Productivity and composition of perennial lupin pastures in response to six sowing rates, lime application and lupin type at Glenmore Station, Lake Tekapo

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Abstract
This study aims to identify the sowing rate necessary to produce lupin dominant and productive pastures in the New Zealand high country under low-moderate fertility, and a regime of late spring/early summer grazing. Blue and Russell lupin were sown on 12 December 2012 at rates of 2, 4, 8, 12, 16 and 32 kg/ha with cocksfoot at 2 kg/ha, and ± 3 t/ha lime. Low lupin sowing rates (<8 kg/ha) produced an open canopy with lupin density <4 plants/m^2, suitable for cocksfoot but also prone to re-invasion by resident species. The blue lupin population was ~5 plants/m^2 for sowing rates ≥8 kg/ha. The Russell lupin population was <4 plants/m^2 at sowing rates ≤16 kg/ha. Cocksfoot population was 1.3 and 1.9 plants/m^2 with blue and Russell lupin, respectively. Dry matter (DM) yield (excluding dead material) was 4.9 t/ha for spring 2014 and 2.1 t/ha for spring 2015, a difference attributed to the low spring rainfall in 2015. Blue lupin contributed more to the total DM yield than did Russell lupin as sowing rates increased. Cocksfoot dominated the remainder of production in spring 2014 but was on a par with resident species production in spring 2015. Summer and autumn regrowth to March 2015 was limited to ~1 kg DM/ha. There was no appreciable regrowth during December 2015-March 2016. A lupin sowing rate of 8 kg/ha was adequate. Blue lupin population was greater than Russell lupin.

Keywords: *Lupinus perennis L. polyphyllus*, plant density

Introduction
Perennial lupin has the ability to grow and persist in acidic soils with high aluminium where other more conventional legumes are unsuited (Davis 1981; White 1995; Scott 2014; Moir & Moot 2014). A review of the agronomic potential of Russell lupin (*Lupinus polyphyllus* L.) in the New Zealand high country identified the need for information on sowing rates of perennial lupin (Ryan-Salter *et al*. 2013). There has been a tendency to use low sowing rates to keep establishment cost to a minimum and rely on reseeding to increase the lupin population by allowing no grazing or only light grazing for several years. Scott (1989) has suggested rates of up to 8 kg/ha but concedes as little as 2 kg/ha can suffice if the lupins are not grazed initially and allowed to set seed. These pastures were then capable of 6-7 t DM/ha during spring in later years (Scott 2014). Black *et al.* (2014) studied DM yield and sheep performance of a perennial lupin dominant pasture at Sawdon Station, Lake Tekapo, sown in October 2003. The lupin was sown at 3 kg/ha and also contained oats, barley, annual ryegrass and white clover, but no cocksfoot. This pasture had been harvested in 2004 then grazed leniently for the first few years to allow the lupin to set more seed. Measurements in years 9 to 11 showed growth rates of ~ 75 kg DM/day during October and November, producing up to 6.7 t DM/ha (excluding dead material) including flower stalks by mid-December. This pasture provided adequate ewe and lamb performance compared with a control mob on lucerne and confirmed the dominance (90% of total DM) and longevity of the lupin. Moot & Pollock (2014) reported lupin yields of up to 9 t DM/ha for the first spring growth period (2013) of the current experiment but by March 2014 the lupin populations had decreased to 12 plants/m^2 or fewer at sowing rates of 8 kg/ha or lower. It remains to be seen whether the population has stabilised and the sward remains lupin dominant.

Scott (2001, 2007, 2008 and 2014) determined that low P fertility (Olsen P <20 and annual applications of 50-100 kg/ha of superphosphate fortified with 20-50% element S) favoured the dominance of lupin above other legumes for up to 12 years under moderate grazing; moderate grazing being the ‘best guess’ between a low stocking rate resulting in under-utilisation and a higher stocking rate potentially detrimental to pasture and stock productivity. Scott maintained the stocking rate by adjusting merino wether numbers in the ratio of 2:3:4 according to the feed available at the highest stocking.

For this study, plots were grazed each spring to eliminate the potential for any reseeding hence contamination of lupin types across plots. This study then examined whether higher sowing rates could indeed advance the utility of these pastures rather than accept delayed grazing in the first year to allow reseeding to build up the lupin population.

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Materials and methods

Site

The study area was at Glenmore Station, Lake Tekapo (43.9025°S, 179.4717°E) with full experimental and establishment details were given in Moot & Pollock (2014). This site was ~10 km north of and at the same altitude (~700 m) as the Mt John, Lake Tekapo site that Scott (2014) has studied extensively for more than 2 decades. Soil tests (Table 1) just before lime treatments confirmed its low fertility (Hill Laboratories 2016), with Olsen P<20 mg/l, pH <5.5 and Al >3 mg/kg. The Glenmore site was grazed, sprayed with glyphosate and the residue burnt in autumn 2012; then sprayed with glyphosate again one week before sowing the lupin and cocksfoot (*Dactylis glomerata*) in December 2012. Half the area had been sprayed with glyphosate in October 2011 but due to colder and wetter conditions than normal this failed to eliminate the resident pasture dominated by browntop (*Agrostis capillaris*) and Kentucky bluegrass (*Poa pratensis*). By autumn 2014, the lupin remained dominant and cocksfoot was well established (Moot & Pollock 2014). However, resident species persisted; these were Kentucky bluegrass, browntop and sweet vernal (*Anthoxanthum odoratum*), with only isolated occurrences of sorrel (*Rumex acetosella*), field speedwell (*Veronica arvensis*), striated clover (*Trifolium striatum*), cheatgrass (*Bromus tectorum*), haresfoot trefoil (*T. arvense*) and hawkweed (*Hieracium pilosella*). Other species were present but not seen in more than 5% of the plots.

Experimental

The experiment occupied 0.27 ha and was grazed in common with other experiments on a total area of 2 ha (Moot *et al.* 2015). Grazing occurred near the end of spring growth each year and in the autumn 2015 (Table 2).

The treatments, applied as a split-split-plot design in three contiguous blocks, consisted of nil or 3 t/ha lime (main plot; 15 x 30 m), six sowing rates; 1, 4, 8, 12, 16 and 32 kg/ha (sub-plot; 15 x 5 m), and two

Table 1 Soil tests results (0-7.5 cm depth), December 2011, before lime application in May 2012, and again just before sowing, December 2012.

Lime rate (t/ha)	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Ca (QTU)*	Mg (QTU)	K (QTU)	Na (QTU)	Al (mg/kg)
	Pre-treatment, December 2011							
0	5.1	15	23	3	14	8	6	8.9
	Before sowing, December 2012							
0	5.0	13.7	18.7	5.7	15.7	6.3	3.3	5.0
3	5.5	36.0	23.3	10.0	12.3	4.7	3.3	2.2

* QTU, Quick test units (me/100g)

Table 2 Measurement schedule. Lupin and cocksfoot density was determined from plant counts in six 0.5 m^2 quadrats per plot; herbage mass from cuts to 5-8 cm in one quadrat per plot. Pasture probe measurements, calibrated to current conditions, were used as proxy determinations of herbage yields only at times when plant height was <30 cm.

Date	Plant pop.	DM yield	Ground cover	Grazing* and other notes
2014				
19 Nov	✓	Quadrat (0.5 m^2)	✓	followed by 675 ewes for 3 days
27 Nov	n/a	Quadrat (0.5 m^2)	n/a	Residual DM
2015				
23 Mar	n/a	Pasture probe	n/a	600 ewes for 2 days in late April.
15 Oct	✓**	Pasture probe	n/a	lightly grazed, 300 ewes for 3 days
31 Oct	n/a	Pasture probe	n/a	Residual DM
1 Dec	n/a	Quadrat (2.5 m^2)	n/a	no grazing: lupins left to reseed
2016				
Jan-Apr		Drought conditions. Pasture monitored but no measurements taken.		

* All grazing was in common with the whole 2.0 ha paddock.
** Lupin population was split between mature, 5 or more leaves per plant, and immature plants.

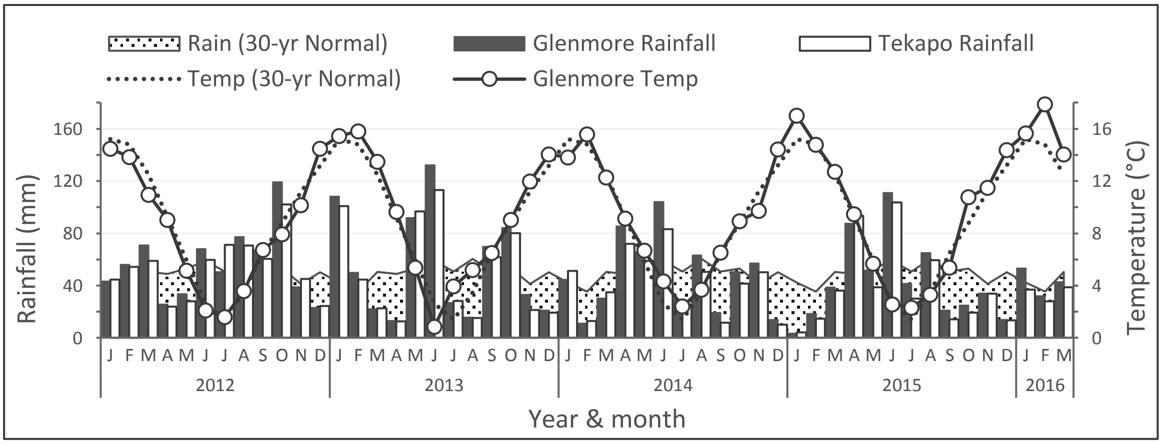

Figure 1 Rainfall and temperature data recorded on the trial site at Glenmore Station; and Tekapo rainfall and 30-year normal temperature and rainfall from Lake Tekapo EWS climate station (NIWA CliFlo data 2016). Updated from Moot & Pollock (2014).

perennial lupin types (sub-sub-plots; 15 x 2.5 m). There was a 0.8 m unsown border strip between the long edges of sub-plots. Lime was applied, once only, in the autumn before sowing. Cropmaster 20 (100 kg/ha, N:P:K:S - 19.3:10:0:12.5) was direct-drilled with the seed. The Russell lupin is a hybrid of *L. polyphyllus* × *L. arboreous* and possibly other lupin species (Edward 2003). Both the Russell and blue lupin were supplied by a local commercial grower but were not registered cultivars. Two kg/ha of Vision cocksfoot (*Dactylis glomerata*) were sown with the lupin seed in all plots. ANOVA (Genstat Release 18.1 © 2015) was applied to measurements of lupin and cocksfoot populations (plant/m^2), ground cover estimates (%) and dry matter (DM) yields. Means separation used Fisher's protected least significant difference ($LSD_{0.05}$) test.

Measurements

All growth ceased over the winter and above-ground green material was largely absent. The spring (September-November) herbage yield was therefore the accumulated growth beginning slowly in August and accelerating through spring. Measurements were made on six occasions (Table 2) with intermediate monitoring and observations by the farm owner and by Lincoln University staff and students.

Clumps of lupin or cocksfoot were counted as single 'plants' since it was not feasible to determine whether a clump consisted of one or several individuals.

Percentage ground cover of lupin, cocksfoot, resident species and bare ground including litter was estimated visually during a walk through each plot. The component with the greatest cover within each plot was given an approximate percentage and all other components scored relative to it; all component scores within each plot were then normalised to total 100%.

Harvested herbage, cut to 5 cm height, was separated into lupin, cocksfoot, other (resident) species and dead leaves. Resident species were lumped together as 'other' grasses, 'dicot' weeds and other legumes or just as 'resident' for analysis. Dead material that was not part of the current season's growth, e.g., old flowering stalks and dead leaf sheaths was discarded. The pasture probe, being insensitive to vegetation >30 cm height, was only used when there was no live material above this height, for example in mid-spring before the flower stalks of lupin elongated above the leaves. The pasture probe was calibrated to material harvested from ~10 quadrats selected to represent the range of yield on each probe assessment date.

Temperature and rainfall were recorded on site and compared with NIWA (2016) temperature and rainfall records from Lake Tekapo.

Results

Monthly rainfall was below normal for December 2014 - March 2015 and again from September through December 2015 (Figure 1); and, with higher than normal temperatures, this resulted in the driest periods since the inception of this experiment in 2012. Rainfall from April through August in both years of this study was adequate to recharge the soil. However, the low rainfall in September in 2014 and throughout the spring of 2015 could not maintain adequate soil moisture for optimum growth through spring. Also, normal rainfall during January to March 2016 along with above average temperature was insufficient to alleviate the soil moisture stress or sustain pasture growth.

Plant population

Lime had no effect (P>0.05) on either lupin or cocksfoot plant density.

November 2014: There was a lupin x sowing rate interaction (P≤0.05) with blue lupin reaching its

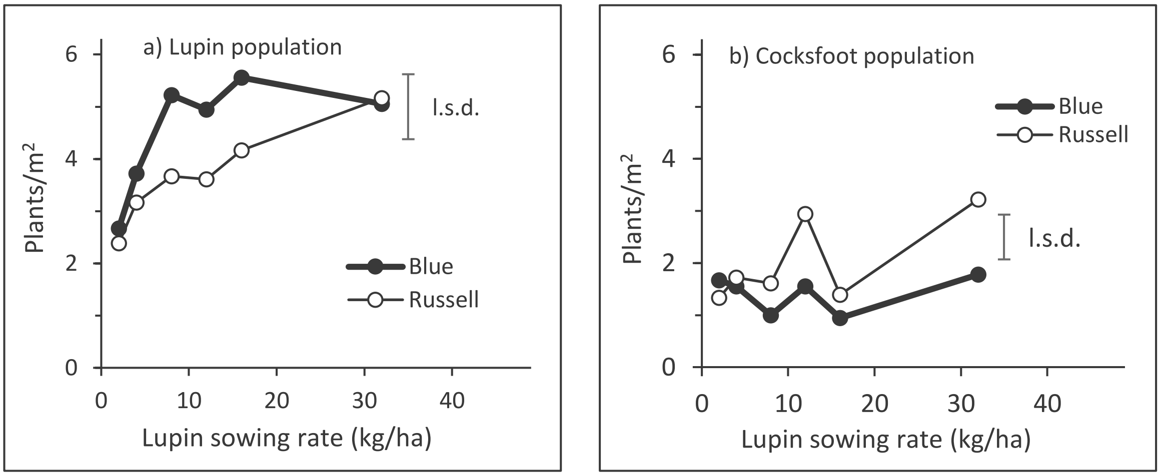

Figure 2 Plant populations for lupins (a) and cocksfoot (b) on 19 November 2014 at Glenmore Station in response to six sowing rates and lupin type.

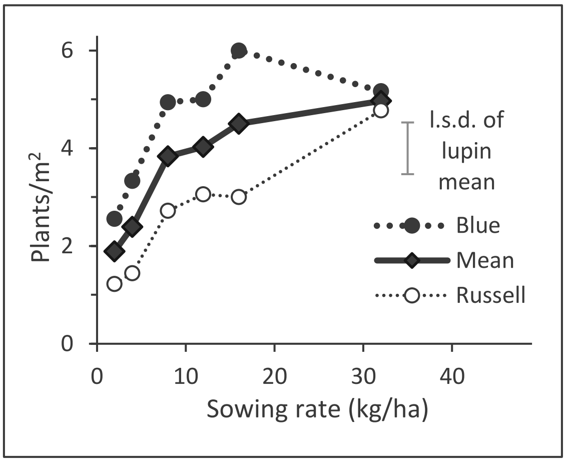

Figure 3 Lupin plant density on 15 October 2015 at Glenmore Station in response to six sowing rates of lupin. The mean is the grand mean of the two lupin types. The l.s.d. is shown for the lupin mean only. There was no lupin type x sowing rate interaction. Blue and Russell lupin types are shown separately only for comparison to Figure 2a.

maximum population of 5 plants/m^2 at 8-16 kg seed/ha (Figure 2a). Russell lupin showed a near linear response to sowing rate increasing from 2 to 5 plants/m^2. The cocksfoot population with blue lupin was mostly <2 plants/m^2 (Figure 2b). However, the cocksfoot response with Russell lupin was variable with up to 3 plants/m^2 and no clear trend ($P \leq 0.01$ for the lupin type x sowing rate interaction).

October 2015: There were no treatment interactions ($P > 0.05$) for lupin populations but there was a lupin type ($P \leq 0.001$) and a sowing rate ($P \leq 0.001$) effect. Blue lupin populations averaged 4.5 plants/m^2 and Russell lupins 2.7 plants/m^2. Overall, the lupin populations averaged 3.6 plants/m^2, and increased from 2 to 5 plants/m^2 with increasing sowing rate ($P \leq 0.001$ for sowing rate effect). In Figure 3 the lupin types are shown separately to illustrate the similar patterns to the previous year (cf. Figure 2a). This does not infer a significant lupin type x sowing rate interaction. Immature lupins, not included in Figure 3, contributed 1.2 plants/m^2 and showed no significant effects of treatment. There were only six lupin seedlings (plants with cotyledons still attached) recorded from all the 432 quadrats (0.5 m^2) measured.

The cocksfoot population was 1.3 and 1.9 plants/m^2 sown with the blue and Russell lupin, respectively ($P \leq 0.001$). There was no effect of lupin sowing rate on cocksfoot plant density ($P > 0.05$); and a regression analysis showed there was no overall relationship between lupin and cocksfoot plant densities ($R^2 = 0.037$).

Ground cover (November 2014)

ANOVA results showed different responses to the treatments for the various components (Figure 4).

When sown at ≥8 kg seed/ha without lime, blue lupin comprised ~60% of ground cover ($P \leq 0.05$ for the 3-factor interaction,). In contrast, the cover of Russell lupin was <20% of ground cover at all seed rates with 3 t/ha lime applied.

Cocksfoot ground cover was 22% with 3 t lime/ha and 9% without ($P \leq 0.05$). Cocksfoot cover, growing with the blue lupin, was 14% and did not change with lupin sowing rate. In contrast, cocksfoot cover with Russell lupin was 17% but showed no clear trend to the increase in lupin sowing rate ($P \leq 0.05$ for lupin type x lupin sowing rate interaction).

Other grasses declined from 23 to 6% cover with increasing lupin sowing rates ($P \leq 0.01$) and averaged 12 and 19% cover with blue and Russell lupin, respectively ($P \leq 0.01$). Other grass cover showed no lime response ($P > 0.05$). Dicot weeds with lime averaged 5% cover. With no lime, their cover was 29% at the low lupin

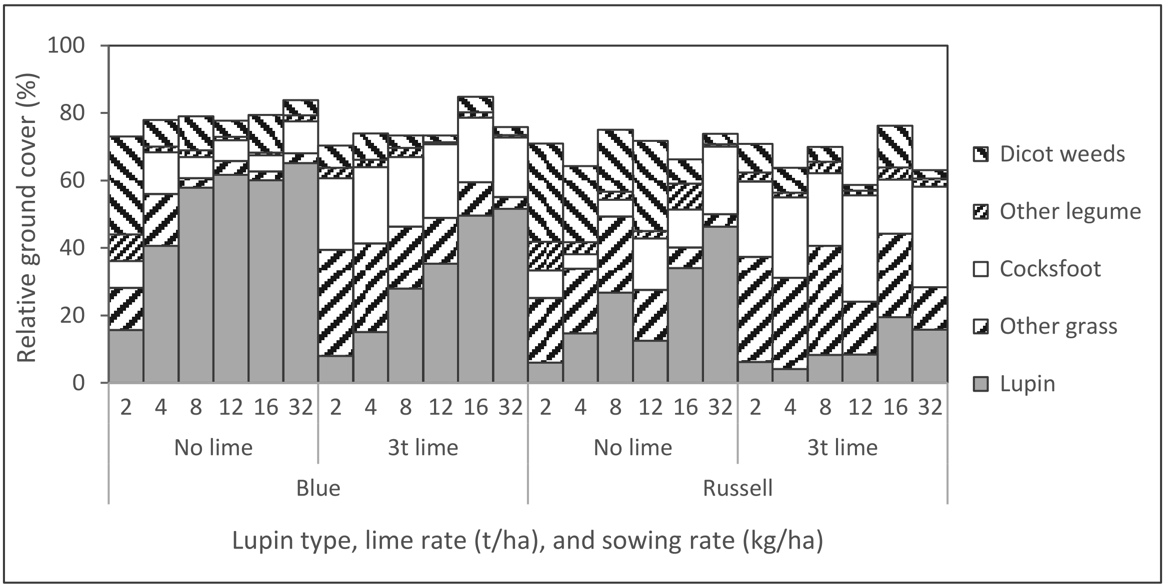

Figure 4 Percentage ground cover of the perennial lupin pasture components on 19 November 2014 at Glenmore Station in response to treatments applied before sowing (lime) and at sowing (sowing rate and lupin type) in December 2012. See text for statistical effects of treatments.

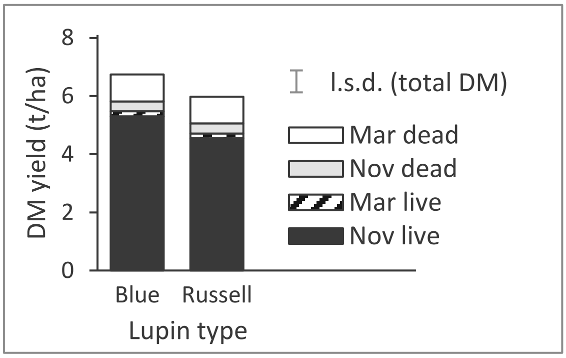

Figure 5 November 2014 and March 2015 contributions of live and dead material to the total annual DM yield in response to the sown lupin type at Glenmore station.

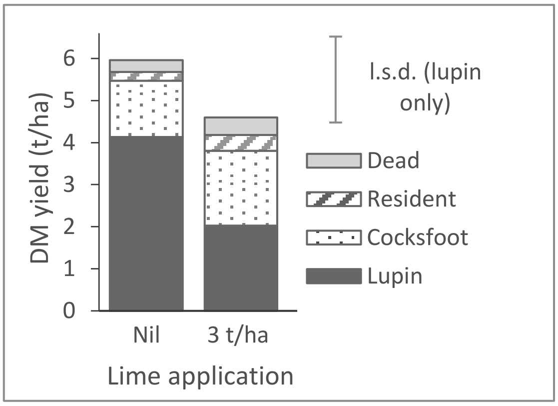

Figure 6 Lupin DM yield on 19 November 2014 at Glenmore station in response to ±lime application in the autumn before sowing in December 2012. Only lupin responded to the lime treatment. The other DM components are included for comparison to the lupin.

sowing rates, decreasing to 4% at the highest lupin sowing rate (P≤0.05 for lime x sowing rate interaction). The adventive annual legumes (mostly striated clover and some haresfoot trefoil) comprised up to 6% cover at the lowest sowing rate and averaged 2% for the remaining sowing rates (P≤0.01). Bare ground comprised 31% of the total ground area for Russell lupin and 23% for blue lupin (P≤0.001).

DM yield

Spring 2014 to March 2015

The annual total DM yield, was 6.6 and 5.8 t/ha for blue and Russell lupin, respectively (P≤0.05; Figure 5). DM yield (excluding dead material) was 5.5 and 4.7 t/ha for the blue and Russel lupins, respectively (P≤0.05). Most growth had occurred during spring. On 19 November, blue lupin yield was 5.3 t DM/ha and Russell lupin yield was 4.6 t DM/ha (P≤0.05). Dry conditions followed the November harvest and grazing (Figure 1).

There were no treatment effects on the herbage yield in March 2015. Lupin leaf dominated the small yield in March (0.17 t/ha) and the dead material (0.92 t DM/ha) was mostly remnants of the lupin flowering stalks and desiccated flowering stems of the resident grasses.

The spring DM yield comprised mostly lupin and cocksfoot. For lupin, the lime had no significant effect on the total DM yield (excluding dead material) to November 2014 but had an effect on the lupin yield (2.0 and 4.1 t/ha) with and without lime, respectively (P≤0.05; Figure 6). Also, the DM yield of blue lupin

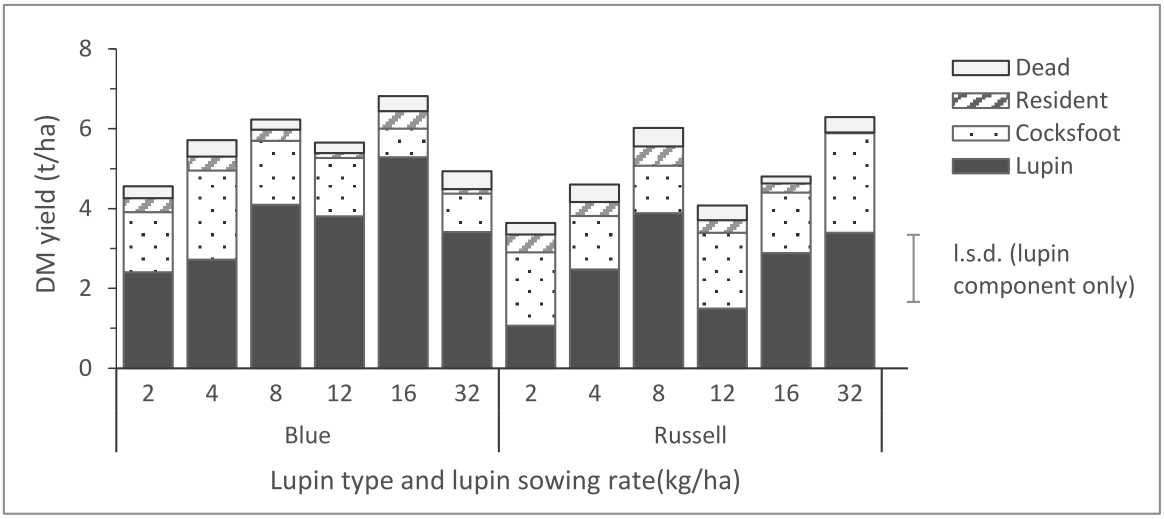

Figure 7 Lupin DM yield on 19 November 2014 at Glenmore station in response to the lupin type x sowing rate interaction. The other pasture components did not respond to the treatment interaction but are included for comparison.

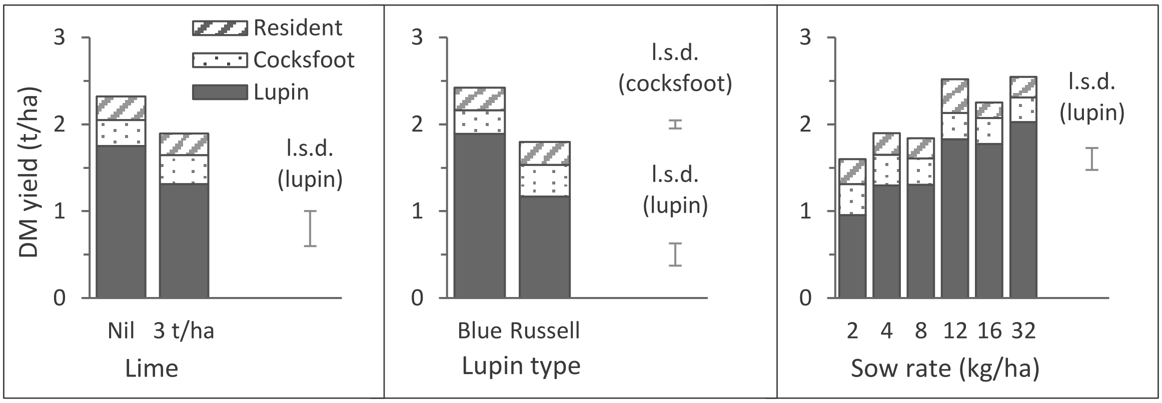

Figure 8 Lupin DM yield in spring 2015 at Glenmore station in response to lime, lupin type and lupin sowing rate; and cocksfoot DM response to lupin type. The contribution of resident species to total DM yield is shown for completeness.

increased from 2.5 to 5.0 t/ha with increased sowing rates <32 kg/ha (Figure 7). The Russell lupin yield response to sowing rate, was significant ($P \leq 0.05$) but showed no consistent trend. Cocksfoot, (Figures 6 and 7), averaged 1.6 t/ha and showed no response to any of the treatments. There were also no treatment effects on the other yield components.

Spring 2015 – March 2016

The mean total DM yield (excluding dead material) during the spring to 1 December 2015 was 1.8 t/ha. Figure 8 shows a) lupin DM yield was 1.3 t/ha with lime and 1.7 without ($P \leq 0.05$), b) lupin DM was 1.9 t/ha for blue lupin and 1.2 t/ha for Russell lupin ($P \leq 0.001$) and c) lupin DM increased from 1.0 to 2.0 t/ha with increasing sowing rate ($P \leq 0.01$). Cocksfoot DM yield was 0.3 and 0.4 t/ha with blue and Russell lupins, respectively (Figure 8b; $P \leq 0.05$).

Intermittent summer rain resulted in some expansion of green leaf but the intervening dry periods soon dried out the pasture again. No quantitative measurements were taken.

Discussion

Lupin yield and dominance

Pasture productivity on soils of low fertility, low pH, and high exchangeable Al can be improved by getting the species right, for example, perennial lupin and cocksfoot; or by improving soil fertility and pH and reducing Al levels for more conventional legumes (Davis 1981; Scott 2001, 2008). The former approach has tended to use low sowing rates for both farm and experimental pastures then apply lenient or no grazing for several years to allow the lupin to establish, set seed and slowly increase productivity over several years. This study, based on the low input approach (except for the lime treatment) with no additional fertiliser after sowing, has shown that the 8 kg/ha of lupin seed was sufficient to produce lupin dominant pasture through to the end of the third spring growth, December 2015 (Figure 8).

Spring production at the lupin sowing rate of 8 kg/ha had declined from 9.1 t/ha in at the December 2013 harvest (Moot & Pollock 2014) to <6 t/ha by 19 November 2014 (Figure 7) and <2 t DM/ha by 1 December 2015 (Figure 8). This corresponded to September - November rainfalls of 187, 127 and 80 mm, respectively, with only spring 2013 being above normal. Scott (2007, 2008, for example) recognised that the grazing capacity (an indication of pasture productivity) fluctuated according to climate-determined pasture growth, but did not examine closely the influence of monthly or annual climate data, rather the overall climate effect of rainfall and temperature over several decades.

Lupins remained dominant in these pastures (Figures 6, 7 & 8), more so without lime, blue lupin was more productive than Russell lupin, and lupin dominance mostly increased with sowing rate except for November 2014 where Russell lupin did not show a consistent trend to increased sowing rates (Figure 7). There was some productivity advantage of using up to 16 kg/ha of lupin seed (Figures 7 & 8) but this extra production may not be cost effective. The fact that the lupin in this study has retained dominance under such contrasting rainfall seasons is consistent with Scott's work and with the results of Black *et al.* (2014).

Overall, blue lupin was higher yielding than the Russell lupin. This is understandable because Russell lupin has been selected for its variation in flower colours (Edward 2003) rather than its agronomic potential. It also suggests that there is potential for genetic selection for improved agronomic performance of perennial lupin.

The perennial lupins were less productive with the application of 3 t/ha of lime (Figures 6 & 8) but this did not translate to any significant lime effects in the total sward production. This suggests some compensatory yield from the other sward components. Some evidence of this was provided by Moot & Pollock (2014) who showed that grazing intensity (ratio of herbage removed) at the December 2013 grazing was greater with lime; and the November 2014 ground cover was proportionally greater for cocksfoot and other species relative to lupin in response to lime application (Figure 4). The grazing in December 2013 was intense and left little or no green leaf. Scott (2007) noted that an increased stocking rate produced instability in the lupin/cocksfoot/other dominated vegetation types.

The mechanism, whether it be was lime-induced, grazing preference or a slight shift in soil resource availability (Laliberte *et al.* 2012), is beyond the scope of this study. However, a precautionary interpretation of the lime effect is necessary because nil lime plots had been established on a previous experimental site on which herbicide was applied in October 2011 and legumes (lucerne, lupin and Caucasian clover) sown in November 2011. It was abandoned by summer 2012 mainly because the resident species were inadequately controlled; then managed as the nil lime rate treatment for the current experiment. It is therefore difficult to determine conclusively whether a) the lupin was adversely affected by the lime or b) the competition from resident species was reduced by the extra herbicide applied before the no lime treatment. Russell lupin and Caucasian clover in an adjacent experiment sown at the same time and with the same pre-sowing preparation as the 3 t/ha lime treatment (i.e., no herbicide applied before autumn 2012) did not respond to lime at 0-4 t/ha (Moot *et al.* 2015).

Grazing

This study has differed from the Mt John studies (Scott 2014), and Black *et al.* (2014) in that grazing, hence utilisation, was included from an early stage, for example, June 2013 at 6 months after sowing, then early December 2013 and March 2014 (Moot & Pollock 2014), and continued in November 2014, March 2015 and December 2015. The late spring or early summer grazing each year also occurred at the time of flowering. This resulted in the near complete removal of flowers and all but eliminated the potential for reseeding.

This study has provided a rigorous test for the sowing rate but we do not necessarily promote the grazing regime employed. Scott (2011) tested annual versus biennial grazing of pasture mainly dominated by lupin and cocksfoot for years 2-7 and concluded that spelling was not likely an issue in pasture maintenance. But he did find that the autumn grazing without previous spring grazing allowed lupin to increase in abundance relative to a regime of grazing in December or grazing in December and autumn. The presence of immature lupin plants recorded on 15 October 2015 and few seedlings (plants with cotyledons) indicated there may have been some seed germination the previous autumn. The source of this seed may have been the occasional reproductive stalk that had avoided being grazed in previous years. This suggests that some light grazing in early to mid-spring, then allowing some flowering and seed production over summer, may be all that is needed to increase the stand density rather than re-sowing.

In the absence of grazing, as occurs along roadsides and non-pastoral land (Ryan-Salter *et al*. 2013), it is clear that natural reseeding and colonisation by perennial lupin occurs which is of concern on conservation land (Department of Conservation 2014; Wardle 2016). Lupin flowers are highly palatable and grazing before seed set can be used to control their spread. Conservation values can be respected by not planting lupin near conservation land or near streams which can carry the seed to river beds.

Cocksfoot productivity

Cocksfoot is regarded as the most suitable companion grass for perennial lupin in high country grazing systems (Ryan-Salter *et al.* 2013) but requires moderate fertility to make a moderate contribution as a secondary species (Scott 1989, 2001, 2011, 2014). There are no published data showing the individual DM yields of lupin and cocksfoot, just the relative abundance. However, Scott reached his conclusions based on more than 2 decades of cocksfoot's suitability in competition with more than two dozen resident and sown species under low to high fertility and low to high grazing intensities. In the present study, cocksfoot DM yield was similar to that of the resident species (Figure 8), each providing <0.4 t DM/ha, whereas lupin yielded from 1.0 to 2.0 t DM/ha with the increasing sowing rates. However, in the previous year DM yield of cocksfoot exceeded lupin yield where lupin yield was <2 t/ha. It is suggested that higher yield of cocksfoot in spring 2014 may have been the consequence of a flush of soil N following the grazing of the 9.1 t/ha lupin yield in December 2013 (Moot & Pollock 2014). The sheep also had grazing access to other trials containing lupin and other legumes.

Lupin plant density

The lupin population for sowing rates ≥8 kg/ha had declined from >12 plants/m^2, measured at 3 months after sowing (Moot & Pollock 2014), to <5 plants/m^2 by October 2015. At December 2015, there were only weak linear relationships between lupin yield and densities ($y = 0.22x + 0.9$, $R^2 = 0.26$; and $y = 0.24x + 0.53$, $R^2 = 0.30$; for blue and Russell lupin, respectively). It is recognised that lupin dominance or abundance in grazed pasture can be increased by allowing the lupin to set seed (Black *et al*. 2014; Scott 1989, 2011). There are no published data on the optimal density for productive lupin, and no other lupin yield data in relation to plant density. The immature plants and a few seedlings counted in this study indicated there was potential for seedling regeneration but no evidence that these young plants were reaching maturity under the grazing management used. Any attempt to identify the parentage of these few seedlings was negated by having the lupin types sown side by side.

Cocksfoot plant density

The low cocksfoot plant density (<2 plants/m^2) may have been due to poor seed burial at sowing. Cocksfoot was mixed with the heavier lupin seed. Forced air, used to distribute seed to the drill's coulters, caused much of cocksfoot seed to be blown out of the tined slot. This was recognised as a potential problem at the time of sowing and subsequent modifications to the air flow design were incorporated into the precision seed drill (John Stevens pers. comm.). The cocksfoot population density was unaffected by the lupin population density thus it is possible that a higher population of cocksfoot could be supported. In contrast, there was no regression relationship between cocksfoot yield and density ($R^2 = 0.08$) in spring 2015 indicating that the cocksfoot may have been at the limit of its productivity without additional P and S fertiliser (Scott 2001).

Percentage ground cover

The percentage ground cover (Figure 4) did not fully represent the abundance or potential yield of any of the herbage components. It did show that the resident species occupied considerable space between the taller lupin and cocksfoot clumps. These resident species have the potential to increase if grazing or other factors such as fertility limit the growth and productivity of the lupin and cocksfoot (Scott 2001). In the present study, both cocksfoot and lupin clumps increased rapidly in height and breadth in spring under the regime of lenient (spring 2015) or no grazing (spring 2014), lupin more so than cocksfoot, whereas the resident grasses and annual clover and broadleaf weeds were barely above the cutting height of 5 cm at harvest. Thus cover data (Figure 4) showed a strong presence of other species where lupin and/or cocksfoot cover was low, whereas the recorded DM yield of the resident species (Figure 7) was only 5-10% of the total yield.

Conclusions

A sowing rate of 8 kg/ha for perennial lupin and 2 kg/ha of cocksfoot was sufficient to produce a productive, lupin dominated pasture at 2-3 years after sowing.

- Blue lupin performed better than Russell lupin
- Cocksfoot was suitable as the complementary grass
- Resident species have persisted but have not overwhelmed the lupin/cocksfoot
- Seasonal yields were highly temperature and rainfall dependent.

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REFERENCES

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

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

Department of Conservation 2014. Weed: Russell lupin. http://www.doc.govt.nz/conservation/threats-and-impacts/weeds/common-weeds-in-new-zealand/russell-lupin/. Date unspecified. Accessed July 2014.

Edward, P. 2003. The Russell lupin story. National Council for the Conservation of Plants and Gardens. 48 pp. (ISBN 0-9544579-0-0).

Hill Laboratories 2016. Soil Aluminium Test Interpretation. www.hill-laboratories.com/file/fileid/45431. Accessed May 2016.

Laliberté, E.; Shipley, B.; Norton, D.A.; Scott, D. 2012. Which plant traits determine abundance under long-term shifts in soil resource availability and grazing intensity? *Journal of Ecology 100*: 662-677.

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

Moot, D.J.; Pollock, K.M. 2014. Perennial lupin establishment and yield when sown at six different rates at Glenmore Station, Lake Tekapo. *Proceedings of the New Zealand Grassland Association 76*: 53-60.

Moot, D.J.; Moir, J.L.; Pollock, K.M.; Berenji, S. 2015. Forage establishment and management in the high country of New Zealand. *June Report to New Zealand Merino Company Ltd*. 115 pp. http://www.lincoln.ac.nz/PageFiles/23855/New Zealand Merino Company Report 2015.pdf. Accessed May 2016.

NIWA CliFlo Database. 2016. http://cliflo.niwa.co.nz/. Accessed April 2016.

Ryan-Salter, T.; Black, A.D.; Lucas, R.J.; Moot, D.J. 2013. Agronomic potential of Russell lupin (*Lupinus polyphyllus* L.) as a legume for high country grazing systems. Literature review. http://www.lincoln.ac.nz/PageFiles/23855/2013-07-10-Agronomic-potential-of-Russell-lupin.pdf.

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

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

Scott, D. 2007. Sustainability of high-country pastures under contrasting development inputs. 9. Vegetation dynamics. *New Zealand Journal of Agricultural Research 50*: 393-406.

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

Scott, D. 2011. Effect of biennial spelling from grazing of a high country, moderate input, mixed pasture. *Proceedings of the New Zealand Grassland Association 73*: 115-118.

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

Wardle, P. 2016. War of the lupins. *New Zealand Geographic 137*: https://www.nzgeo.com/stories/war-of-the-lupins/ accessed April 2016.

White, J.G.H. 1995. A review of legume introduction in tussock grassland with particular reference to species tolerant of low nutrient inputs. *Proceedings of the New Zealand Agronomy Society 25*: 77-85.