19). Reduction in the DMD of lucerne is associated with a reduction in stem to leaf ratio (Terry & Tilley 1964). Hughes *et al.* (1984) reported that lambs will avoid dead material more than sheep of other age classes. Therefore the quality of the pasture consumed by the animals is likely to be of higher quality than the pasture offered as a whole. This is shown in the clear reduction in lucerne leaf material and increase in dead material (Figures 4.15B & 4.16B). During the autumn period lupin only made up 15% of the pasture on offer (Table 4.3) so the sheep would have likely consumed more cocksfoot than lupin despite the higher nutritive value of lupin leaf (Table 4.8). In the autumn DMD and ME was higher in lupin, whereas protein was higher in lucerne (Table 4.7). The quality of lucerne leaf/petiole was greater for all reported nutritive parameters compared to cocksfoot leaf (Table 4.6). Therefore it was likely the lack of leaf material restricted the growth of lucerne fed lambs in the autumn.

5.5 Conclusions

This experiment supports the findings of Black *et al.* (2014) who found live-stock production was greater on lucerne than lupin, but still comparable.

Lucerne live-weight gain per hectare was greater in spring. The higher feed and protein intake on lucerne and potentially higher ME intake as a result of increased feed consumption may explain the observed difference in sheep live-weight gain per animal in spring. Lucerne animals may have eaten more due to faster intake and digestion rates. The lucerne pasture also may have been more palatable than both cocksfoot and lupin. Further, the increased stocking rate on lucerne allowed live-weight gain per hectare to exceed that of the cocksfoot-lupin pastures.

The increased livestock performance on lucerne in the spring-summer period was due to the higher pasture intake on lucerne. The higher intakes lead to higher protein intake and total ME intake due to increases in intake volume. Intake was increased on lucerne pastures possibly due to the increased palatability which increased voluntary intake and the reduced selection ability of sheep on cocksfoot-lupin pastures due to high proportions of dead material and cocksfoot stem.

During the autumn period there was no significant difference in individual animal production. This was likely due to the lack of lucerne leaf and accumulation of dead material which reduced the quality of the pasture and acceptance of the lambs. The higher stocking rate on lucerne pastures allowed the difference in cumulative live-weight gain from spring-summer to be maintained until the end of autumn.

From a nutritional standpoint, lupin-cocksfoot pastures provided quality forage over the entire season. The herbage disappearance data suggests that animals will eat lupin at all times of the year. Sheep showed preference for the lupin leaf component of lupin in particular. An advantage of the cocksfoot-lupin pastures was the ability to graze the pasture 41 days earlier than lucerne, possibly due to the cocksfoot component. Overall production on cocksfoot-lupin pastures was 70% of that of lucerne in the first year after establishment suggesting cocksfoot-lupin as an alternative forage in areas unsuitable for conventional forages such as lucerne.

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May the road rise up to meet you.

May the wind always be at your back.

May the sun shine warm upon your face,

and rains fall soft upon your fields.

And until we meet again,

May God hold you in the palm of His hand

-An Old Irish Blessing

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