New Zealand Merino Company

Forage establishment and management
in the high country of
New Zealand

June Report 2013

Lincoln University

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Executive Summary

The series of experiments have provided several key findings that can be drawn from across sites. Lucerne – has been successfully established and is being integrated into a grazing system at Bog Roy. Two highly successful field days have been held on site and raised awareness means several farmers have enquired about lucerne conversions on their property. However, results at Glenmore highlight the issues of lucerne establishment in the high country. The patchy survival and poor growth have been caused by high soil aluminium which restricts root development and nodulation. This can be overcome in the top soil with the application of lime but the economics of this will be dependent on each individual property. At Quailburn, where lime was applied to overcome lucerne toxicity, root growth has been horizontal rather than vertical. This has resulted in a comparatively successful establishment but the longevity of the stand is questionable. Before sowing lucerne deep soil auguring to at least one metre is recommended with routine tests for aluminium at 4 depths required. Site selection for lucerne needs to be fully investigated to ensure aluminium levels are below 3 mg/kg. Overcoming aluminium constraints with surface applied lime will be time consuming and the rate of lime penetration will be investigated in a parallel Ballance agri-nutrients funded research programme. Equally, the ability to supply lime at depth will be investigated as part of the PhD programme. Where lucerne is possible to be grown it should be. Where soil constraints (aluminium or depth) prevent this other legumes will be more appropriate.

Caucasian clover continues to show its potential as a legume for high country environments but there are some technical aspects that need to be overcome before it will thrive. These are being examined based on results at Lake Heron. Confirmation of nodulation favour and a response to low fertilizer (line and P) inputs have been made but seed supply and fresh inoculant remain impediments to wide spread uptake. At Glenmore, Caucasian clover has thrived in the higher aluminium environments and is suitable as a companion species with lupins. Lotus remains a viable option for high aluminium environments but sed availability and grazing constraints currently limit its use on farm. Balansa and white clover showed the need for lime to grow at Glenmore but balansa may be a suitable companion in a mix with lupin. Lupin results at Glenmore and Sawdon continue to be encouraging. Both blue and Russell lupin were successfully established in December at 8 kg/ha with 30% emergence. Populations were sufficient to give 80% ground cover but sown companion species (cocksfoot and Caucasian clover) have failed to thrive. The resident species have responded to lime applications but the lupins themselves have shown little response. Lupin establishment at Ashley Dene and Omarama station failed and so there is still some question over the ease of establishment. The grazing of lupins at Sawdon station continues to show pleasing results relative to conventional pastures and initial results show wool growth may be enhanced.

Annual clovers have failed to regenerate in large numbers at any of the trial sites but they have been shown to survive, complete their life cycle and set seed. Alternative strategies of spring sowing or using a paddock for seed are being trialled at farm scale at Omarama station and Mt Grand. The project has generated a high level of activity with two PhD and four Honours students now working on related projects to address some of the science questions in more detail.

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Site 1 – Sawdon Station

Lupin grazing trial

Primary objective

To quantify animal performance and grazing preference on lupins vs. control (lucerne and clover-based) pastures. Emphasis is on documenting nutritional changes in lupins at different phenological stages e.g. vegetative, flowering, green pods, mature plants.

Goals

- Quantify ewe and lamb liveweight gain during lactation.
- Compare the growth rates of weaned lambs grazing either lupins or lucerne.
- Scanning % of ewes flushed on all pastures (1 March – 31 May grazing period).
- Ascertain approximate grazing day data for lupins.
- Determine dry matter production, botanical composition and nutritive value of lupin stands.

Site and soil

The lupin stand was located beside Edward Stream, 1 km south west of State Highway 8 (44°03’54” S 170°29’22” E elevation 677 m). It was divided into five paddocks of similar size (Figure 1.1). Olsen P, pH and sulphate S were optimum and soil Al was low (Table 1.1)

Table 1.1 Pre-treatment (2011) soil analysis for the lupin block at Sawdon Station.

Sample	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
Lupins	6.0	24	9	4	25	13	5	<0.5

- The pH, Olsen P and sulphate S are at optimum levels at this site, while soil aluminium is low.
- As a result, maximum growth would be expected from the lupins at this site, provided that soil moisture is not limiting.

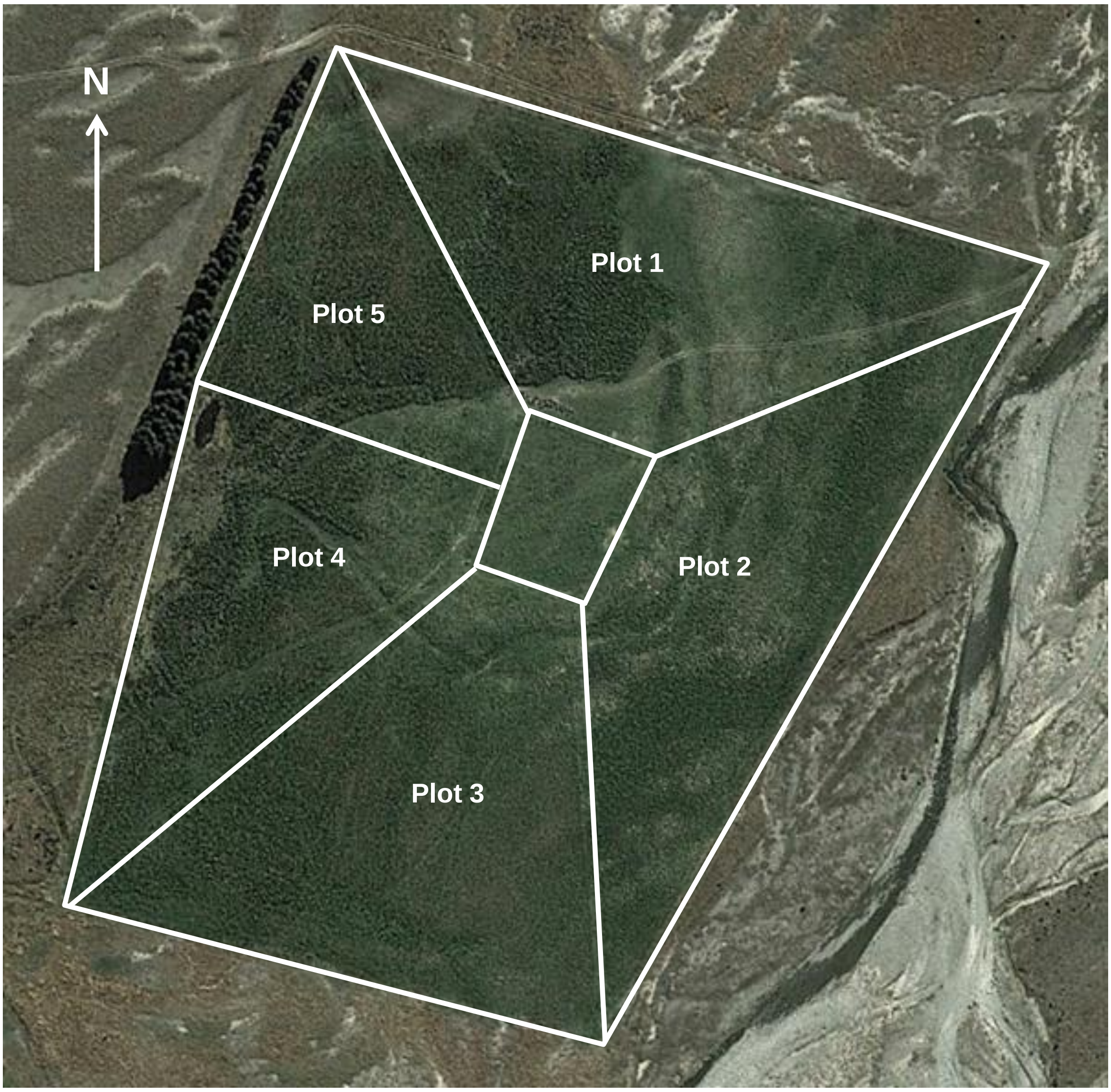

Figure 1.1 Lupin grazing trial at Sawdon Station.

Results

Stock performance on lupin

Trial 1: Ewes and lambs pre-weaning (2011/12)

On 12 December 2011, lactating 2-tooth ewes and their lambs were assigned to a lupin mob (143 ewes and 114 lambs) and a lucerne control mob (320 ewes and 234 lambs), weighed and started on their respective pastures. Lambs and ewes were weighed once a month, and lambs were weaned on 10 February 2012 and sold on the Tekapo sale. This trial showed that stock will eat lupin and the performance of ewes and lambs in this experiment was satisfactory. The ewes and lambs in the control mob gained 91 and 218 g/day, respectively, whereas in the lupin mob the ewes lost 55 g/day and the lambs gained 164 g/day (Table 1.2)

Table 1.2 Average liveweights of Merino ewes and lambs on lupin and lucerne (control) over 55 days from December 2011 to February 2012 at Sawdon Station.

Date	Lupin mob		Control mob	
	Ewes	Lambs	Ewes	Lambs
	Live weight (kg)			
12 Dec. 2011	56	19	55	18
17 Jan. 2012	54	23	56	25
10 Feb. 2012	53	28	60	31
	Liveweight gain (g/day)			
	-55	164	91	218

Trial 2: Ewes pre-tupping (2012)

On 23 March 2012 mixed aged ewes were assigned to a lupin mob (120) and a control mob (90), weighed and started on their respective pastures. The lupin mob was shifted fortnightly so that each of the four plots was grazed once over a period of eight weeks. The control mob was stocked on lucerne for the first four weeks until the lucerne was frosted, and then on triticale for the remaining four weeks. The ewes were weighed again on 19 April (27 days) and 18 May (56 days). Ewe liveweight gains pre-tupping were on average 7 kg on lupin and 9 kg on control pasture (Table 1.3).

Table 1.3 Average liveweights (including the range of liveweights in parentheses) of Merino ewes on lupin and in the control group (lucerne and triticale) over eight weeks from March to May 2012 at Sawdon Station. Both mobs were stocked at comparable stocking rates.

Date	Lupin mob	Control mob
	Liveweight (kg)	
23 Mar. 2012	54 (51-59)	53 (50-58)
19 Apr. 2012	57 (53-64)	59 (51-65)
18 May 2012	61 (57-68)	62 (56-69)
	Liveweight gain (g/day)	
	125	161

Trial 3: Lambing to weaning (2012/13)

On 11 October 2012, 119 pregnant mixed age ewes (average 66 kg), which had been mated on lupins, were set stocked in approximately equal numbers on four of the five plots (7.5 ha) of lupin for lambing. After tailing (14 December) the lupin mob was put into plot 1, which had been closed during spring, and then rotated around the five plots over summer (normally 2 weeks/plot) until weaning on 18 February. The ewes and lambs were weighed again at tailing and weaning along with a sample of ewes and lambs on the lucerne and also a sample on native pastures (average 63 kg at start). Lambs were counted at tailing to determine lambing percentage. Stock performance is given in Table 1.4.

Table 1.4 Average liveweights (including the range of liveweights in parentheses) and lambing percentages of Merino ewes and lambs on lupin, lucerne and 'native' grassland (control mobs) from lambing in October 2012 to weaning in February 2013 at Sawdon Station.

	Lupin mob		Lucerne control mob		Native control mob	
Date	Ewes	Lambs	Ewes	Lambs	Ewes	Lambs
			Liveweight (kg)			
11 Oct.	66	-	63	-	63	-
14 Dec.	58 (46-66)	20 (12-27)	61 (46-82)	21 (12-29)	55	16
18 Feb.	58 (52-67)	28 (17-39)*	64 (52-78)	31 (20-40)	62 (54-81)	30 (18-40)
			Lambing percentage (%)			
14 Dec.	103		93		106	

* Ewe lambs: 28 (17-35) kg; wethers: 29 (18-39) kg

<u>LWG tupping (2013) - uncontracted</u>

After weaning the lupin mob was mixed with a larger mob and put on conventional pastures. The lupins were stocked with another 100 mixed-age ewes from 18 March until we were able to find most of the original lupin ewes (103) at crutching (11 April). These ewes along with 75 control ewes were number tagged (yellow for lupin and white for control), weighed and started on their pastures. Rams joined the ewes on 20 May and the ewes were weighed on 22 May (Table 1.5). The lupin ewes continued to graze the stand until 19 June but were not weighed again.

Table 1.5 Average (range) weights of merino ewes on lupin and control pastures over six weeks from April to May 2013 at Sawdon Station.

Date	Lupin mob	Control mob	SED	P value
	<u>Liveweight (kg)</u>			
11 April	56 (48-68)	56 (48-67)		
22 May	59 (51-68)	61 (54-71)	0.6	<0.001
	<u>Liveweight gain (g/day)</u>			
	66	120	9.3	<0.001

<u>Wool characteristics (2013) - uncontracted</u>

To test whether lupins affect the wool characteristics of merinos, a mid-side sample was collected at crutching on 11 April 2013 from each of the tagged ewes (178 in total) and put through a Fibrescan analyser with help from Eugene O'Sullivan of Pastoral Measurements Ltd (PML). These preliminary results were in favour of the lupin mob for staple length (Table 1.6).

Table 1.6: Wool characteristics on 11 April 2013 of merino ewes grazed on lupin or control pastures at Sawdon Station (data are means of 103 samples for lupin and 75 samples for control).

Characteristic	Lupin mob	Control mob	SED	P value
Staple length (mm)	53	49	1.2	0.005
Mean micron	18.57	18.28	0.201	0.116

Lupin feed supply (2012/13)

The lupin plots were sampled at monthly intervals from October 2012 to May 2013 to determine feed supply and its botanical composition (Figure 1.2). Herbage mass was estimated by cutting a strip of 3 m by 1.15 m at three random points across each block to a height of 40-50 mm using a sickle-bar mower. The cut herbage was weighed in the field and a subsample was taken back to Lincoln University where 500 g was dried at 65°C to determine dry matter percentage. Another subsample of approximately 500 g was separated into lupin leaf, petiole, stem, flower, dead material and other species, and dried to determine composition. Total herbage mass and herbage mass of each fraction were calculated as:

Total herbage mass = fresh weight*DM percentage/100*10000/(3*1.15)

Fraction herbage mass = fraction dry weight/total fraction dry weight*total herbage mass

Total animal intake was not estimated as the sheep consumed both lupin and other species (mainly grasses) that were present in the lupin plots and this made any determination of animal intake difficult.

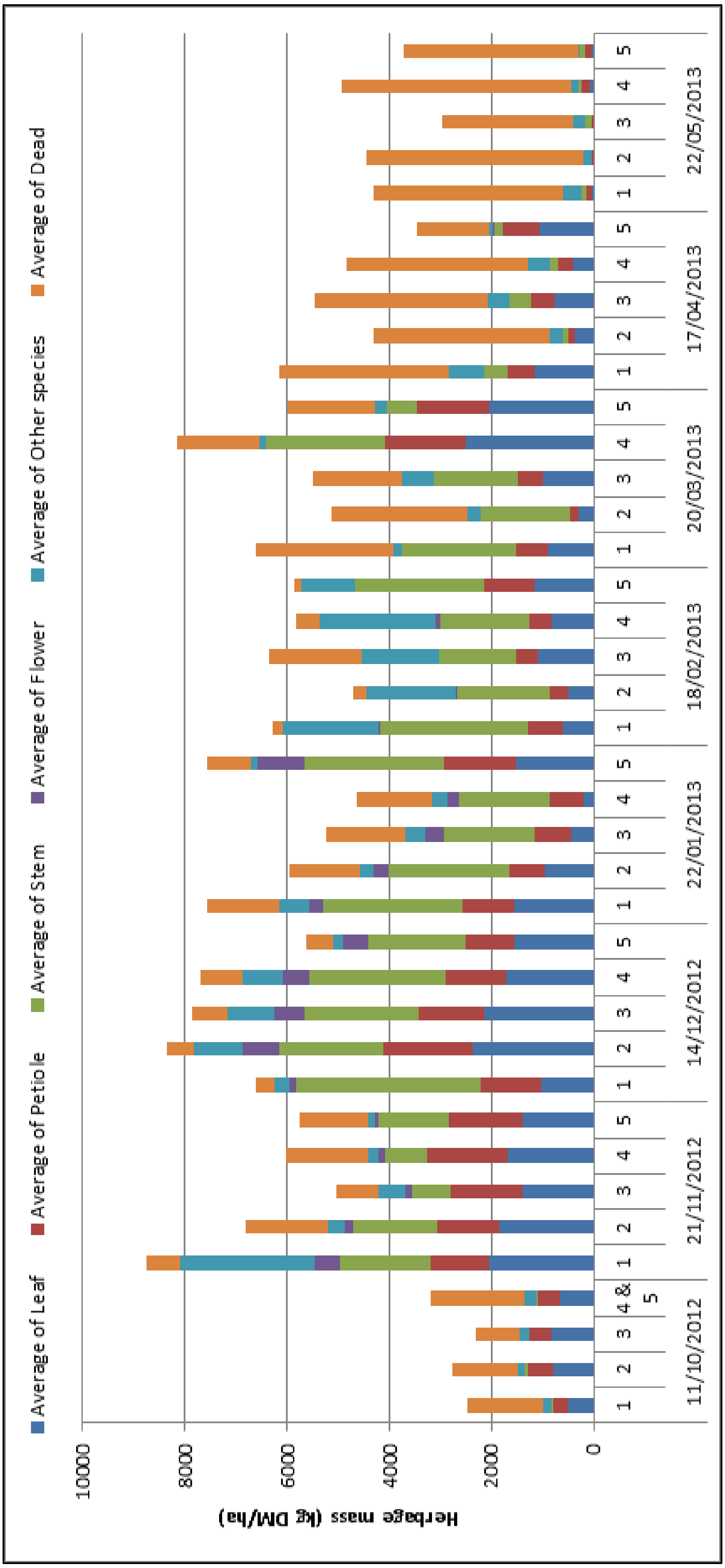

Figure 1.2 Feed supply and composition of the five paddocks in the lupin grazing trial at Sawdon Station during 2012/13.

Lupin nutritive value

2012/13

To estimate the nutritive value of the lupin herbage on offer to stock, herbage samples were collected in January, March and April 2012. These samples were botanically separated (into lupin leaf, lupin stem, lupin flowers, grass, yarrow and weeds) at Lincoln University, and each separate fraction dried, ground and then analysed for metabolisable energy and crude protein (N% x 6.25) content by NIRS (Table 1.7). NIRS values are probably inaccurate for the lupin samples that were submitted for analysis as there is currently no (not enough) reference samples entered into the system for calibrations. The samples will therefore be kept, and these and any additional samples collected will be analysed through wet chemistry before final nutritive value estimations are made.

Table 1.7 Metabolisable energy and crude protein concentrations of lupin components and companion species on three dates from Sawdon Station.

Date	Lupin leaf	Lupin stem	Lupin flowers	Grass	Yarrow
			Metabolisable energy (MJ/kg DM)		
Jan. 2012	11.2	10.8	10.6	-	-
Mar. 2012	11.2	10.6	10.4	10.3	10.7
Apr. 2012	11.1	-	-	-	-
			Crude protein (g/kg DM)		
Jan. 2012	214	210	218	-	-
Mar. 2012	185	183	184	141	180
Apr. 2012	170	-	-	-	-

Goals for 2013/14 - uncontracted

1) Record the scanning % of the tagged ewes (178) tupped on lupin and control pastures
2) Measure wool characteristics of tagged ewes again at shearing in September
3) Measure ewe and lamb growth from lambing to weaning and ewe growth in autumn
4) Describe the yield and nutritive value of lupins throughout the 2013/14 season
5) Analyse the lupin samples for nutritive value

Site 2 – Glenmore Station

Overall Objective

Investigate the effect of coulter type, lime rate and pre-sowing treatment (burn/herbicide) on the establishment and production of three legumes in a hill country environment.

Experiments 1- 4 (herbicide and lime pre-treatments x legume x drill type)

Experimental design

These experiments were sown in November 2011. Four experiments (1-4) were established each with the same design (layout) of treatments, which is a randomised split-plot design with three replicates. Three legume species formed the main plots and three drill types the sub-plots (a total of 108 plots).

Treatments

Exp. 1	Spring herbicide applied in late October 2011, no lime.
Exp. 2	No herbicide, no lime**. N.B.:** In May 2012, remaining herbage was sprayed and burnt off. Due to a lack of success in this experiment, this block became a species by lime rate experiment in May 2012 involving six legume species and five rates of lime (0, 0.5, 1, 2, 4 t/ha).
Exp. 3 & 4	Autumn herbicide applied in 2011 and dressed with either 2.5 or 5 tonne/ha of lime, (Experiments 3 & 4, respectively). Residual material was burnt off in October and a second herbicide application was applied in late October.
Legumes:	Caucasian clover, lucerne and 'Russell' lupin sown at 8, 7 and 6 kg/ha, respectively (but only half rates for Flexiseeder, i.e. 4, 3.5 and 3 kg seed/ha, respectively). All legume seed was inoculated.
Drill types:	Taege drill, Flexiseeder and Duncan triple disc.

The results of these experiments for the first year were summarized in the report to the New Zealand Merino Company (June 2012). In brief, Experiment 2 showed that, without the removal of existing vegetation, seedling survival was poor and by the end of the summer the resident species of browntop, sweet vernal and, in some plots, resident white clover had overwhelmed the sown legumes. On this basis, Experiment 2 was replaced with Experiment 5 (see below). In Experiment 1 (spring herbicide and no lime) seedling establishment was higher but resident species quickly re-established and dominated the site by autumn (2012). This experiment was continued for monitoring in 2012-13. The full autumn and spring herbicide and lime treatments in Experiments 3 and 4 allowed the most successful establishment but this was extremely variable within plots and between plots. The type of coulter (triple disc, tyned-coulter or tyned- and winged-coulter) had less influence than the effect of depth of seed placement. There was also the likelihood that the soil firmness and the depth of an organic/thatch layer, which varied across the site, may have affected the drills' depth of penetration and seed placement.

Experiments 1, 3 and 4 (2012/2013)

Experiments 1, 3 and 4 were monitored for growth and species composition during the 2012/2013 season. These experiments were not re-sown as proposed in earlier reports because there was sufficient legume cover to continue monitoring. Also, there was too much cover of re-established resident species to expect new seedlings to survive.

December 2012

By December 2012 the regrowth of resident grasses, adventive clovers and other broad-leaved weeds had mostly overshadowed the sown legumes (Figures 2.1 and 2.2). There was a weak but positive legume response to the lime. The lupin plants, though few in number, stood out. Caucasian clover was the dominant sown legume for ground cover (Figure 2.1). Sown legume had highest cover with the Taege drill. Plant populations for lucerne and lupin were also highest for the Taege drill (Figure 2.3). **N.B.:** The sowing rates for lucerne with the Taege drill in November 2011 were 1.5-2.5 times the rate with the other drills. Lupin seed sown with the Taege drill was the same rate as the Duncan drill but three times that of the Flexiseeder drill. The lack of good control of the seeding rate of these small seeds was identified as a problem. The Flexiseeder drill was most consistent at delivering seed, although its target sowing rate was only 50% of the other drills to allow for its wider (300 mm) coulter spacing. Lucerne was mostly less than 30 cm high although a few plants were around 40 cm. There were fewer than 10 stems per plant and there was no canopy closure of the lucerne. Caucasian clover plants had by this time over-grown each other and it was impossible to count individual plants.

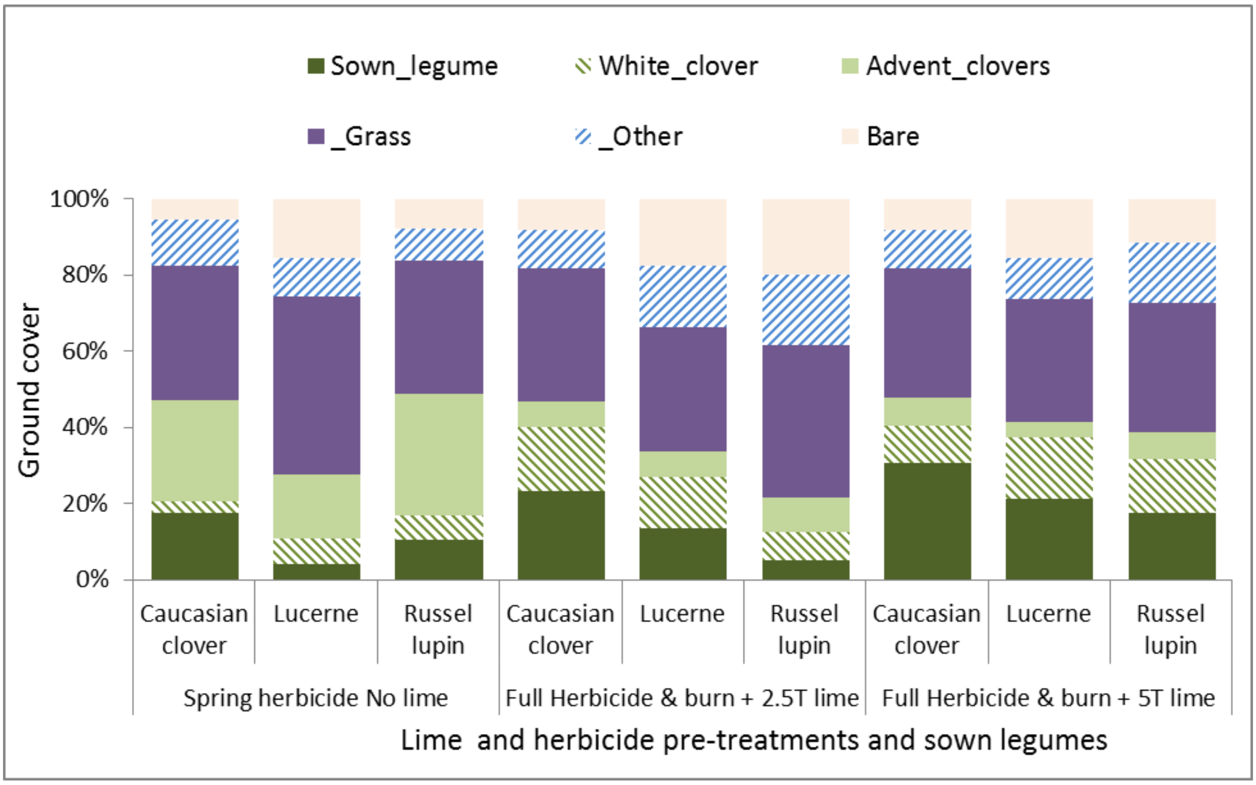

Figure 2.1 Effect of lime pre-treatments and legume species on ground cover of sown legumes and re-established resident vegetation at Glenmore on 11 December 2012, 13 months after sowing in November 2011.

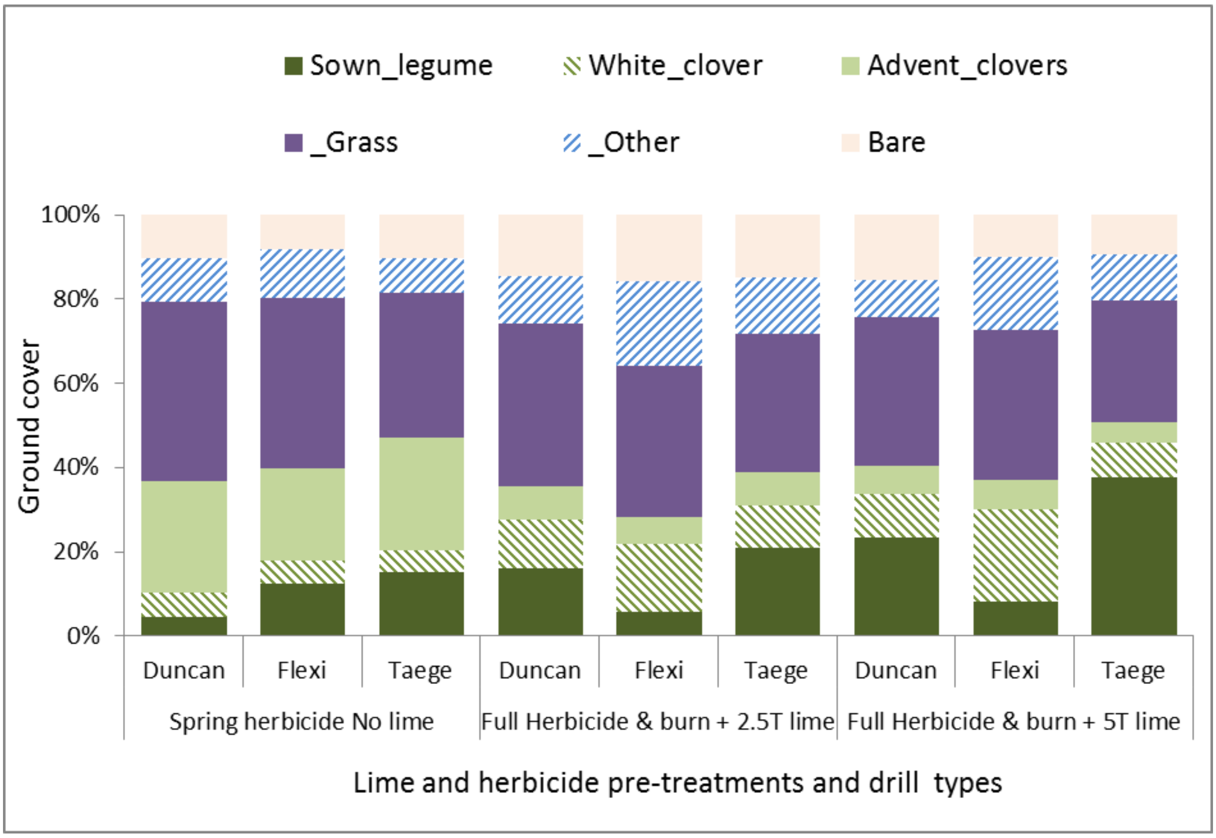

Figure 2.2 Effect of lime pre-treatments and drill type on the ground cover of sown legumes and re-established resident vegetation at Glenmore on 11 December 2012, 13 months after sowing in November 2011. Note: drills delivered different seeding rates.

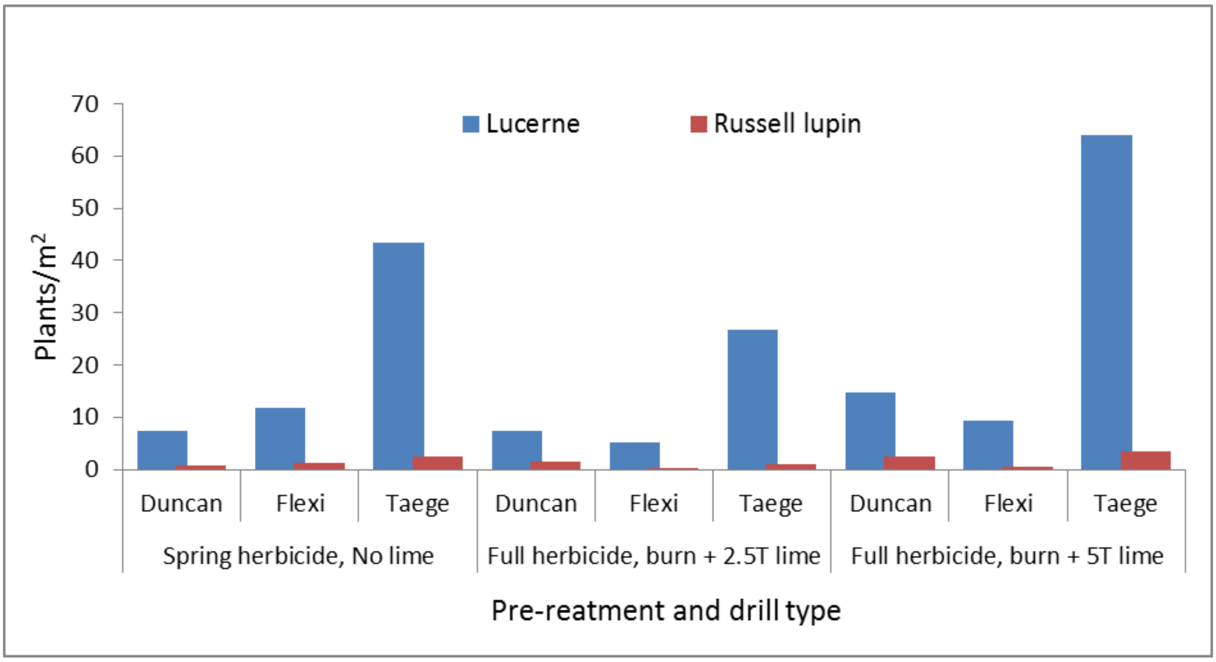

Figure 2.3. Plant population (plants/m^2) of lucerne and 'Russell' lupin at Glenmore on 11 December 2012, 13 months after sowing in November 2011. Note: Taege drill delivered lucerne seed at 152% and lupin at 131% of the target rate.

February 2013

For each experiment there was an effect (*P*<0.05) of sown legume on the sown legume dry matter measured on 7 February, 2013 (Table 2.1). There was also a drill effect (*P*<0.05) for the sown legume content in the 'No lime' and '5T lime' experiments, and a treatment interaction for the resident grass content in the 2.5T lime experiment. No harvests or grazing had taken place throughout the spring and summer.

Table 2.1 Summary of analysis of variance (P values) of DM yield at 7 February 2013 for three experiments at Glenmore. Least significant differences (kg/ha) are shown for significant effects (*P*<0.05).

	No lime			2.5T lime			5T lime		
Factor	Total DM	DM sown legume	DM grass	Total DM	DM sown legume	DM grass	Total DM	DM sown legume	DM grass
Sown legume	0.507	0.037	0.363	0.489	0.020	0.938	0.309	0.040	0.510
l.s.d.		450			816			1266	
Drill type	0.265	0.007	0.923	0.282	0.258	0.018	0.559	0.009	0.047
l.s.d.		248						573	640
Interaction	0.081	0.153	0.355	0.081	0.482	0.019	0.988	0.958	0.410
l.s.d.						1090			

The contribution of sown legume was highest for Caucasian clover (Figure 2.4), being more than 50% of the DM yield in some treatments. Legume yield was highest in the 5T lime experiment. Lucerne was over-mature by this stage but had not started new regrowth from the base. There were fewer than 10 stems per plant. Resident grasses dominated where legume establishment was poor or, vice versa, legume dominance was greatest where the adventive grasses did not re-establish quickly in the previous year (Figure 2.5). Sweet vernal was a large component of the resident grasses in the no lime experiment but was often absent in the 5T lime experiment.

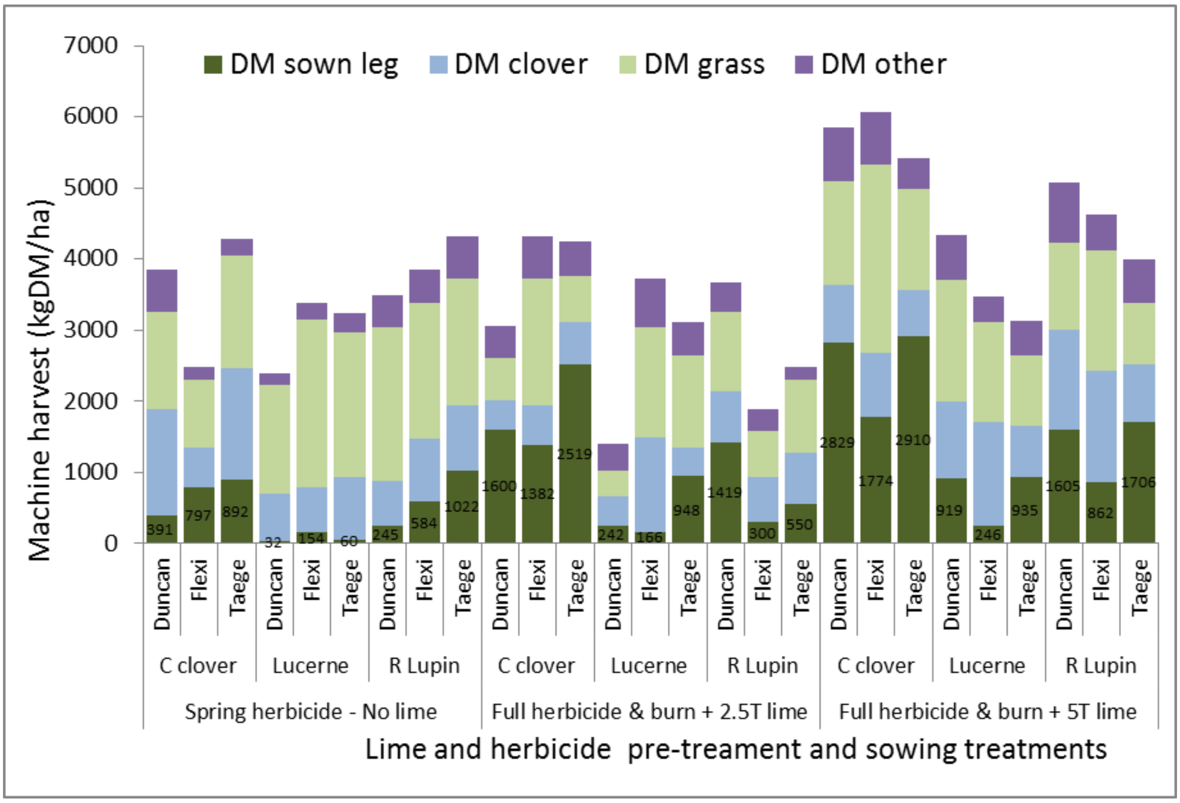

Figure 2.4 Effect of lime pre-treatment, sown legume and drill type on the subsequent herbage DM yield and composition at Glenmore, on 7 February 2013, 15 months after sowing in November 2011. DM values (kg/ha) are shown for the sown legume component.

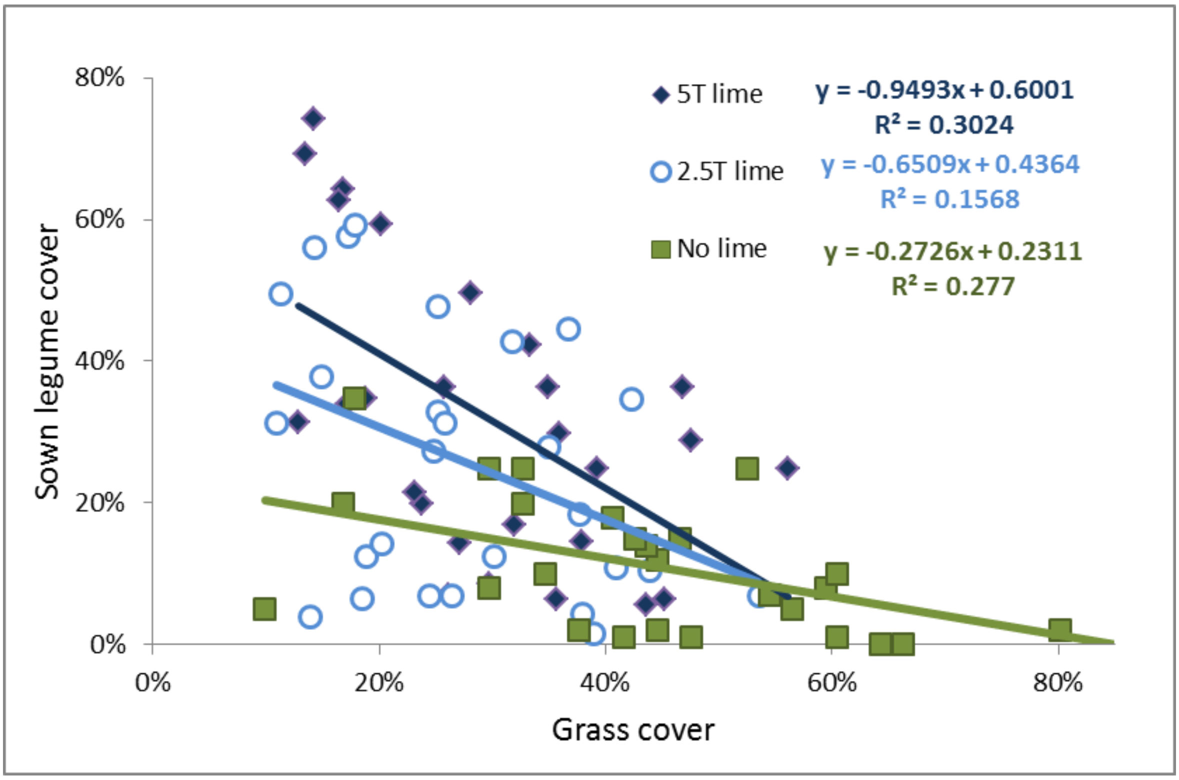

Figure 2.5 Relationship between legume cover and grass cover for the No lime, 2.5T lime and 5T lime experiments at Glenmore across all treatments on 7 February 2013, 15 months after sowing in November 2011.

By this stage the pastures had reached maturity and had stopped growing due to a lack of moisture. Plots were sampled on 7 February 2013 (Plate 2.1), and the remaining herbage machine harvested, baled and removed from the plots.

Plate 2.1 View of Experiments 3 and 4 at the time of herbage sampling, on 7 February 2013.

<u>March – April 2013</u>

Autumn regrowth after the February defoliation was minimal. Resident grasses greened up a bit and sown legume regrowth from the summer drought did not get above stubble height. No further measurements were taken.

Plate 2.2 View of Experiments 3 and 4 on 7 March 2013. Note the vigorous growth of the December 2012 sown plots on either side of the machine harvested area, cf. Plate 2.1.

Plate 2.3 View of Experiments 3 and 4 on 18 April 2013 showing the lack of autumn growth.

Soil tests

Soil sampling occurred in December 2012 for the spring 2011 lime rates x legumes experiments (Experiments 1, 3 and 4). Thirty samples of 25 mm diameter were collected per lime treatment (0, 3 and 5 T/ha) in all three replicates, for 0 – 7.5 cm and 7.5 – 15 cm horizons. Deep (auger) samples were also taken at 20 cm intervals on the 0 T/ha lime treatment at six sites, to a maximum depth of 1 m. These samples were then bulked on a horizon basis.

Table 2.3 Soil test results for bulked 2.5 cm diameter core samples taken from Experiments 1, 3 and 4 at Glenmore Station in December 2012

Lime (T/ha)	Soil depth (cm)	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
0	0-7.5	5.0	13.7	18.7	5.7	15.7	6.3	3.3	5.0
	7.5-15	5.3	-	-	-	-	-	-	5.0
3	0-7.5	5.5	36.0	23.3	10.0	12.3	4.7	3.3	2.2
	7.5-15	5.2	-	-	-	-	-	-	5.9
5	0-7.5	5.4	32.7	37.0	8.7	11.7	5.3	3.0	2.6
	7.5-15	5.2	-	-	-	-	-	-	4.9

Table 2.4 Soil test results for auger samples collected from the 0T lime treatment of Experiments 1, 3 and 4 at Glenmore Station in December 2012.

Sample (Native, 0 Lime)	pH	Exch Al (mg/kg)
GMO 0-20 cm	4.9	7.4
GMO 20-40 cm	5.1	7.1
GMO 40-60 cm	5.1	8.9
GMO 60-80 cm	5.3	9.7
GMO 80-100 cm	5.3	8.0

- Exchangeable Al was found at toxic levels in the Glenmore soils and increased with soil profile depth.
- Lime application elevated the pH of the soil surface (0-7.5 cm) from 5.0 to 5.4 and Al levels decreased from ~ 5.0 to < 2.6 mg/kg. At these levels lucerne would grow roots but only to 15 cm.
- The Olsen P levels were moderate-high and surface applied lime appears to have increased Olsen P and calcium levels. Sulphate occurred at high levels throughout the profile.
- Soil aluminium levels below 20 cm indicate toxic levels of aluminium to at least 1 m.

Root growth and nodulation of sown legumes at Glenmore station
(PhD funding has supported some of this work)

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Background

Aluminium toxicity is a major factor limiting crop production and yield in acid soils worldwide (Foy, 1988). In New Zealand low soil pH coupled with toxic levels of soil aluminium and low phosphorus limit establishment and maintenance of legumes on about 500 000 ha of farmed high country (Moir and Moot, 2010). Reductions in nodulation and root growth combine to severely inhibit lucerne survival, nitrogen fixation and production in these regions (Humphries *et al.*, 2008). Liming is often recommended for these low pH soils (Edmeades *et al.*, 1983). Most of the lime response by lucerne has been attributed to improved nodulation (Munns, 1965). Monitoring the production and persistence of different legumes leads us to find the most appropriate legume species for each hill and high country region in the South Island.

- Soil test results showed low pH and toxic levels of aluminium, especially in the top 10 cm of the soil surface at Glenmore station.
- Four experiments were conducted in a Randomised split plot design containing legume species ('Endura' Caucasian clover, 'Force 4' lucerne and 'Russell' lupin) as main plots and drill type as the sub-plots in three replicates.
- Seeds were inoculated with peat inoculant for each legume before sowing.
- Monitoring the nodulation of sown legumes has occurred from seedling stage in December 2011 until January 2013.

Capturing rhizobia

To capture any indigenous rhizobia that may exist in this experimental site, bare seeds of lucerne, lupin and Caucasian clover were also sown at the same sowing date as the main four experiments. Bare seeds were sown at a distance of 10 meters from main plots to reduce the risk of plant roots being contaminated with existing rhizobia from the peat inoculant in main plots.

Seedling emergence (06/12/2011)

In all four experiments, Taege drilled plots had the highest legume plant population (seedling/m^2) among the three coulters due to delivering the highest sowing rate (Figure 2.6). Low plant density of lupin was expected due to a low sowing rate.

Lucerne had the highest plant population (seedling/m^2) among sown legumes in all four experiments. Lucerne seedling population was higher in experiments with lime application than those without in Experiments 1 and 2 (Figure 2.6).

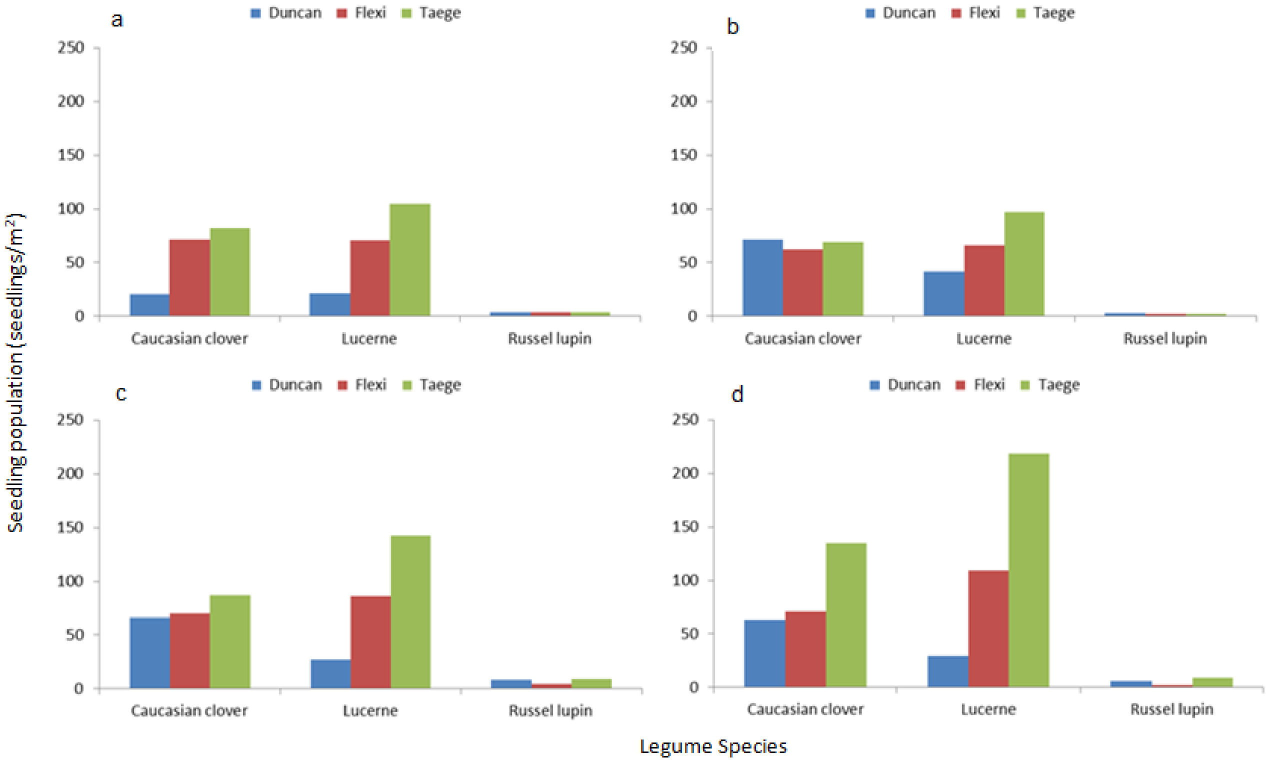

Figure 2.6 Emergence rate (Seedling/m^2) in December 2011 of sown legumes by three different coulter types in: **(a)** Experiment 1, spring herbicide; **(b)** Experiment 2, no-herbicide; **(c)** Experiment 3, autumn herbicide with 2.5 t/ha of lime; and **(d)** Experiment 4, autumn herbicide with 5 t/ha of lime.

Monitoring the nodulation

10 seedlings of each legume were excavated from each plot in December 2011. Roots were washed and all the nodules were counted and scored. The percentage of nodulated seedlings in each experiment was calculated (Table 2.2).

Table 2.2 Nodulated seedlings (% of total seedlings) of sown legumes in different pre-sowing treatments, 1 month after sowing. Treatments were: Experiment 1, spring herbicide (**SH**); Experiment 2, no-herbicide (**NH**); Experiment 3, autumn herbicide with 2.5 t/ha of lime (**3 FH**); and Experiment 4, autumn herbicide with 5 t/ha of lime (**5 FH**).

	Percentage nodulated seedlings (%)		
Pre-sowing treatment	Lucerne	Lupin	Caucasian clover
SH	11	100	66
NH	26	100	25
3 FH	29	100	85
5 FH	85	100	89

All lupin seedlings were nodulated in all experiments. Lucerne nodulation was 85% in Experiment 4 with 5 t lime/ha application. *Ensefier Melilotii* (Lucerne especial rhizobia) was the most sensitive rhizobium species to soil acidity among other rhizobia species nodulating legumes (Lowendorf *et al.*, 1981). Failure of lucerne persistence was mostly related to failure of root growth and nodulation in these soil conditions. No nodules were found from bare-seed sown legumes suggesting that there were no bacteria available in the soil capable of nodulating legumes.

Root Growth

Some lucerne plants managed to send their tap root into a deeper (20-25 cm) soil layer in Experiments 3 and 4 (with lime application) and thrive during first year (Plate 2.4).

Plate 2.4 Secondary lucerne roots penetrating the Al^{3+} layer at Tekapo, New Zealand on: **(a)** 7 May 2012, **(b)** 15 Nov 2012, and **(c)** 10 Dec 2012.

Caucasian clover establishment was slow during the first year but has shown fast area coverage of plots by the end of 2012, especially in Experiments 3 & 4 with lime application. Most of the Caucasian clover roots were in normal vertical orientation (Plate 2.5).

Plate 2.5 Caucasian clover persistence with extended root system and nodules on them on **(a)** 7 May 2012, **(b)** 15 Nov 2012, and **(c)** 10 Dec 2012.

Most lupin roots have grown horizontally to escape the high Al layer of soil (Plate 2.6). The number of nudules (per plant) decreased from May 2012 to December 2012. Despite disoriented roots and declining nodules per plant, lupin shoot growth was normal with reasonable yield.

Plate 2.6 Lupin persistence with horizontal root system and nodules on them; **(a)** 7 May 2012, **(b)** 15 Nov 2012, and **(c)** 10 Dec 2012.

Lucerne production was low in all four experiments. Plate 2.7 shows lucerne response to lime application. Lime application improved lucerne shoot growth by elevating the pH in the soil surface. However, most of the roots have grown horizontally. No fine roots or nodules were found in excavated lucerne plants in January 2013. The absence of root hairs could be an explanation for the observed nutrient deficiency symptoms caused by failure in nutrient uptake, which consequently resulted in low yield.

Plate 2.7 Lucerne growth in response to lime application (Dec. 2012). **(a)** No lime, **(b)** 2.5 t lime/ha, and **(c)** 5 t lime/ha.

Genotypic characterisation of rhizobia captured from sown legumes

The rhizobial suspension from each nodule was plated and cultured. After obtaining a single colony culture, 100 isolates of bacteria were selected for DNA extraction. DNA was extracted using the PUREGENE™ (Gentra Systems, USA) DNA extraction kit. PCR amplification of bacterial DNA was done using ERIC primers. Electrophoresis of each PCR product was done on a 1% agarose gel.

Gel images showed a wide range of endophytic bacterial/rhizobial genotypes. Two isolates of 21 lucerne nodules were the same as the commercial inoculant genotype used for seed inoculation (Figure 2.7). Isolates will be fully identified until before 2013. The next step is to investigate the nodulation capability of these different genotypes and their role in symbiosis with lucerne.

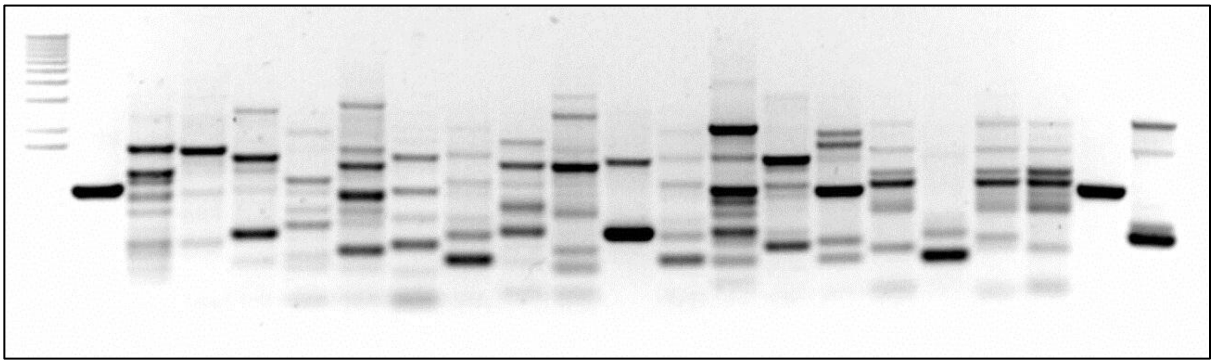

Figure 2.7 ERIC-PCR fingerprints of 21 different isolates of bacteria obtained from lucerne nodules.

Acknowledgments

Authors thank Dr. A. Rafat for his assistance in molecular studies.

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Experiment 5 (legumes x lime rates)

Experiment 5 was sown in December 2012 into the space previously occupied by Experiment 2, sown in November 2011.

Experimental design

The experiment is a strip-plot design with three replicates. Main plots were five lime rates (Nil, 0.5, 1.0, 2.0 and 5.0 t/ha) and sub-plots six legumes (Table 2.3). The latter three legumes (white clover, Balansa clover and lotus) were used for their tolerance to water logging conditions to help assess whether water-logging may have been a factor in some of the poor establishment of the other legumes in the previous year. This may be the main issue for poor lucerne growth rather than the soil aluminium.

Table 2.3 Legume sowing rates, germination rates (%), thousand seed weight (TSW) and the number of seed sown per meter and per meter squared at Glenmore, 11 December 2012.

Legume	Sowing rate (kg/ha)	Germination (%)	TSW (g)	Seed/m^2	Seed/m
Lucerne	10	95	2.1	476	71.4
Lupin	30	55	26.0	115	17.3
Caucasian	8	90	2.5	320	48.0
White	4	95	1.8	222	33.3
Balansa	5	90	1.8	278	41.7
Lotus	5	85	1.8	278	41.7

The resident vegetation was sprayed with glyphosate in March 2012, then grazed and burnt shortly afterwards. Lime rates were applied in May 2012. Glyphosate was again applied in early December 2012.

Seedling maturity (Figure 2.8) and emergence (Figure 2.9) were recorded on 24 January 2013. Earlier observations indicated that there was little germination/emergence before 2-3 January 2013 when 75 mm of rain was recorded on site. The age class distribution indicated that some seed had likely germinated and emerged before the rain in early January. Caucasian clover was the slowest in leaf appearance which was expected. All species except white clover also had some seedlings still at the cotyledon or spade leaf stage. Plant density at six weeks after sowing was not significantly different among the six legumes (Figure 2.9; P=0.37, s.e.m.=7.5). Plant density was uniform across replicates for lupin and Caucasian clover but other species were inconsistent across reps.

The percentage emergence (Figure 2.8), relative to the number of seeds sown, was highest for lupin (35%; P<0.001, l.s.d.=8.8) whereas all other legumes ranged from 9.7% for balansa to 17.7% for lotus and were not significantly different.

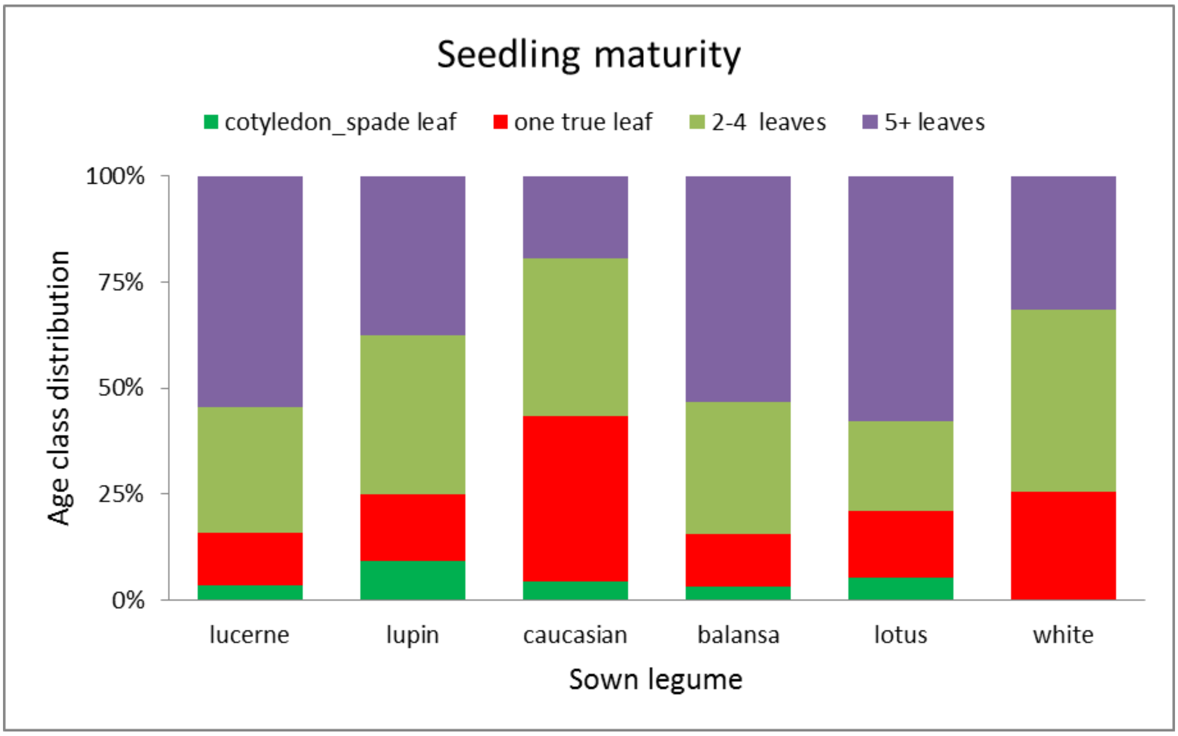

Figure 2.8 Legume seedling development at Glenmore, six weeks after sowing on 11 December 2012.

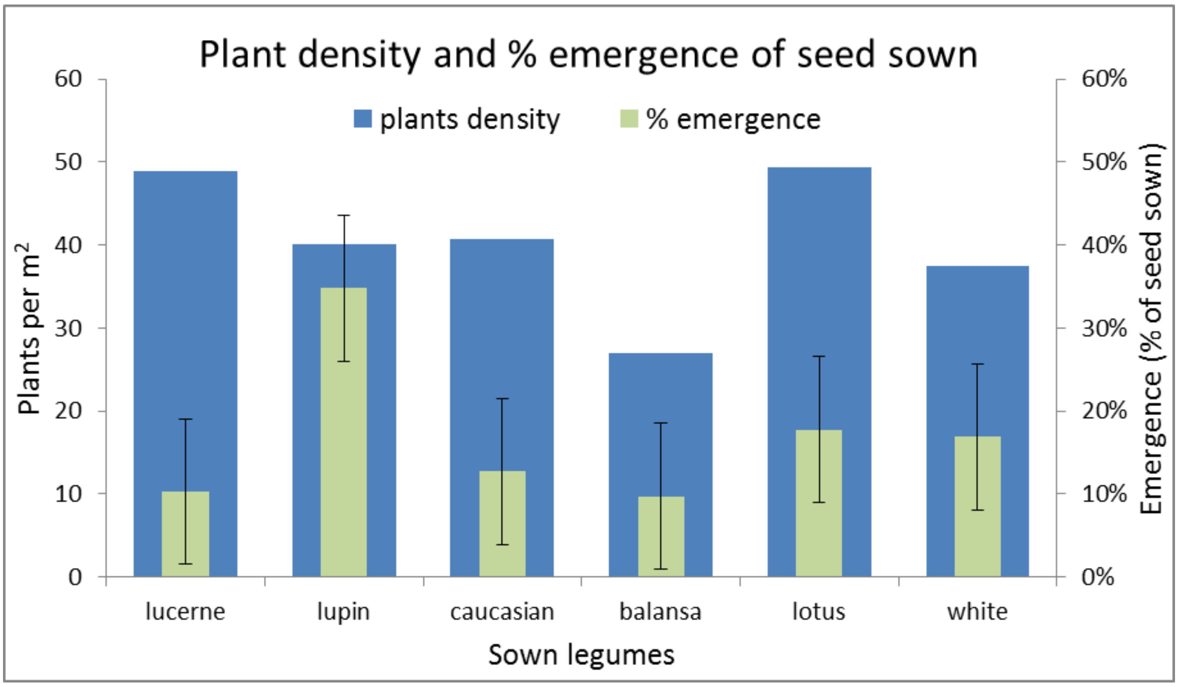

Figure 2.9 Legume plant density and % emergence of sown seed at Glenmore, six weeks after sowing on 11 December 2012.

Plant distribution within drill rows was uneven with frequent gaps of more than half a meter (Figure 2.10). Coefficients of variation (CV) > 100% indicated it was a highly likely that there were 0.5 m sections of drill row with few or no plants/m in them mostly at the lower overall plant populations. These gaps and the range of plant populations recorded are likely a consequence of irregular seed placement during sowing, with the frequency of these gaps diminishing at higher plant populations. There was no effect of lime on either CV of plants/0.5 m or plant population.

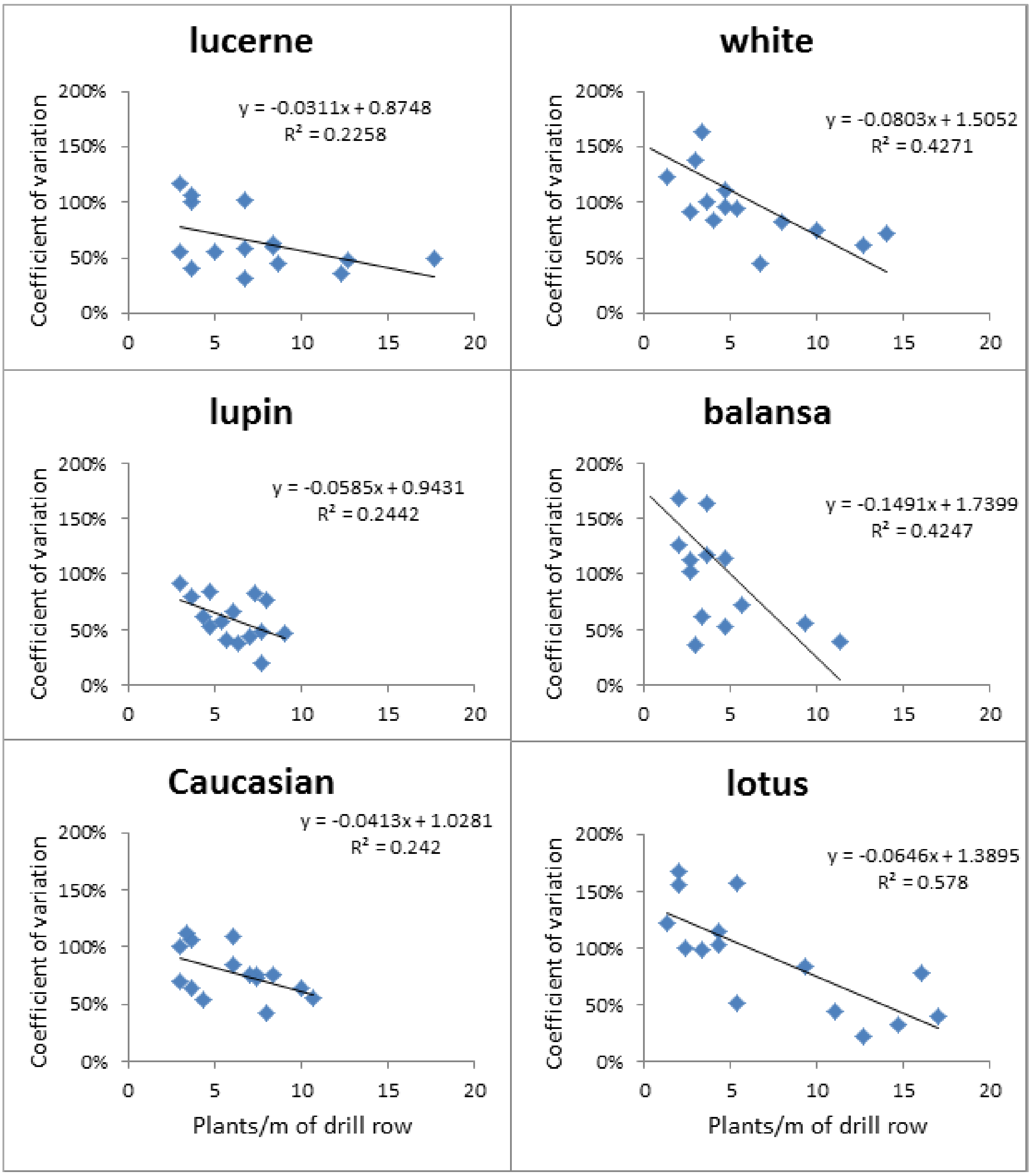

Figure 2.10 Spatial variation of legume seedlings at Glenmore, six weeks after sowing on 11 December, 2012. The coefficient of variation is a measure of the variability of the number of seedlings counted per 0.5 m of drill row.

March 2013

Percentage ground cover, sown legume population and standing herbage mass were measured on 7 March 2013.

The species of sown legume had a significant effect on the relative cover of sown legume (P<0.001), other species (P<0.001) and bare ground (P=0.041), (Figure 2.11). Lupin was the most dominant of the sown legumes with only small proportions of bare ground and other species. There was also a significant legume x lime interaction so that the relative legume cover showed a significant response to lime for balansa and white clovers (*P*=0.017; l.s.d.=26.8%; Figure 2.12). Also, the relative cover of the 'other species' showed a variable response to lime depending on the species of sown legume (legume x lime interaction: *P*=0.004; l.s.d.=17%; Figure 2.13), but no clear trends associated with the amount of lime applied. The 'other species' consisted mainly of Kentucky bluegrass, fathen, sweet vernal, browntop, haresfoot trefoil, sorrel and mouse-eared hawkweed, in decreasing order of occurrence.

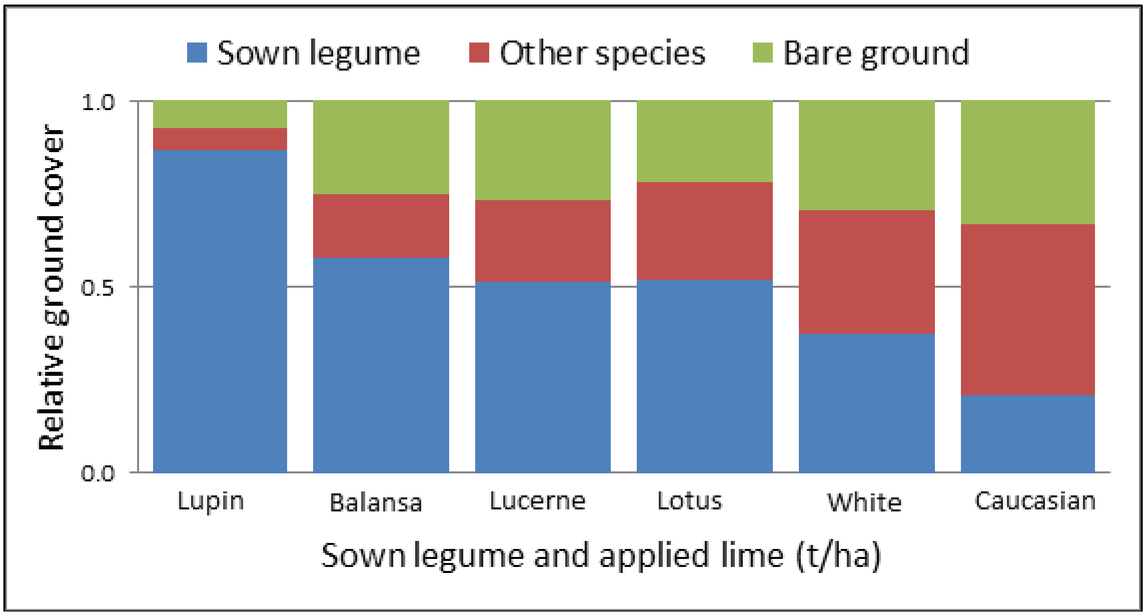

Figure 2.11 Relative cover of sown legume, other species and bare ground in Experiment 5 at Glenmore Station on 7 March 2013, three months after sowing. Lime was surface applied the previous May (2012).

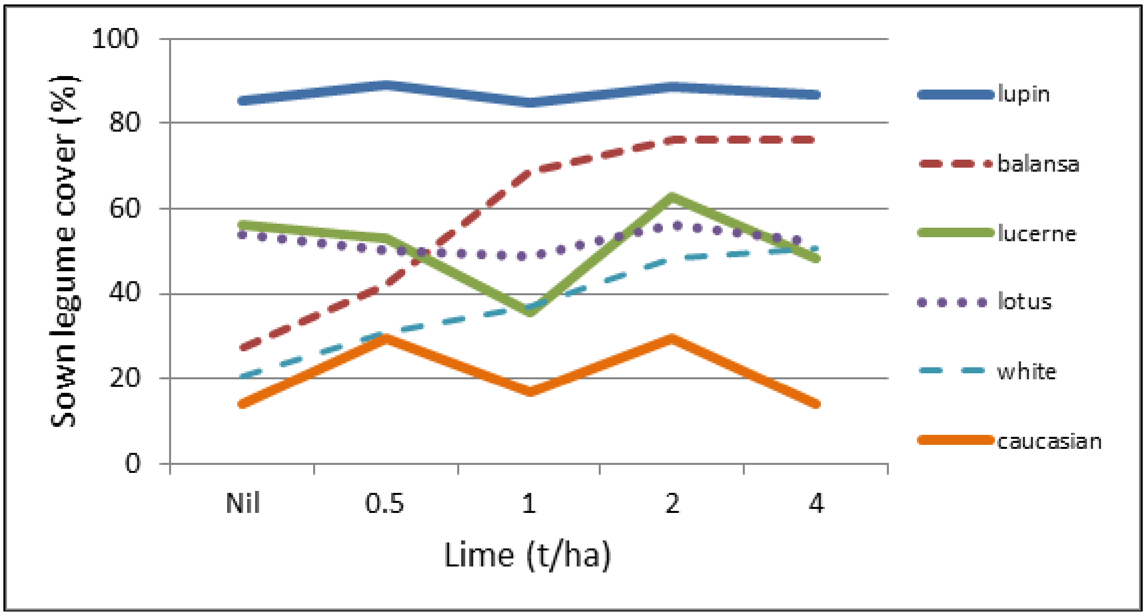

Figure 2.12 Relative cover of sown legumes in response to applied lime in Experiment 5 at Glenmore Station on 7 March 2013, three months after sowing. Lime was surface applied the previous May (2012).

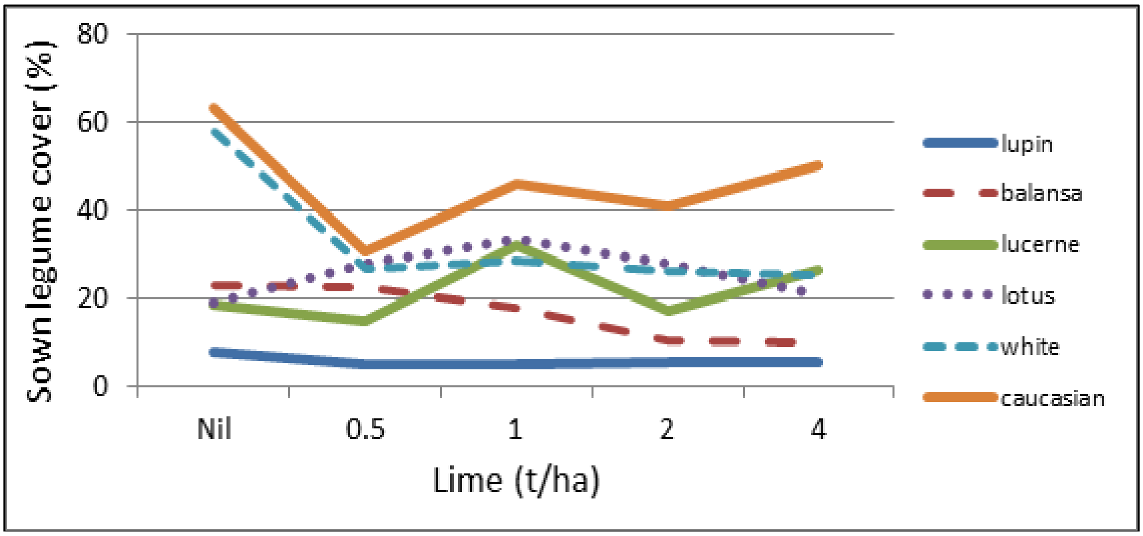

Figure 2.13 Relative cover of other species in response to applied lime in Experiment 5 at Glenmore Station on 7 May 2013, three months after sowing.

The sown legume population was the same for all legumes and lime rates (*P*=0.089 for sown legume and *P*=0.387 for lime rate). Note that plant population was not determined for white clover because individual plants could not be distinguished without destructive sampling. However, the ratio (%) of plants relative to the number of seeds sown for each legume species was highly significant (*P*<0.001; l.s.d=0.061). The ratios in descending order were: lupin, 33.5%; lotus, 17.3%; Caucasian clover, 13.4%; lucerne, 8.3% and balansa clover, 7.5%. Figure 2.14 compares plant populations in March with seedling population in January and seed sown in December. Emergence and then establishment of ~ 30% for lupins was higher (*P*<0.01) than other species that averaged about 10%. These data also confirm high survival of all seedlings from January to well-established plants in March.

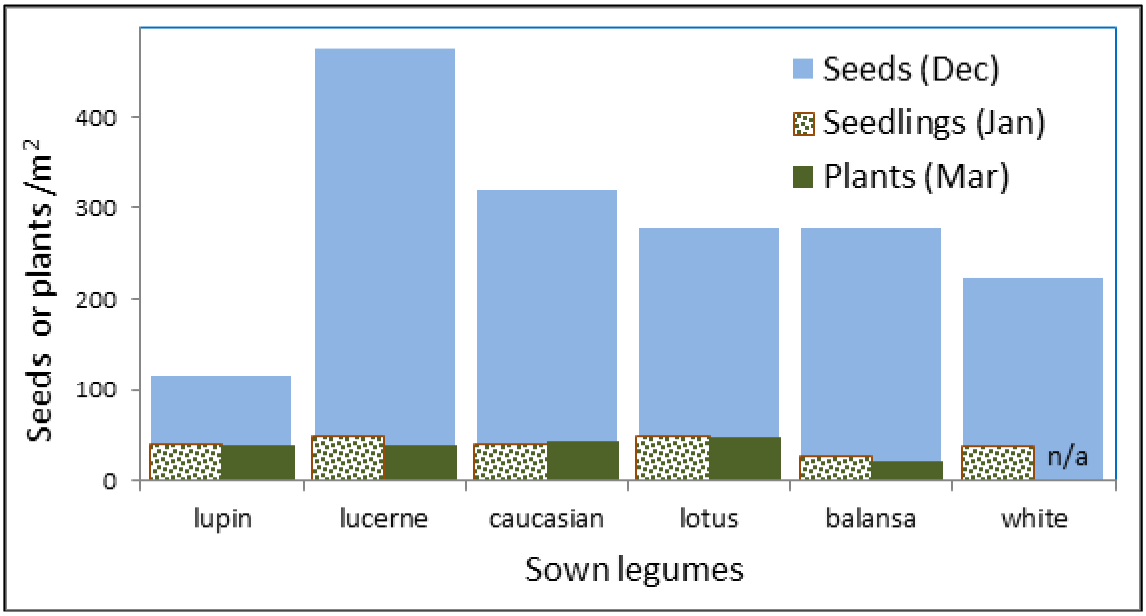

Figure 2.14 Plant populations for six legume species in March 2013, relative to seedling populations in January 2013 and seed rates in December 2012, in Experiment 5 at Glenmore Station.

The effect of sown legume species on the total DM yield, sown legume DM yield and DM yield of all other species on 7 March 2013 were all highly significant (*P*<0.001, *P*<0.001 and *P*=0.005, respectively). There were no lime or lime x legume interaction effects on DM yield (Figure 2.15).

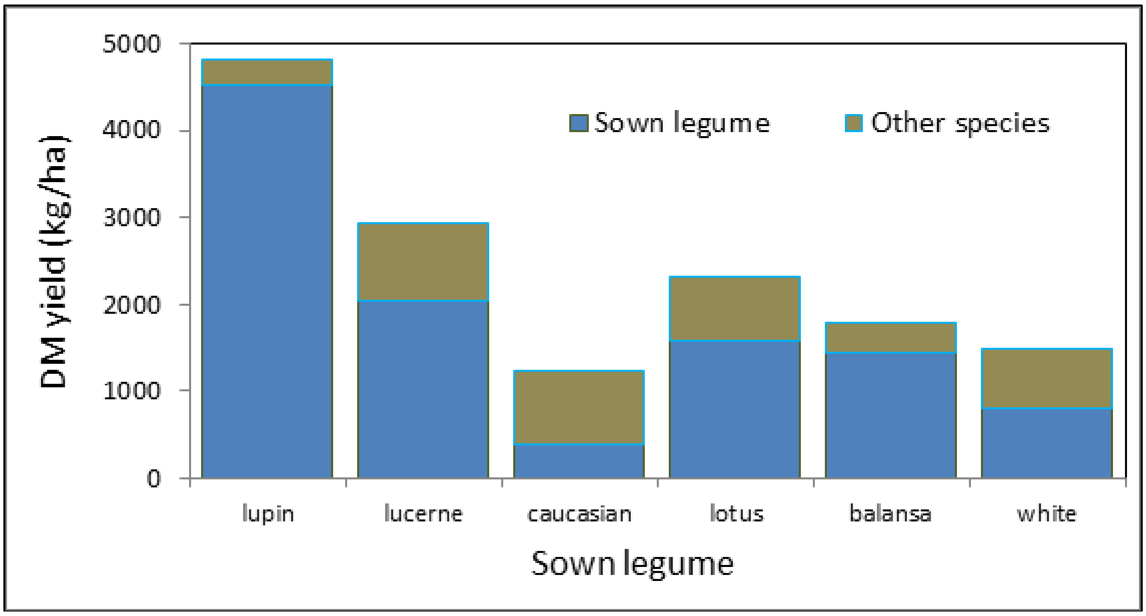

Figure 2.15 DM yield of sown legume and other resident species on 7 March 2013, three months after sowing (l.s.d. = 818 and 298 for sown legume and other species, respectively).

Plate 2.8 Lucerne and lupin in Experiment 5 at Glenmore Station on 7 March 2013, three months after sowing.

<u>April 2013</u>

Plots were harvested again on 18 April 2013. Only total DM yields were measured (Figure 2.16). The relative contribution of other species remained similar except for the balansa clover where it showed strong autumn growth and became even more dominant. Most other sown legume species had good growth in the autumn. Lucerne, however, had flowered earlier and was becoming senescent with the cooler temperatures (Plate 2.9). By mid- May only the lupin and white clover were still relatively green, while lucerne and Caucasian clover were senescent and lotus and balansa clover had succumbed to frost.

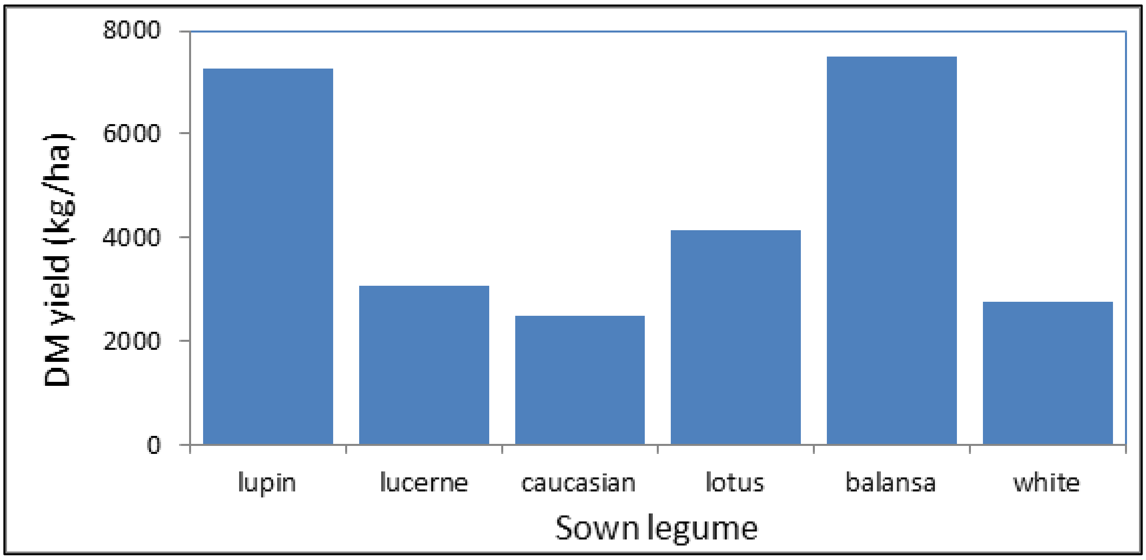

Figure 2.16 Total DM yield of sown legume plots on 18 April 2013, four months after sowing (l.s.d.=1013).

Plate 2.9 View of Experiment 5 (lime rates x legume species) on 18 April 2013. The flowering lupin is clearly visible. The yellowish plots are over-mature lucerne. Balansa clover is immediately in front of the strip of lucerne.

<u>Soil tests</u>
Experiment 5 was soil sampled in December 2012 by taking 60 soil cores of 25 mm diameter per lime rate. These cores were then bulked across replicates for 0 – 7.5 cm and 7.5 – 15 cm horizons (Table 2.5).

Table 2.5 Soil test results for bulked 25 mm diameter core samples taken from Experiment 5 at Glenmore Station in December 2012.

Lime (T/ha)	Soil depth (cm)	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
0	0-7.5	5.2	14	33	6	18	9	2	3.6
	7.5-15	5.2	7	16	5	13	7	4	5.7
0.5	0-7.5	5.1	14	41	6	16	8	3	2.3
	7.5-15	5.3	-	-	-	-	-	-	3.1
1	0-7.5	5.2	20	25	7	17	8	3	2.4
	7.5-15	5.2	-	-	-	-	-	-	3.7
2	0-7.5	5.2	24	22	6	16	7	4	3.7
	7.5-15	5.2	-	-	-	-	-	-	7.3
4	0-7.5	5.7	21	39	10	17	7	5	1.1
	7.5-15	5.2	-	-	-	-	-	-	4.5

- Only the application of 4 t/ha of lime elevated the pH of the soil surface (0-7.5 cm) from 5.3 to 5.7 and decreased Al levels to 1.1 mg/kg.
- The application of lime again increased Olsen P levels.

Soil samples were taken from legume root samples collected at 7.5-15 cm depth in April 2013. Lime application the previous autumn had elevated the soil pH (*P*=0.002) from 4.8 to 5.3 (Table 2.6). There was no effect of the species of legume sown. The soil pH was measured at 1:2.5 air-dried soil:water ratio by pH probe at soil department laboratory.

Table 2.6 Effect of lime application the previous autumn on soil pH at 7.5-15 cm depth measured at Glenmore on 18 April 2013.

Lime rate (t/ha)	Soil pH (7.5-15 cm)	Mean comparison*
0	4.81	A
0.5	4.88	Ab
1	5.05	Bc
2	5.08	C
4	5.30	D

*LSD= 0.18; means with the same letter are not significantly different

Experiment 6 (lime rate x sowing rate x lupin variety)

The lime rates were applied as two adjoining experiments (3 t of lime - Experiment 6a; and no lime - Experiment 6b).

Experimental design

The experiment was a split-plot design with three replicates. Main plots were sowing rates (2, 4, 8, 12, 16 and 32 kg/ha) and subplots were lupin varieties ('Blue' and 'Russell'). Plots were cleared of vegetation in March 2012 with herbicide, grazing and burning of the residual herbage. The 3 t/ha of lime (Experiment 6a) was applied in May 2012. Follow-up herbicide was applied one week prior to sowing in December 2012. After sowing with a Flexiseeder tyne drill it was decided to 'Cambridge roll' a 3 m strip through each lime treatment across all lupin and sowing rate strips leaving the rest unrolled.

Results

Rolling the plots after sowing had no effect on the population of emerged seedlings measured at six weeks after sowing (t-test; P=0.393). Also there was no detectable difference in plant population (t-tests; P=0.78) or percentage emergence (t-tests; P=0.66) between the 3T lime and Nil lime.

Plant population was directly related to the sowing by a factor of 0.39 for 'Blue' lupin (r^2 = 0.99) and 0.34 for 'Russell' lupin (r^2 = 0.95) (Figure 2.11). Sowing rate had a large effect on the plant population in both experiments (P<0.001; l.s.d. = 5.91 & 9.35 plants/m^2 for the No lime and 3T lime, respectively). There was also a lupin effect (P=0.009; l.s.d.=2.24 plants/m^2) in the No lime experiment. The percentage emergence of sown seed was slightly higher (P=0.057) for 'Blue' lupin (47% vs. 35%) with 3T lime which may have reflected its slightly higher germination (65% vs. 55%), but there was no difference with No lime. There was no effect of sowing rate on the percentage emergence although it was difficult at times to distinguish between multiple stems or multiple seedlings.

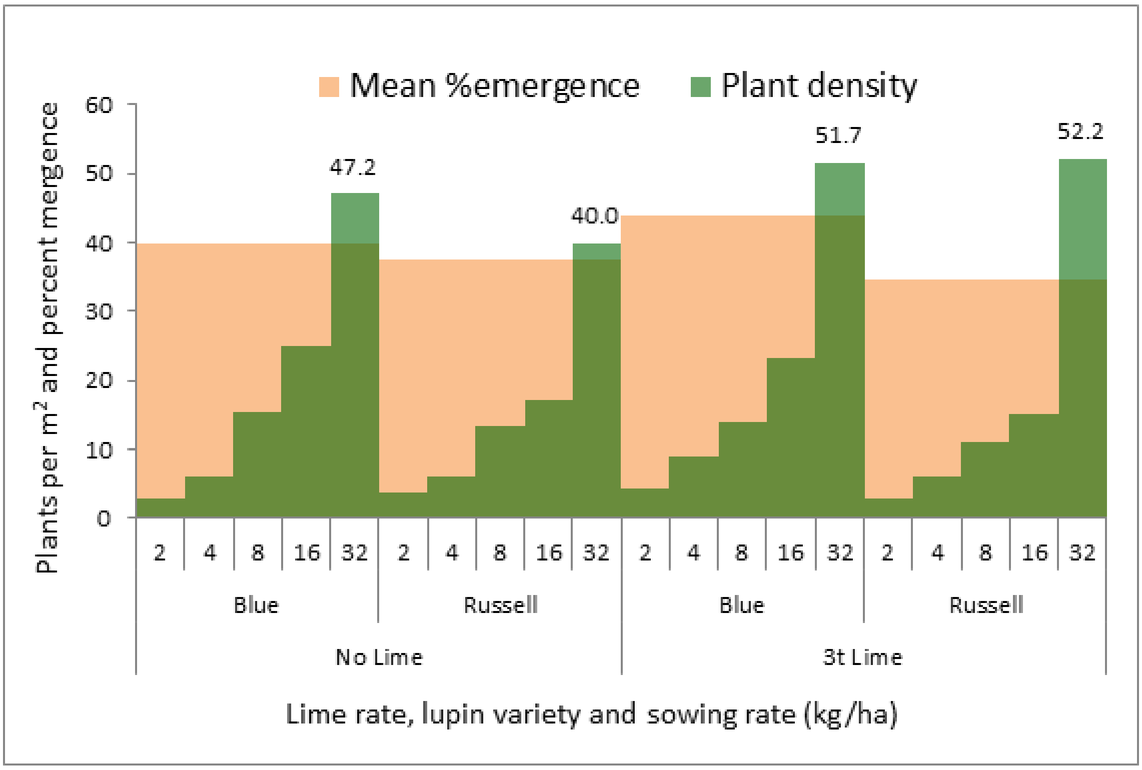

Figure 2.11 'Blue' and 'Russell' lupin plant density and percentage emergence at Glenmore on 24 January 2013, six weeks after sowing on 11 December 2012. The % emergence is the mean across all sowing rates since there was no significant effect of the sowing rate on % emergence.

Variation in plant distribution was illustrated using the coefficient of variation (CV) of the within plot count of plants per 0.5 m of drill row (n = 16) for the combined lime and no lime experiments (Figure 2.12). Overall, the CV was larger than 40%. This indicated there was a large variation in the number of seedlings in any given 0.5 m of drill row. At low sowing rates hence, low plant population, the CV rose to over 250%. This confirmed that there were significant sections of drill row without any plants. Early establishment of a closed canopy by the lupin is an important step in controlling the re-establishment of the resident vegetation. Otherwise subsequent grazing management must allow the lupin to produce seed, open up the canopy for seedlings and allow sufficient time for seedlings to fully establish.

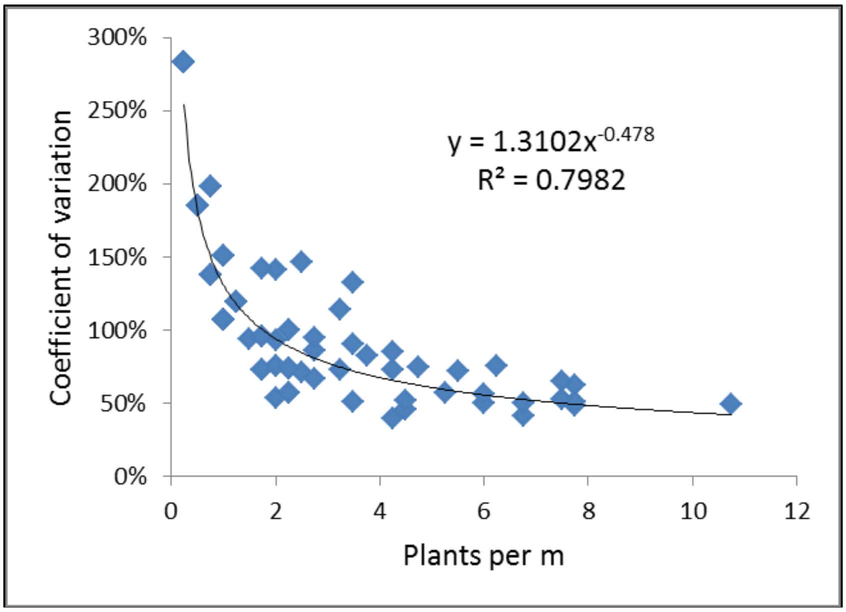

Figure 2.12 Spatial variation of lupin seedlings at Glenmore, six weeks after sowing on 11 December, 2012. The coefficient of variation is a measure of the variability of the number of seedlings counted per 0.5 m of drill row. Results are combined across the No lime and 3T lime experiments because a t-test showed no effect of the lime on plant density at this stage.

March 2013

Plant population and DM yield were measured on 7 March 2013. This experiment was established as two parallel experiments with the same layout of sowing rates and variety of lupin: Experiment 6a had no lime applied and Experiment 6b had 3T/ha of lime the previous autumn. The lime effect was therefore compared using a t-test (Table 2.6). There were no overall effects of the lime on the lupin establishment or yield. There was more bareground cover with no lime and other species were more prevalent with the 3T lime. The no lime experiment had received two herbicide applications during the previous year which reduced resident species to a minimum.

Table 2.6 Summary of the effects of lime on the cover and yield lupin in Experiment 6 on 7 March 2013 using a two-sample t-test.

	DM yield (kg/ha)			%Cover			Establishment	
	Total	Lupin	Other	Lupin	Other	Bare	Plants per m^2	Percent of sown seed
3T lime	2974	2115	859	51.1	22.3	26.6	20.1	57.1
No lime	2440	2140	300	49.6	7.3	43.3	19.6	51.1
Sign. (*P*)	n.s.	n.s.	<0.001	n.s.	<0.001	0.003	n.s.	n.s.
s.e.d.			81.5		1.9	5.4		

Not surprisingly the sowing rate of the lupin affected (*P*<0.01) plant population, plant cover and DM yield of lupin but had only a small effect on the resident species re-establishing (Table 2.7).

Figure 2.13 shows the main effect of the lupin sowing rate on the plant population for both Nil and 3T lime applications. While there was a trend in the no lime experiment for the 'Russell' lupin to have a lower population than the 'Blue' lupin the analysis of variance showed no significance (*P*=0.137). The interaction of lupin variety x sowing rate (*P*=0.029; l.s.d.=8.0) in the 3T lime experiment appears to be more the result of the site variability within reps. A cofactor such as depth to stones might help to explain some of the large variances. In both experiments, 8 kg/ha of seed sown have given adequate plant populations.

Table 2.7 Summary of analysis of variance for the yield, relative ground cover and lupin plant population as affected by the amount of seed sown and variety of lupin for the two parallel experiments where Nil and 3 t/ha of lime were applied the previous autumn.

	DM yield (kg/ha)			Cover (%)			Establishment	
±Lime and treatment factor	Total	Lupin	Other	Lupin	Other	Bare	Plants per m^2	Percent of sown seed
No lime								
Sow rate	<0.001	<0.001	n.s.	<0.001	n.s.	<0.001	<0.001	n.s.
Lupin variety	n.s.	n.s.	n.s.	0.002	n.s.	0.009	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	0.018	0.047	n.s.	n.s.	n.s.
l.s.d. (SR)	831	657		18		21.3	7	
l.s.d. (L)				3.1		3.7		
l.s.d. (SRxL)				18.4	12.5			
3T lime								
Sow rate	<0.001	<0.001	n.s	<0.001	0.022	<0.001	<0.001	<0.001
Lupin variety	n.s.	n.s.	<0.001	0.001	0.003	n.s.	0.009	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.029	n.s.
l.s.d. (SR)	865	679		13.2	12.1	11.4	6.3	
l.s.d. (L)			586	2.8	2.4		3.2	
l.s.d. (SRxL)							8	

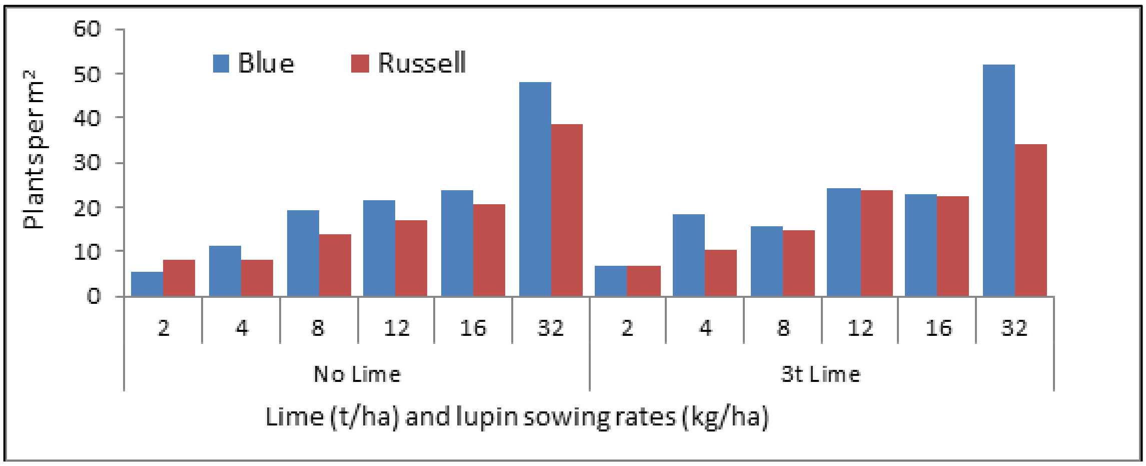

Figure 2.13 Lupin plant population in response to lime and sowing rate on 7 March 2013, three month after sowing at Glenmore Station.

Lupins dominated the ground cover at sowing rates above 8 kg/ha (*P*<0.001; l.s.d.=18% for no lime and 13% for 3T lime)(Figure 2.14). 'Blue' lupin provided slightly more cover than 'Russell' lupin. The mean lupin cover with 3T lime across all sowing rates was 23.3% for 'Blue' lupin and 18.6% for 'Russell' lupin (*P*=0.001; l.s.d.=2.8%). For the no lime treatment the significant interaction showed that 'Blue' lupin had higher cover for 12 and 16 kg seed/ha only (*P*=0.018; l.s.d.=7.5% when comparing the % lupin cover within the same sowing rate). This subtle difference between the two lupin varieties was probably due to the slightly higher germination and emergence of the 'Blue' lupin rather than any growth rate differences.

The lupin DM yield increased with increasing sowing rates (P<0.001; l.s.d.=657 and 679 for the Nil lime and 3T lime, respectively) (Figure 2.15). A linear regression of lupin DM yield vs. the logarithm of sowing rate ($y = 1292.6 \ln(x) - 457.58$; $R^2 = 0.87$) was no better than a linear regression using untransformed sowing rate data ($y = 117.12x + 873.08$; $R^2 = 0.86$). The DM yield of other species was greater for the 'Russell' lupin in the 3T lime (P<0.001; l.s.d.=105 kgDM/ha) (Figure 2.15).

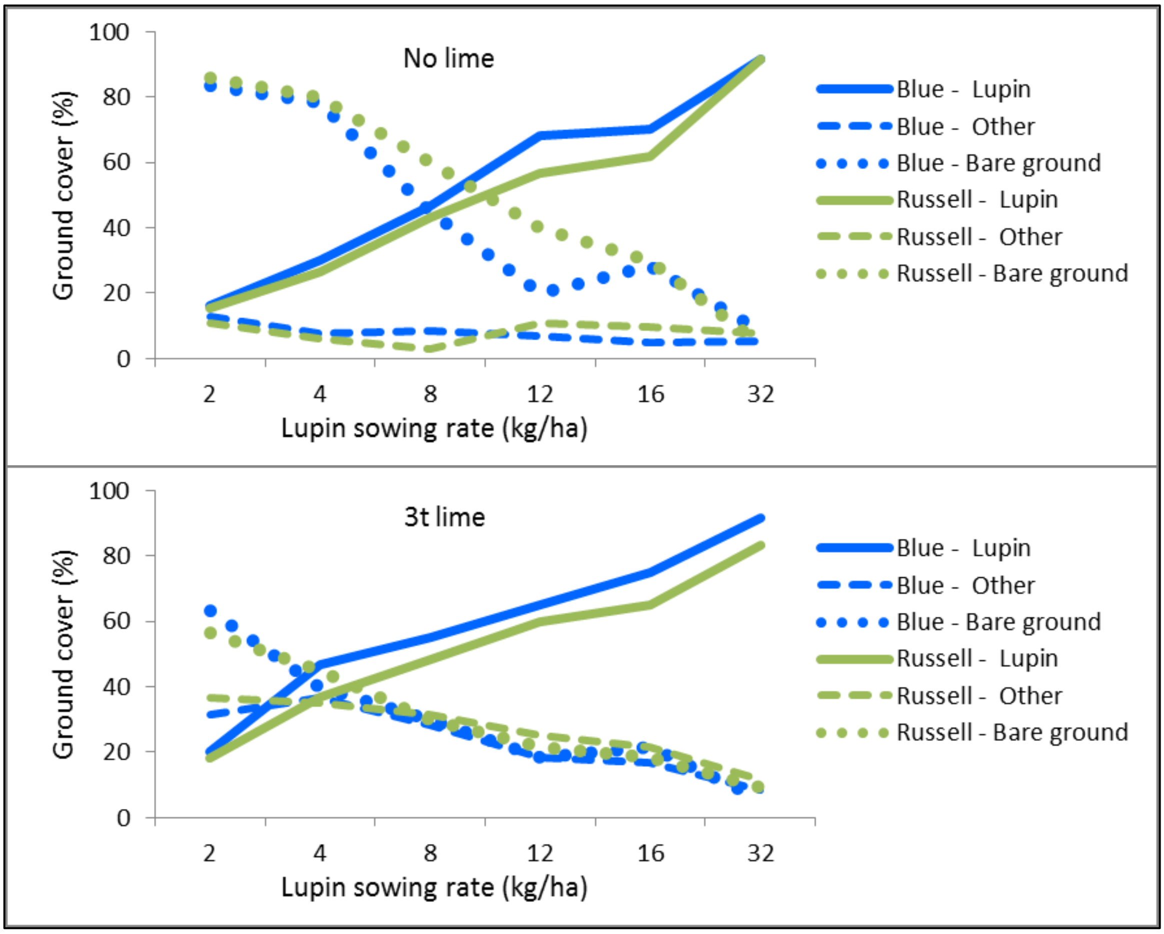

Figure 2.14 Lupin, other species and bare ground cover for 'Blue' and 'Russell' lupin measured on 7 March 2013, sown at five rates at Glenmore Station in December 2012. The Nil or 3T/ha lime treatments had been applied autumn 2012.

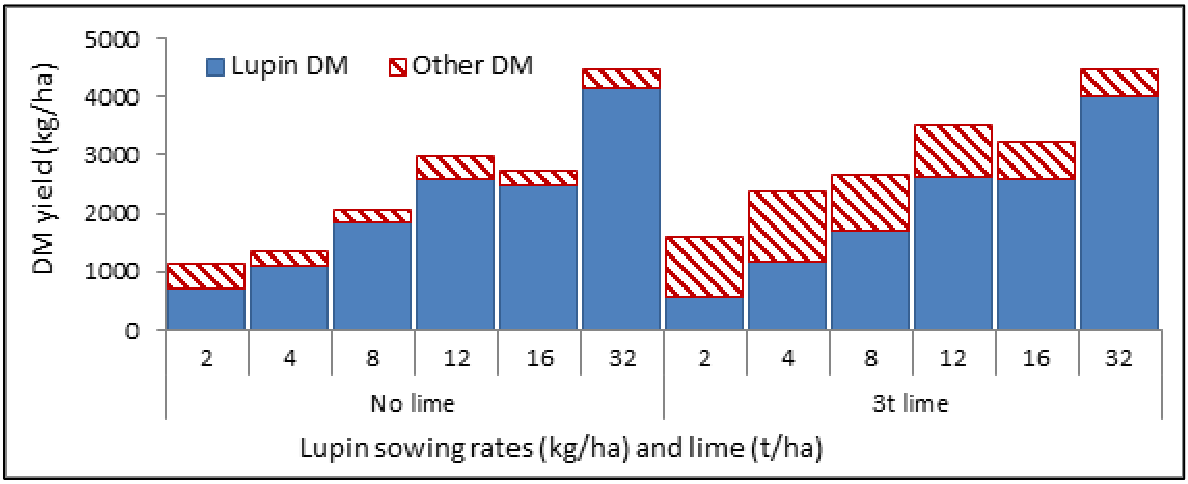

Figure 2.15 Lupin DM yield in response to lime application and sowing rate, on 7 March 2013, three month after sowing at Glenmore Station.

The DM yield of other species was greater for the 'Russell' lupin in the 3T lime (*P*<0.001; l.s.d. = 105 kg DM/ha) (Figure 2.16). Other species consisted (in descending order) of: Kentucky bluegrass, fathen, browntop, sweet vernal, striated clover, sorrel, suckling clover, white clover, haresfoot trefoil, and small plants of cocksfoot which were sown with the lupin seed. In the 3T lime experiment other species tended to have a greater dominance of grass and the Nil lime experiment had a greater dominance of the adventive legumes. Rep 3 was mostly on thinner soil and had the greatest prevalence of clovers, especially striated clover.

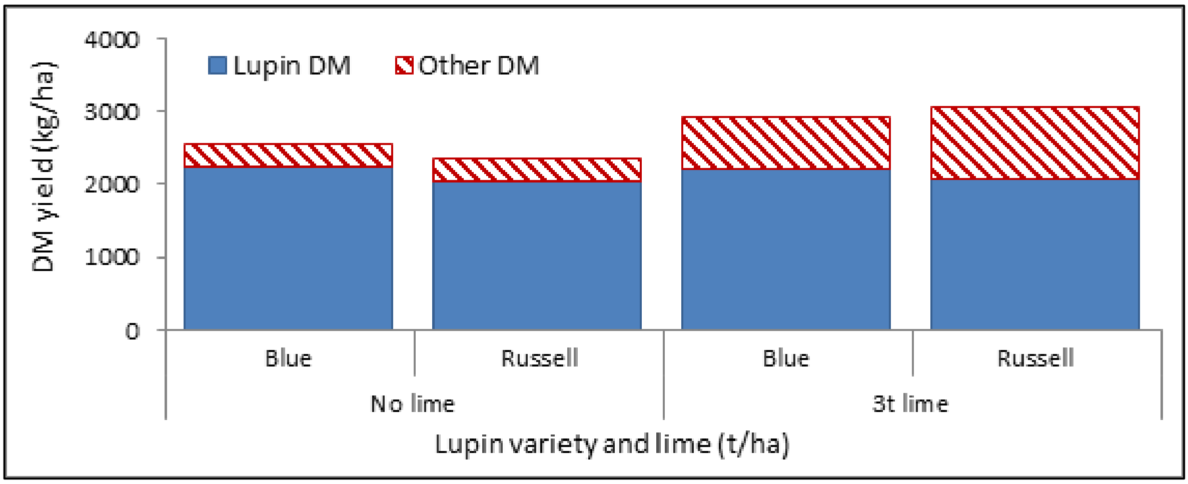

Figure 2.16 Lupin DM yield in response to lime and the variety of lupin sown, on 7 March 2013, three month after sowing.

The data above indicate that there was little difference between 'Russell' and 'Blue' lupin during the establishment phase. The data also indicate that lupin did not respond to the lime. However, the Nil lime experiment had received four applications of glyphosate herbicide (October 2011, November 2011, March 2012 and December 2013, just prior to sowing). The area had also been planted with legumes the previous year which did not do well, hence were removed by herbicide and burning in March 2012. The 3T lime experiment, although adjacent to the Nil lime, had received herbicide only in March and December 2012. The rejuvenation of the resident species in the 3T lime does not appear to have affected the lupin although it could be argued that the 3T lime compensated for or masked any detrimental effect that may have been caused by the greater abundance of other species.

April 2013

Plant and bare-ground cover were assessed on 18 April and a 4.0 x 1.16 m strip was mechanically harvested near the centre of each plot. Herbage was weighed fresh and subsamples taken for separation into lupin, cocksfoot and other species. Table 2.8 summarizes the treatment effects for Experiment 6a (Nil lime) and 6b (3T lime). Sown lupin dominated the ground cover in all but the 2 and 4 kg/ha sowing rates (Figure 2.17). The 'Blue' lupin was more dominant than the 'Russell' lupin. A significant sowing rate x lupin interaction in the Nil lime experiment indicated that 'Blue' lupin had greater cover in the mid-range of sowing rates than 'Russell' lupin. The cover of sown cocksfoot was generally low. Cocksfoot seed (2 kg/ha) was sown with the lupin seed but low plant numbers rather than lack of vigour appeared to be the main cause of the low cocksfoot cover. Bareground was more prevalent in the Nil lime experiment and other species more prevalent in the 3T lime experiment.

Table 2.8 Summary or analysis of variance for the effect of sowin**g** rate and lupin variety on the percentage ground cover and DM yields. There were no significant effects.

	% cover				DM yield (kg/ha)*	
±Lime and treatment factor	%Lupin	%Cocksfoot	%Other	%Bare	Total	Lupin
No lime						
Sow rate	<0.001	n.s.	n.s.	0.017	<0.001	<0.001
Lupin variety	0.001	0.026	n.s.	<0.001	n.s.	n.s.
Interaction	0.05	n.s	n.s.	0.041	n.s.	n.s.
l.s.d. (SR)	18.8			30.8	1821	1608
l.s.d. (L)	4.1	1.38		3.8		
l.s.d. (SRxL)	17.6			31.1		
3T lime						
Sow rate	<0.001	n.s.	<0.001	<0.001	<0.001	<0.001
Lupin variety	0.017	n.s.	0.033	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
l.s.d. (SR)	17.2		15.3	7.7	493	702
l.s.d. (L)	2		4.2			

* There were no significant effect of treatments for either cocksfoot or other specie DM yield

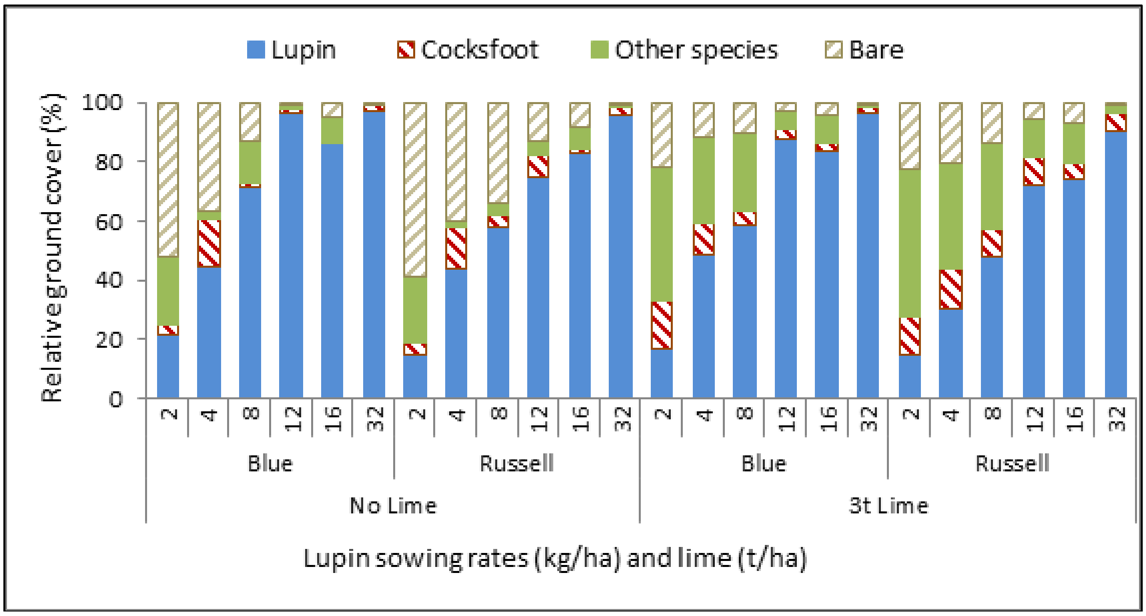

Figure 2.17 Relative ground cover of lupin, cocksfoot, other species and bareground for different lime, lupin species and sowing rate treatments on 7 March 2013, three months after sowing at Glenmore Station.

Lupin dominated the DM yield across all sowing rates in both experiments (Figure 2.18). The very low DM yields for cocksfoot and other species, compared with the ground cover values, was mostly due to their low growing stature and inability of the reciprocating-bar mower to harvest this component of the pasture adequately. It is likely that cocksfoot ground cover will increase over time.

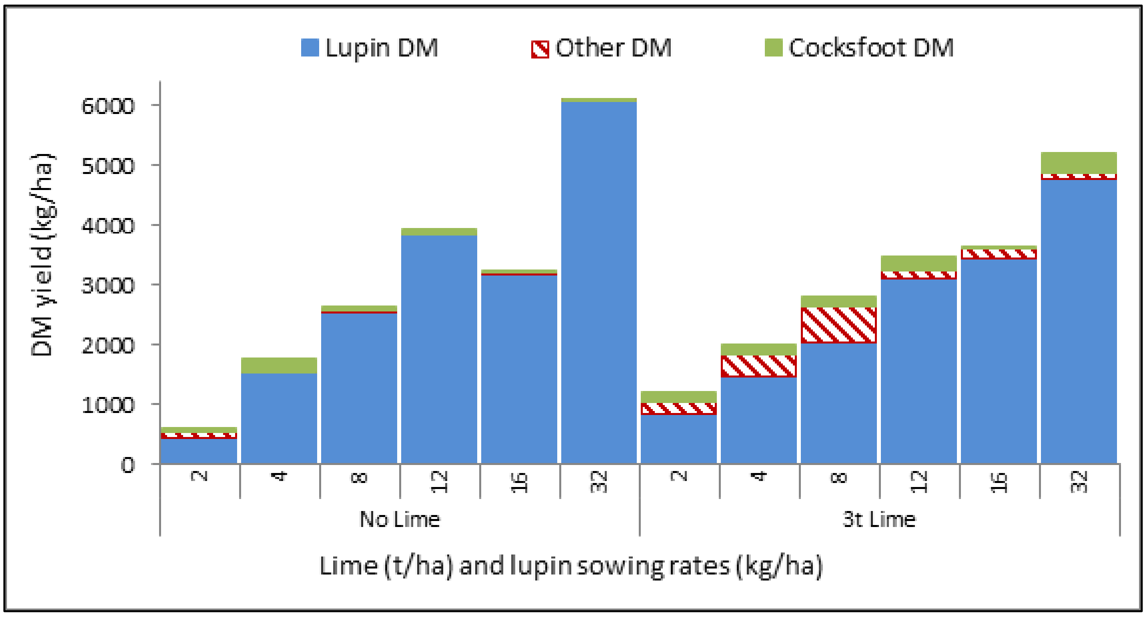

Figure 2.18 Dry matter yield of lupin, cocksfoot and other species for different lime rates and lupin sowing rates on 7 March 2013, three months after sowing at Glenmore Station.

Conclusions for Lupin sowing rates:

- Lupin dominance as measured by plant cover and DM yield was proportional to the amount of seed sown.

- There was little difference between the ‘Blue’ and ‘Russell’ lupin other that the slightly higher germination hence plant population, cover and yield.
- There appeared to be little direct influence of the applied lime on lupin yield.
- The amount of rejuvenating resident species was probably a function of the amount and effectiveness of pre-sowing herbicide application.

At the establishment phase of lupin control of competing vegetation by pre-planting herbicide or high rates of seed application, or both, provided a better return than lime application.

Experiment 7 (Lupin and lucerne establishment)

Lupin and lucerne were sown around the edges of Experiments 1, 3, 4, 5 and 6 at Glenmore Station. These areas had been sprayed with glyphosate, followed by grazing, burning and 3t/ha of lime applied in autumn 2012. The middle area in Plate 2.10 was used for Experiment 5. Experiment 7b was sown in lupins a strip along the fence on the left (Plate 2.10). Experiment 7c was established in the centre of the burnt-of area on the right with low density lupin and cocksfoot. The remainder, Experiment 7a, was sown in lucerne to fill in around the edges.

Plate 2.10 View of the experimental site at Glenmore Station.

<u>Experimental design</u>

Experiment 7a - Lucerne and cocksfoot

- Located around outside edges of existing experiments (e.g. Experiments 1, 3, 4, 5, 6a, 6b, and 7a & 7b described below).
- Sown on 11 December 2012 with 'Kaituna' lucerne at 10 kg/ha, cocksfoot (2kg/ha) and Crop 20 (100 kg/ha) using a Taege drill.

Experiment 7b - 'Russell' lupin

- Located inside the fence next to the road.
- Sown on 11 December 2012 with 'Russell' lupin (12 kg/ha) using a Flexiseeder plot drill. Crop 20 fertiliser (100 kg/ha) was drilled with the seed in the two outside drill strips and no fertiliser in the centre three drill strips.

Experiment 7c - Mixture of 'Russell' lupin and cocksfoot at low rates

- Located on the slope facing the lake on the lower end of the experimental area.
- Sown on 11 December 2012 with 'Russell' lupin (4 kg/ha), cocksfoot (2kg/ha) and Crop 20 (100 kg/ha) using a Taege drill.

<u>Results</u>

Plant emergence was slow until after 78 mm rain fell on 2-3 January 2013. Denis Fastier visited the Glenmore site on 7 January and wrote:

> "Definitely not worth an emergence count yet. There are random plants that have struck early, and the odd localised small area where plants are past the 2-leaf stage, but this is a very small percentage. The 'Russell' lupins in the lime trial are showing some promise, a few up to an inch tall, but everything else is down on hands and knees, glasses on, and there are some very tiny 2-leafers, if you can find anything at all.

The 78 mm of rain had a huge beneficial effect. Seedling emergence proceeded at pace and there was no repeat of the difficulties of the previous year. By 24 January 2013 plant populations were similar to the same sowing rate in Experiments 5 and 6 above. By early February there was only a tinge of green but good growth ensued through the summer and early autumn, mostly reliant on the stored soil moisture at depth and adequate rainfall (a further 30 mm in January, 50 mm in February and 22 mm in March)(Plate 2.11). Measurements in April 2013 showed good establishment but very poor growth in dry stony soils at the bottom of Experiment 7c and the portion of lucerne, Experiment 7a next to the bottom fence (Table 2.9).

Plate 2.11 Experiment 7c, sown with lupin and cocksfoot in December 2012, on 1 February 2013 (top) and five weeks later on 7 March 2013 (above). Lucerne from part of experiment 7a is visible on the left hand edge of the lower photo.

Table 2.9 Dry matter yield and plant population of the pastures in Experiments 7a, 7b and 7c in early April 2013, four months after sowing.

Experiment	Description	kg/ha	plants/m^2
7a-1	Lucerne - Near gate on deep soil	4759	95.2
7a-2	Lucerne/cocksfoot - east end of trial	2777	35.7
7a-3	Drought-stressed lucerne/CF - bottom	509	42.4
7b	Lupin - roadside	5985	30.0
7c-1	Unstressed lupin/CF - east end of trial	2238	16.0
7c-2	Drought-stressed lupin/CF - bottom	1797	10.9

<u>Autumn grazing of Lupins</u>

All plots were grazed in mid-June 2013. Beforehand, in mid-May, portions of Experiments 7b and 7c were fenced off and/or caged to exclude grazing of the lupins to see if there would be any detrimental effect of grazing lupin in their year of establishment. A sample of individual plants were also marked, measured and photographed to subsequently observe specific grazing effects and regrowth next spring. Small plants dominated the area of shallow, stony soil. They had an average of only five green leaves per plant and low plant weights (5 g), and were less than 6% of the weight of the larger lupin plants on the deeper soil nearby (Table 2.10). Although small, these plants were no longer 'seedlings' judging from the total number of leaves including dead leaves.

Table 2.10 Mean measurements per plant from plants collected from the moist (deep) soil and dry shallow (stony) soil in Experiment 7c at Glenmore in May 2013 prior to grazing. Plant heights were measured as the longest vegetative leaf petiole on each plant.

Soil	Plant height (cm)	No. of green leaves	No. of dead leaves	Green leaf DM (g)	Dead leaf DM (g)	Nodule score (max 10)	Shoot DM (g)	Root DM (g)	Crown DM (g)	Root Shoot Ratio
Deep	35.2	31	21.7	19.8	10.1	5.8	41.7	36.9	7.3	0.89
Stony	11.5	5.0	9.3	0.6	1.1	0.8	1.8	2.3	0.8	1.22

Autumn (May) grazing effects on summer-sown lupin at Glenmore Station – to replace Ashley Dene sowing date experiment

Questions:

1. Is autumn grazing of summer-sown (December) lupin detrimental to the subsequent survival and spring growth of 'Russell' lupin?
2. Does the size of the plant or its stage of growth alter the outcome?
3. Do we seek ± lime? This may affect the palatability hence grazing intensity?
4. Do we see any effect of the lupin variety (e.g. 'Russell' vs. 'Blue')?

Method:

1. Half of Experiment 7b (near the road) to be fenced parallel to the road, e.g. a ± 6 m strip next to the perimeter fence ungrazed.
2. Southern half of Experiment 7c was fenced off (not grazed). Two cages were also put in place.
3. Cages (1.1 x 0.7 m) were placed to exclude grazing in the unfenced section of Experiment 7c but not in Experiments 6a or 6b.
    a. Each cage in Experiment 7c was paired with an un-caged quadrat close by (approximately 2 m to the north). Quadrats were marked by two white pegs in diagonal corners.
    b. Cages were installed on 23 May 2013.
    c. Seven cages:
        i. 2 on the drier thinner soils (smaller plants) in the newly fenced (un-grazed) area.
        ii. 2 on the drier thinner soils (smaller plants) in the unfenced (grazed) area.
        iii. 3 in the damper areas (bigger plants) in the grazed area.
4. Experiments 6a and 6b: No cages were placed but four plants on each of 12 plots (2 lime x 2 lupin x 3 reps) were marked with wire staples (and tied with white string) to see whether there is a palatability effect of the lime (Nil vs. 3T) and/or lupin ('Russell' vs. 'Blue') on subsequent survival.

Autumn measurements:

1. Prior to grazing:
   Two or three plants within each size class in each cage and un-caged quadrat were marked with metal staples in the soil at the base of the plants and tied with coloured string to differentiate the size class.
2. Plant size class was based on the longest vegetative petioles, i.e. ignoring leaves on flower stalks:
    a. Green string – petiole < 10 cm;
    b. White string – petiole 10-25 cm;
    c. Blue string – petiole 25-40 cm;
    d. Red string – petiole > 40 cm.
    e. Also recorded:
        i. 'c' for cotyledons present;
        ii. 'r' for reproductive stalk present;
        iii. 'f' if plant is flowering or has flowered.
3. Taken photos with scale showing:
    a. Before grazing:
        i. Position of marked plants relative to each other;
        ii. Size of plants.
    b. After grazing:

        i. Intensity of grazing.
4. Dug up 10-12 plants of each size class:
    a. Washed roots;
    b. Scored nodules;
    c. Root:shoot ratios;
    d. Length of longest petiole, leaf numbers and leaf scars.
5. After grazing:
    a. Take photos showing grazing intensity;
    b. Observe intensity of grazing, looking for removal of lamina, petioles, reproductive stalks and whether or not the crowns have been chewed into:
        i. Less than 50% of leaf lamina removed;
        ii. Most of the lamina removed and less than 50% pf petiole removed;
        iii. Petioles removed near crown level;
        iv. Evidence of crowns being chewed into.

Spring measurements 2013:

1. Photos again in spring to show recovery;
2. Count plants again in September or early October and harvest in early December;
3. Count the number of reproductive stems at harvesting.

Glenmore Rainfall

Seed germination and seedling survival are dependent on favourable soil conditions including the right fertility and soil moisture. There is also competition from resident vegetation or weed seedlings for light and/or moisture. On shallow or stony soils winter rainfall is usually adequate to fully recharge.

Rainfall at Glenmore has been monitored with a tipping bucket rain gauge since December 2011 (Figure 16). These data are compared with data from the NIWA (National Institute of Water and Atmospheric Research) Tekapo climate station and the nearest virtual stations from NIWA's virtual climate station network (VCSN). Mostly the Glenmore and VCSN data show close correspondence. For both years there was more than adequate rain in October for planting. The October rain in 2011 saved the spring from being drier than normal but subsequently it was a 'normal' rainfall summer (Figure 17). The December sowing in 2012 benefitted hugely from the substantial rainfall in early January, 2013, which kept the accumulated rainfall above normal.

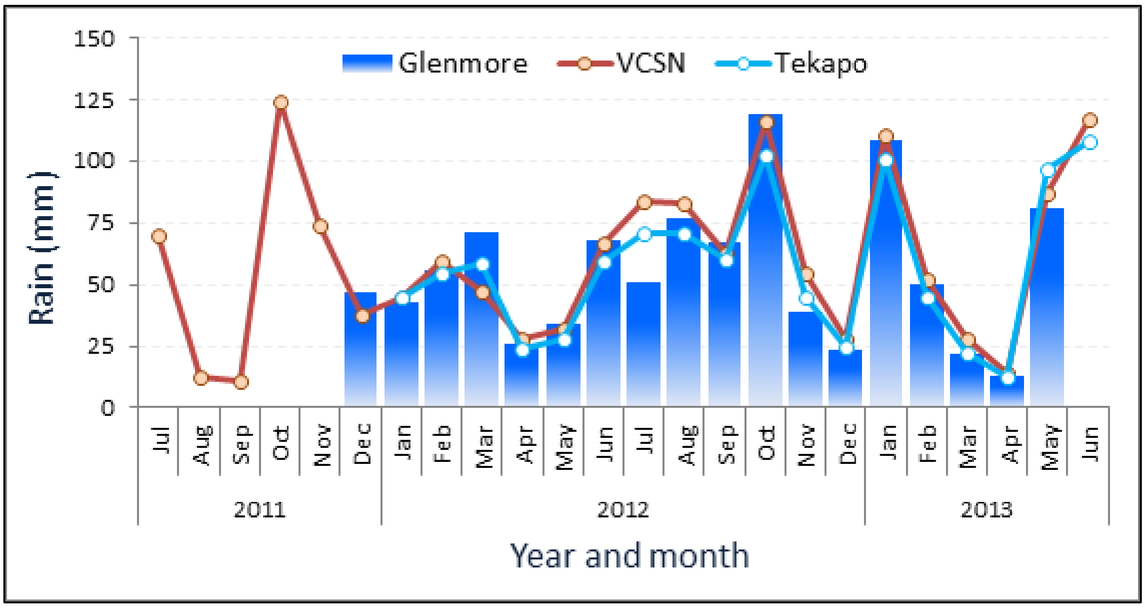

Figure 2.19 Rainfall at Glenmore recorded on site, NIWA's Tekapo climate station located at the airstrip 11 km to the S, and NIWA's virtual data from VCSN stations 19318 and 19319 located within five km of the experimental plot. Note: May 2013 data from Glenmore are incomplete as is the NIWA June data.

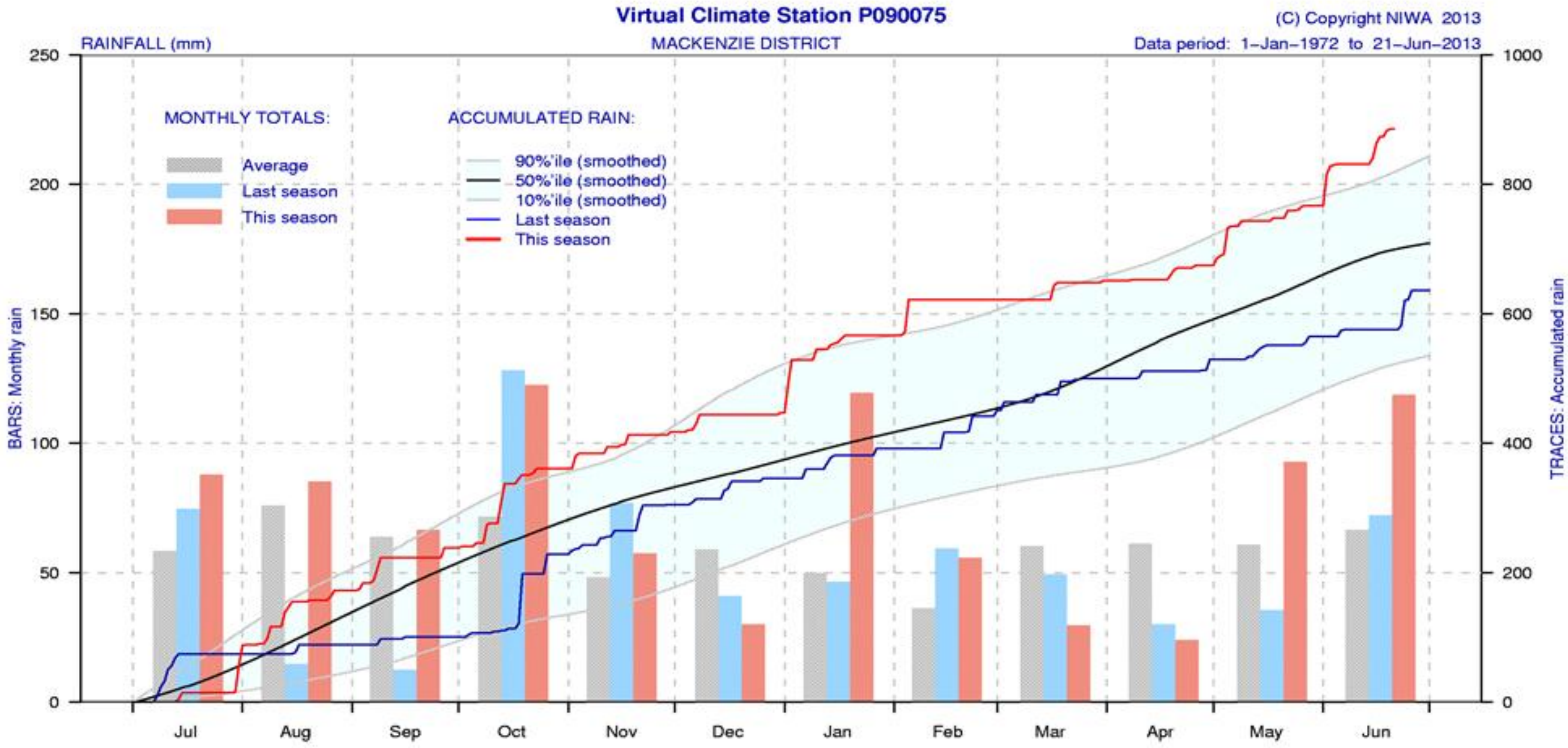

Figure 2.20 Rainfall summaries for a point 2.5 km north of the Glenmore experiments. Data are from NIWA's virtual climate station network (VC SN Agent No: 19318, Network No: P090075). These and other climate/water summaries are freely available at http://wrenz.niwa.co.nz/webmodel/.

Site 3 – Simon’s Hill

Experiment 1 - Cocksfoot and Caucasian clover trial at Simon's Hill

Primary Objective

Determine whether fertiliser type and ‘Russell’ lupin affect the establishment and survival of Caucasian clover and cocksfoot drilled with a unique coulter.

Experimental design

The trial was a 6 x 2 factorial experiment with six fertilisers and ± Russell lupin as a cover crop. The 12 fertiliser x lupin combinations were drilled with a unique coulter in a randomised block design with four blocks and 3 m × 10 m plots, repeated on 2 sites of different aspects (‘sunny face’ and ‘dark face’) on Simon’s Hill Station.

This experiment was discontinued in 2012 because of strong resident perennial grass and haresfoot clover competition. To replace it, an annual clover experiment on a sunny face was introduced.

Experiment 2 – Sunny face (autumn-sown) annual clovers trial at Simon's Hill (uncontracted)

Primary Objective

Determine whether autumn herbicide and fertiliser application immediately prior to sowing affects the establishment of different annual clovers.

Experimental design

The experiment was designed with five seed mixtures ± autumn herbicide. A 15 m wide strip was sprayed with 10 L of Round-up for 140 m down the sunny face of the hill. 15 m strips on either side of the herbicide sprayed strip were left unsprayed. This provided three strips of 15 m x 140 m, and a total area of 45 m x 140 m as the experimental site. The five seed mixtures were drilled across the three blocks and replicated 10 times down the hill. The experiment was not designed as a randomised experiment with the order in which the seed mixtures were sown in each replicate not changing (the order was the same as in the 'seed mixtures' section below).

Seed mixtures

1. 'Bolta' balansa clover (5 kg/ha); 'Denmark' subterranean clover (10 kg/ha).
2. Bladder clover (5 kg/ha); 'Campeda' subterranean clover (10 kg/ha).
3. 'Prima' gland clover (5 kg/ha); 'Campeda' subterranean clover (10 kg/ha).
4. Lucerne (8 kg/ha); 'Sensation' red clover (4 kg/ha); 'Russell' lupin (3 kg/ha).
5. 'Blue' lupin (5 kg/ha); *Lotus corniculatus* (4 kg/ha).

All seed mixtures included 1 kg/ha cocksfoot and 0.5 kg 'Tonic' plantain.

Soils

Soil sampling in recent years revealed typical values to be:

- pH around 5.9.
- Olsen P 12-20 mg/L.
- Sulphate S 2-5 mg/kg.

Treatments

The middle 15 m strip of the trial area was sprayed with 10 L of Round-up on 22 February 2012. 100 kg of 50% Sulphur Super was applied in spring and 200 kg of 30% sulphur super was applied at sowing. An additional 100 kg of Cropmaster 20 was sown through the drill. A Flexiseeder drill was used to direct drill the seed on 24 and 25 February 2012.

Plate 3.1 Autumn sown 'Bolta' balansa clover with mature seed heads (spring sown strips in background) at Simon's Hill on 11 December 2012.

In December 2012 visual assessments of plant population (mainly observations of which species were doing well) and phenological stage were made. 'Bolta' balansa clover was the most successful of the autumn sown species. Regeneration of balansa and other annual clovers (subterranean, gland and bladder) will be assessed in autumn and spring 2013. The persistence of the perennials (lucerne, lupin, lotus, plantain and cocksfoot) will also be measured after autumn grazing. Annual brome grasses dominated the autumn sprayed strip while perennial grasses remained dominant in the unsprayed strips (Plate 3.1). Grass competition suppressed all drilled species to varying degrees. Some species were affected more than others because of the need to postpone grazing until all annual species had set seed.

On 23 May 2013 the top half of the balansa clover plots of reps 1, 2 and 3 were mown to around 5 cm height. Observations will then be made in spring 2013 to determine whether the removal of the vegetation was advantageous to the re-establishment of balansa clover or whether the vegetation protected the seedlings from frost/snow.

Experiment 3 – Sunny face (spring-sown) annual clovers trial at Simon's Hill (uncontracted)

Primary Objective

Determine whether herbicide sprays in autumn and spring before spring sowing affect the establishment of different legume species in a high country environment.

Experimental design

Two sprayed strips were sown in five seed mixtures which were replicated eight times in each block. The experimental design was not randomised with the order in which the seed mixtures were sown remaining the same in each replicate (in the order shown in the 'seed mixtures' section below). 100 kg of Cropmaster 20 was sown through the drill at sowing.

Drilling success on the hill was variable with large areas with uneven emergence, especially in the eastern strip. For this reason, it was decided that any sampling and observations will only be performed in the western strip. Areas where it was evident that uneven drilling was responsible for poor sown species emergence and establishment were and will be avoided during any measurements taken for this experiment.

Seed mixtures

1. 'Bolta' balansa clover (5 kg/ha); 'Denmark' subterranean clover (10 kg/ha).
2. Bladder clover (5 kg/ha); 'Campeda' subterranean clover (10 kg/ha).
3. 'Prima' gland clover (5 kg/ha); 'Campeda' subterranean clover (10 kg/ha).
4. Lucerne (8 kg/ha); 'Sensation' red clover (4 kg/ha); 'Russell' lupin (3 kg/ha).
5. 'Blue' lupin (5 kg/ha); *Lotus corniculatus* (4 kg/ha).

All seed mixtures included 1 kg/ha cocksfoot and 0.5 kg 'Tonic' plantain.

On 30 January, 1 m drill rows were harvested from each plot of the western block for dry matter and botanical composition analyses. In each plot, the phenological stage of each sown species was scored. Samples of leaf and petiole were also taken for sodium and other nutrient analysis. Results are still pending. On 23 May 2013, it was observed that balansa clover was re-establishing from seed (Plate 3.12). It was, however, hard to determine whether seedlings in the other plots were of the sown legumes or resident species as only cotyledons were present. This could be confirmed in spring 2013.

Plate 3.2 General shot of direct drilled spring sown plots at Simon's Hill on 9 November 2012.

Plate 3.3 French interns conducting plant establishment counts in direct drilled spring sown plots at Simon's Hill on 11 December 2012.

Plate 3.4 Emerging plantain, cocksfoot and clover in one of the direct drilled plots (sown early November 2012) at Simon's Hill on 11 December 2012.

Plate 3.5 General view of the spring sown direct drilled plots with improved pasture species at Simon's Hill on 8 January 2013. The area was sown 2 months prior.

Plate 3.6 Vigorous growth in direct drilled, spring sown plots at Simon’s Hill sunny face on 22 January 2013 (11 weeks after sowing).

Plate 3.7 Gland clover in flower in spring sown plot at Simon’s Hill on 8 January 2013.

Plate 3.8 Spring sown gland clover plot on 22 January 2013 approximately 11 weeks after sowing.

Plate 3.9 General view from the Simon's Hill sunny face spring-sown experimental area with one of the direct drilled strips in the foreground on 22 January 2013.

Plate 3.10 Wilted herbage in the spring-sown plots on 25 February 2013 about 16 weeks after sowing.

Plate 3.11 The spring-sown annual clover plots on the sunny face at Simon's Hill, 30 January 2013. The arrow points to the autumn sown herbicide strip where annual brome grasses are dominant in the direct drilled plots.

Plate 3.12 Balansa clover seedling re-establishing seven months after the initial crop was sown at Simon's Hill, taken on 23 May 2013.

Experiment 4 – Lupin winter survival and grazing at Simon's Hill (to replace Ashley Dene experiment)

A 5 ha paddock of lupins was sown with 100 kg Crop Zeal 20 at Simon's Hill on 23 February 2013 by Denis Fastier after a capital dressing of 50 kg Durasol and molybdenum. This paddock will be used to assess the winter survival of autumn-sown lupins in the high country.

On 23 May 2013, cages were placed in the paddock. All plants in each cage were marked (by inserting coloured string into the soil close to the base of the seedling) according to the number of true leaves (Table 3.1). There were three categories:

1) Green string for plants with cotyledons only (i.e. without unfolded leaves) (Plate 3.13);
2) Blue string for plants with 1-3 unfolded leaves (Plate 3.14);
3) Red string for plants with 4 or more unfolded leaves (Plate 3.15).

Table 3.1 Number of lupin seedlings (plants) in each of the three categories per cage at Simon's Hill on 23 May 2013.

Sample ID	Plant size class	Number of plants
SH 1a	Cotyledons only	6
SH 1b	1-3 unfolded leaves	3
SH 1c	4+ unfolded leaves	3
SH 2a	Cotyledons only	3
SH 2b	1-3 unfolded leaves	6
SH 2c	4+ unfolded leaves	3
SH 3a	Cotyledons only	3
SH 3b	1-3 unfolded leaves	13
SH 3c	4+ unfolded leaves	3

On the same day a number of plants were dug up outside the caged areas to count the number of nodules and to obtain a root: shoot ratio. It was established from these plants that:

- Seedlings with only cotyledons had no nodules;
- Seedlings with 1-3 unfolded leaves had fewer than three nodules;
- Seedlings with 4-6 unfolded leaves had three to 10 nodules;
- Seedlings with 7-10 unfolded leaves had more than 11 nodules.

<u>Soil test</u>

A basic soil test was taken in 2013 on the Mayburn Dry Flat at Simon's Hill. The results in Table 3.1 show that sulphate sulphur and sodium are the only limiting nutrients.

Table 3.1 Soil test results for Mayburn Dry Flat at Simon's Hill in 2013.

Site	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch K (QTU)	Exch Ca (QTU)	Exch Mg (QTU)	Exch Na (QTU)
Mayburn Dry Flat	6	21	1	13	4	17	<2

Plate 3.13 Lupin seedling in the cotyledon only category at Simon's Hill on 23 May 2013.


Plate 3.14 Lupin seedling in the 1-3 unfolded leaves category at Simon's Hill on 23 May 2013.

Plate 3.15 Lupin seedling in the four or more unfolded leaves category at Simon's Hill on 23 May 2013.

Site 4 – Bog Roy

Experiment 1 – Lucerne yield at Bog Roy

Primary Objective

Quantify the seasonal production of lucerne and ryegrass pastures at varying altitudes in response to temperature, soil type and aspect, compared with unimproved pasture.

Experimental design

Exclusion cages were placed in eight different paddocks across the property. Each cage measured 0.6 x 0.6 m (0.36 m^2) and enclosed a representative sample/area of the paddock. Sown species in these paddocks included lucerne and lucerne/grass mixes, and are compared with unimproved pastures and irrigated ryegrass/white clover pastures. Cages were lifted and herbage samples cut on roughly a monthly basis. Samples were then dried and weighed to determine dry matter production. Pasture heights were also measured to build a relationship between height and DM yield so that sward height can be used to estimate DM in whole paddocks. This is not a designed experiment, but the unimproved control grassland provides baseline data.

Soil tests

Basic soil tests were conducted at two sites at Bog Roy on 20 May 2013. These sites were south-east facing Cone Hill and west facing Pillars.

Table 4.1 Soil test results at two hill sites at Bog Roy Station, sampled on 20 May 2013.

Site	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)
Cone Hill	6.0	9	3	9	34	21	1
Pillars	6.3	7	4	9	42	22	1

Results (September 2012 – June 2013)

DM production was much greater for the lucerne paddocks (Figure 4.1).

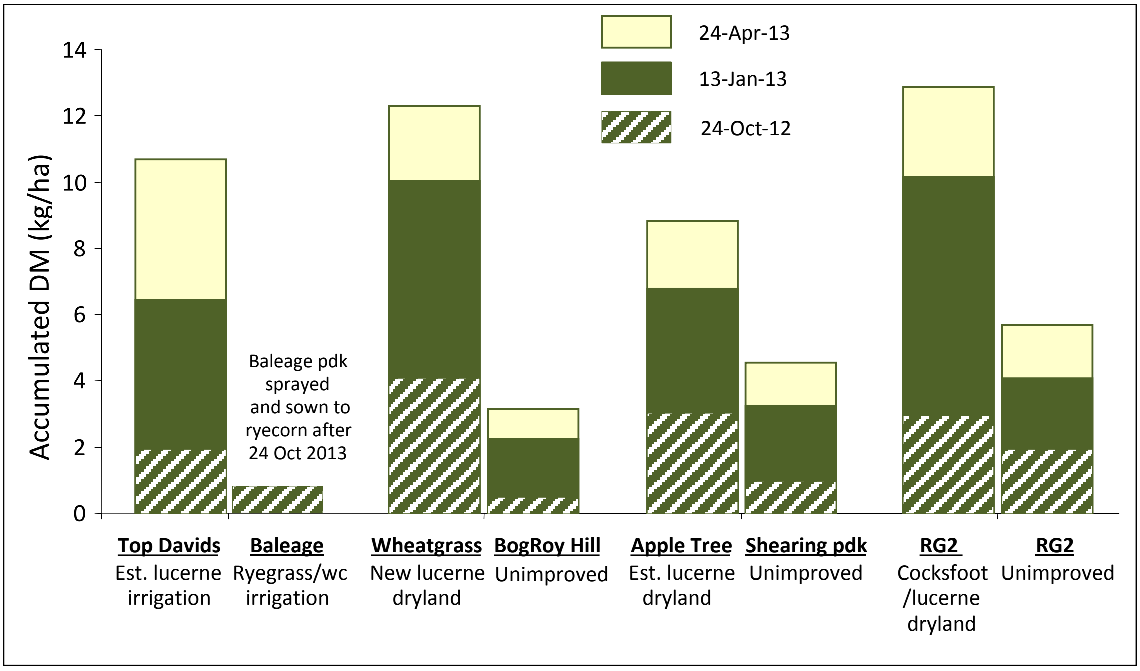

Figure 4.1 Accumulated DM yield from cages cuts at Bog Roy station, September 2012- April 2013, Data are presented in paddock pairs, the lucerne sown paddock then the 'grass' or unimproved paddock. N.B.: Harvests were usually at monthly intervals except that the January harvest was for two months growth.

DM yield estimates from the cage cuts showed growth continuing into January in response to rainfall in spring and early summer (Figure 4.2). Also shown are the rainfall data available from nearby NIWA climate stations.

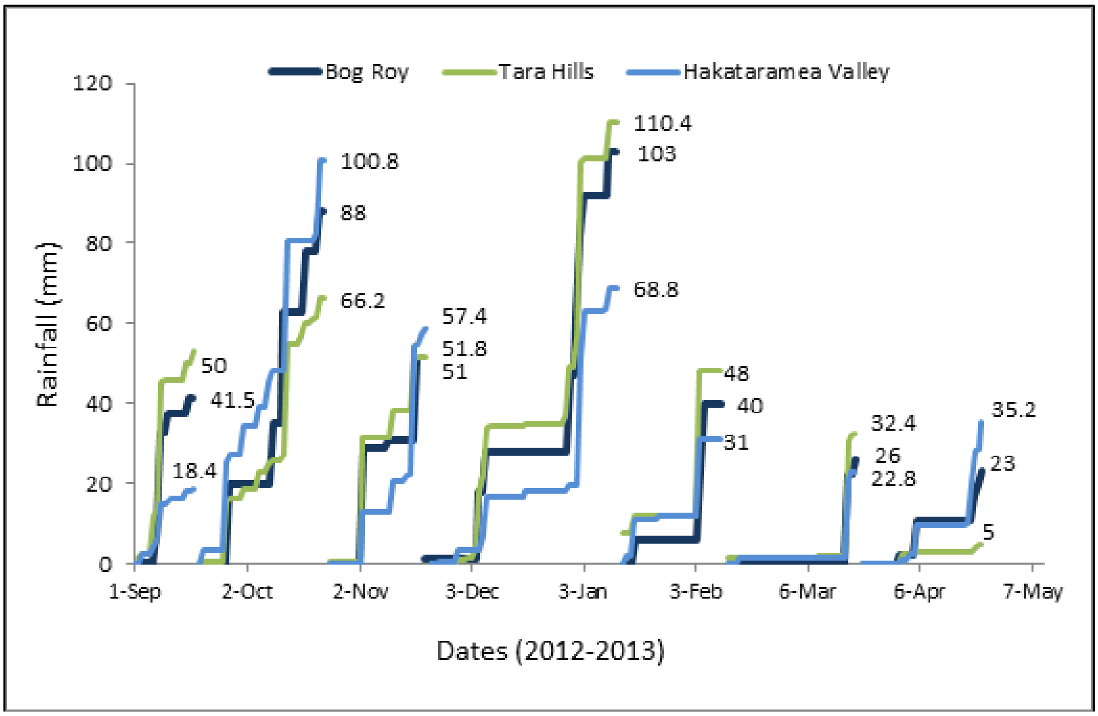

Figure 4.2 Accumulated rainfall at Bog Roy Station and nearby NIWA (National Institute of Water and Atmospheric Research) climate stations corresponding to cage harvest dates during September 2012- April 2013. (Rainfall data courtesy NIWA CliFlo online database).

Whole paddock dry matter yield

The paddock dry matter yield was estimated by measuring the canopy height and using the information given in Table 4.2. These data have been gathered from quadrat cuts where heights are measured and the relationship to DM yields (the coefficients) determined. The dataset from Bog Roy is very small at this stage compared to the Lincoln dataset but shows that with more data farm specific relationship between height and DM yield can be determined.

The pre- and post-graze DM yield of the Bog Roy paddocks (Table 4.3) were then calculated by multiplying the measured canopy height and pre- or post-graze coefficient shown for the Lincoln data in Table 4.2.

Example charts of yield and grazing history over the growing season for three paddocks at Bog Roy station are shown in Figure 4.3.

Figure 4.4 shows the grazing history for the Royals mob through to January. The pre-graze data points indicate the feed on offer and the series of post-graze data points show the residual as sheep are shifted to the next paddock. Only shifts onto lucerne are shown here.

Table 4.2 Coefficient for estimating lucerne DM yield (kg/ha) from height (cm) measurements.

	Lincoln Data – Long term		Bog-Roy (2012- 2013)
Month	**Pre-graze co-efficient**	**Post-graze co-efficient**	Pre-graze coefficient
Jan	60	46	71*
Feb	60	45	46
Mar	60	45	43
Apr	60	45	51
Jun	60	42	
July	60	40	
Sep	105	60	104
Oct	100	55	67
Nov	80	51	64
Dec	65	48	50

* January data was from a long rotation of 7 weeks

Table 4.3 Mean dry matter yields (kg DM/ha) and utilisation of feed on offer for lucerne paddocks at Bog Roy Station from September 2012 to April 2013.

		Rotationally grazed			Set-stocked*			Cut for silage**			Totals/means across all grazings/harvests		
Paddock	**Area (ha)**	**Number of rotations**	**DM yield**	**Utilisation (%)**	**Number of grazings**	**DM yield**	**Utilisation (%)**	**Number of harvests**	**DM yield**	**Utilisation (%)**	**Total grazings and/or harvests**	**DM yield**	**Mean utilisation (%)**
Apple tree Paddock	9.7	4	6750	70							4	6750	70
Baleage 4	7.0	4	8893	71							4	8893	71
Bottom Davids	7.0	3	5633	75							3	5633	75
Slope	7.0	4	6440	78							4	6440	78
Top Lake Paddock	8.5	3	4005	73							3	4005	73
Top Saddle Paddock	8.0	4	7081	73							4	7081	73
Middle Shearing	16.2	3	4565	63	1	565	38				4	5130	57
Roadside Shearing	12.9	3	5096	75	1	565	38				4	5661	66
Rough Gully Lucerne	9.8	3	5185	72	1	290	19				4	5475	59
Shearing Pdk Gully	20.0	3	4875	66	1	565	38				4	5440	59
Btm Lake Paddock	8.5	4	5317	70							4	5317	70
Davids' Paddock	7.0	3	6080	69				1	3396	94	4	9476	75
Wheatgrass	10.0	2	4570	70				1	2196	92	3	6766	77

*DM yield and utilisation estimates are low because the recording of lucerne heights before and after grazing did not allow for growth during the longer grazing period.

** Utilisation values of the silage harvest do not correspond directly to utilisation under grazing.

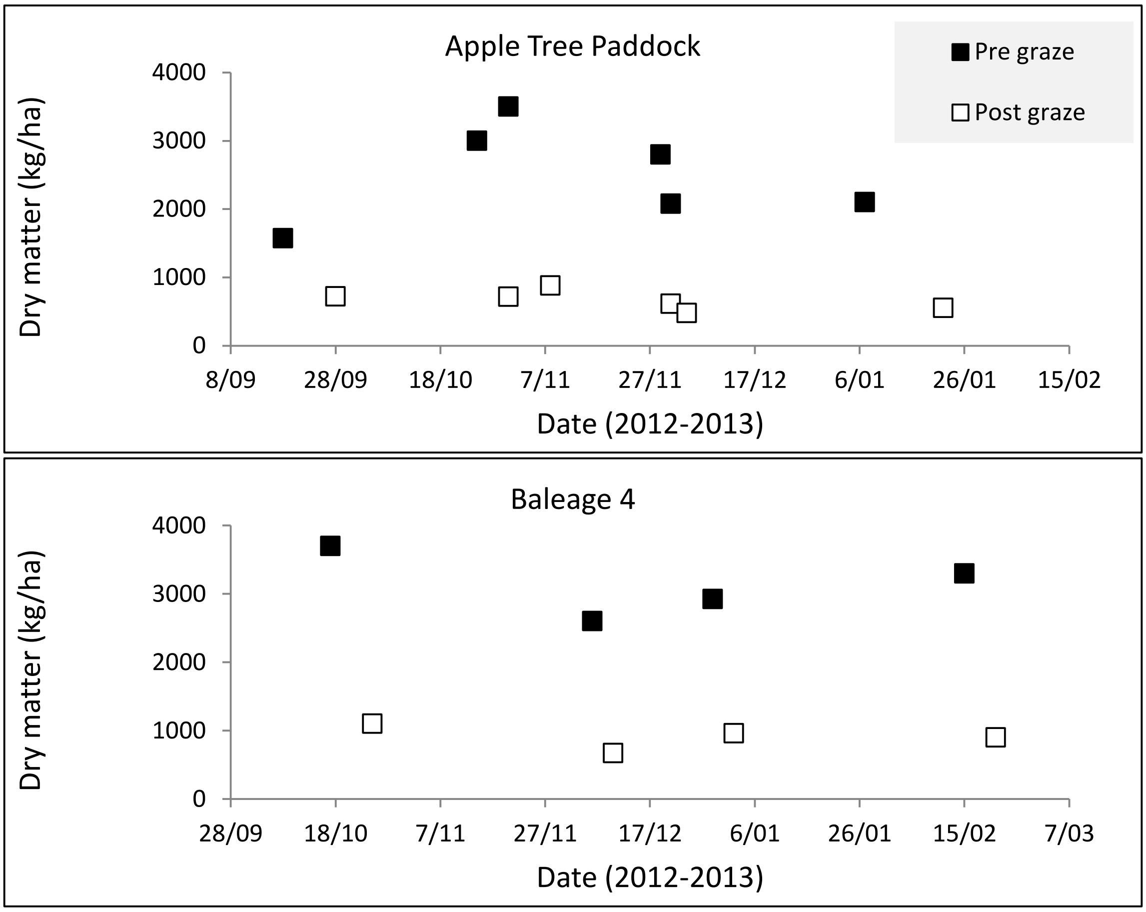

Figure 4.3 Examples of yield and grazing history for two paddocks at Bog Roy Station showing the feed on offer at the start of grazing rotations and the residuals after grazing throughout the growing season.

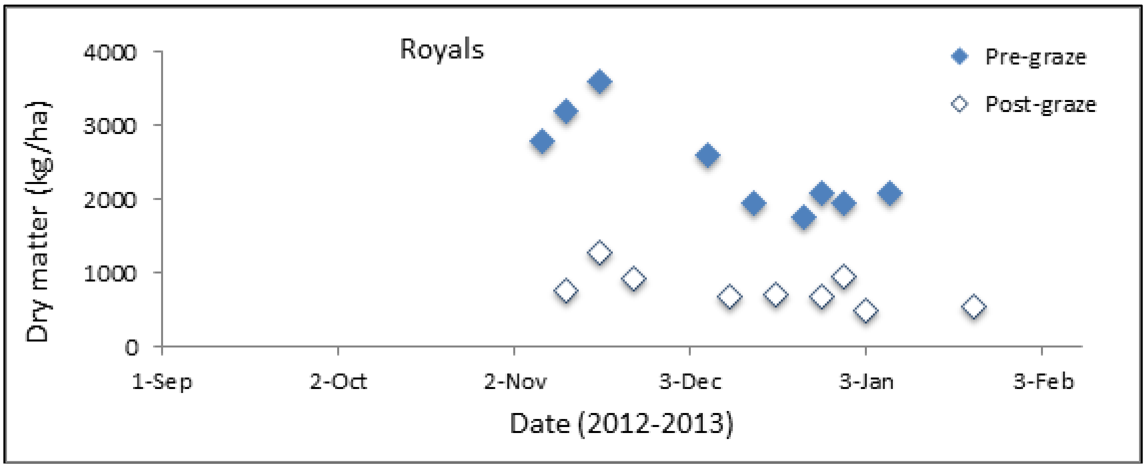

Figure 4.4 Example of yield and the 'Royals' mob's movements at Bog Roy station showing the feed on offer at the start of each mob shift and the residual after grazing throughout the growing season.

Rain records

Annual rainfall accumulations for July-June periods for Bog Roy Station, nearby NIWA stations, and the closest NIWA record from their virtual climate station network (VCSN) were generally very similar (Figure 4.4). On-farm annual rainfall recorded at Bog Roy Station for 2011 and 2012 was 519 and 514 mm, respectively. This was above the farm's average of 416 mm from 1992 to

2010. Climate data summary from the NIWA virtual climate station near Bog Roy shows a similar comparison with long-term (40 year) means (Figure 4.5).

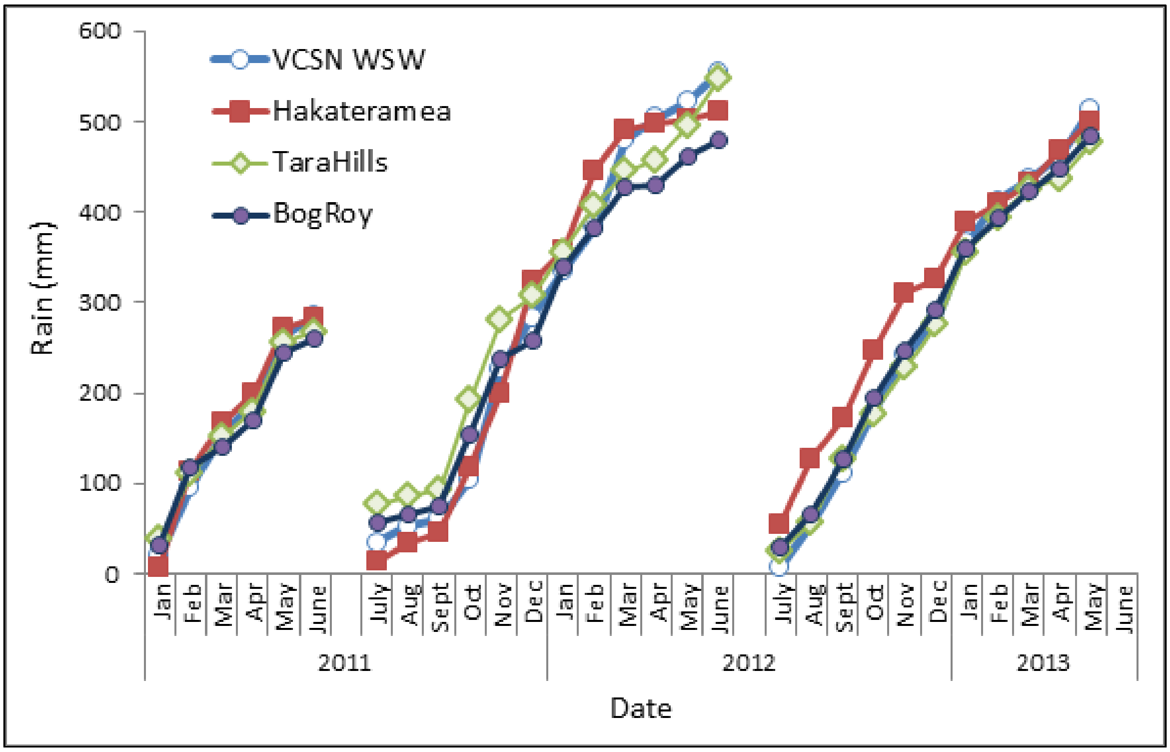

Figure 4.4 Comparison of monthly rainfall accumulations collected at Bog Roy Station, and from the NIWA Hakateramea Station, the NIWA Tara Hills climate station and the NIWA virtual climate network station (VSCN P082061) located approximately 2.5 km WSW of the Bog Roy homestead.

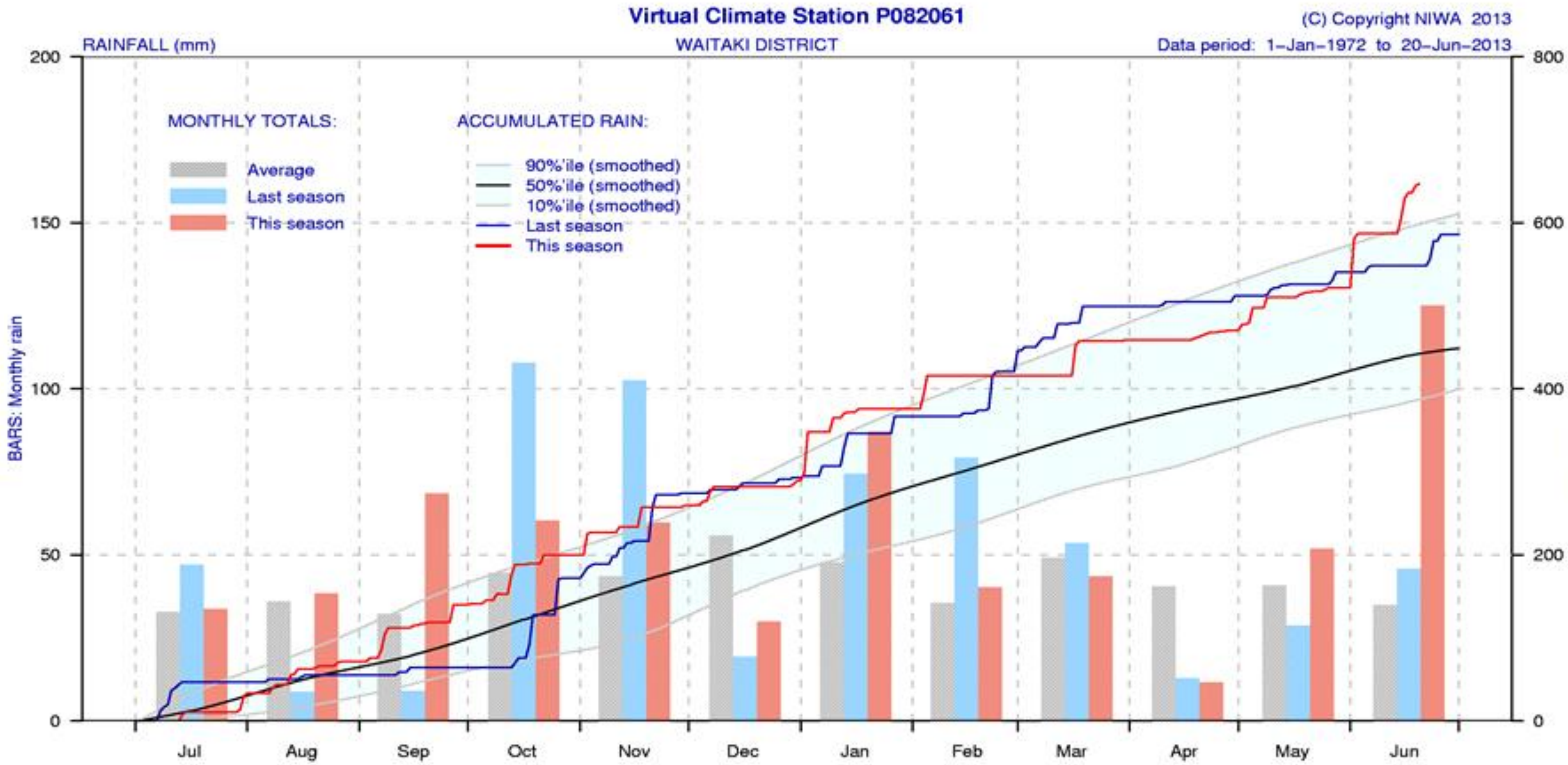

Figure 4.5 Rainfall summaries for a point 2.5 km WSW of Bog Roy Station homestead. Data are from the NIWA virtual climate station network (VC SN **Agent No:** 14202, Name: Waitaki District, Network No: P082061).These other climate/water summaries are freely available at http://wrenz.niwa.co.nz/webmodel/.

Experiments 2 and 3 – Annual clovers at Bog Roy

Experiment 2

A 1 ha area was fenced on a low altitude site so grazing could be controlled on broadcast plots and a direct drilled area.

Experiment 3

An annual clover mix was broadcast on three aspects at medium and high altitudes in autumn 2012 and spring 2012. Half of each plot was caged to protect seedlings from grazing.

Monitoring includes:

- Visual assessment of survival through winter.
- Ability of annual clovers to flower and set seed.
- Ability of annual clovers to re-establish from seed.
- Dry matter production of annual clovers at different altitudes and aspects.
- Annual clover responses to fertiliser at establishment.

Measurements and Dates for all experiments at Bog Roy

2011

16 Nov — First cage cut was taken for improved vs. unimproved pasture experiment (Experiment 1).

19 Dec — Second cage cut taken (Experiment 1).

2012

18 Jan — Third cage cut taken (Experiment 1).

19 Feb — Fourth cage cut taken (Experiment 1).

15 Mar — Annual clover experiment was visually assessed for seedling establishment. Fifth cage cut taken (Experiment 1).

17 Apr — Final cage cut was taken for improved vs. unimproved pasture experiment (Experiment 1).

16 May — Three sites were selected with quadrats being laid out at each (Experiment 3). One cultivar of bladder clover, subterranean clover, balansa clover and 'Russell' lupin were oversown within each quadrat. Quadrats also received a dressing of Sulphur Super 15.

22-23 Nov — Dry matter harvests and visual vigour scores of sown legumes and resident clovers (Experiment 1). Plant heights and stolon lengths measured, number of subterranean clover stolons and flowers per plant counted. Height and maturity of lucerne plants measured.

2013

29 Jan	Harvested exclusion cages (Experiment 3). Results from this harvest are still pending.
6 May	Seed was spread on half of each plot in Experiment 2. Plots will be checked in spring 2013 to see whether seedlings are present.

Plate 4.1 Boy Roy Station. Annual clover exclosure area 26 September 2012 (Experiment 2). Balansa clover established moderately well but other species were disappointing.

Plate 4.2 Bog Roy Station. Close up of improved pasture mix (includes gland in flower and lupin seedling centre of shot). 9 November 2012 (Experiment 3).

Plate 4.3 Bog Roy Station. Close up of clover and lupin seedlings, 9 November 2012 (Experiment 3).

Plate 4.4 Bog Roy Station. General shot of exclosure area, 9 November 2012 (Experiment 2).

Plate 4.5 Spring broadcast plots with part of each plot caged at Bog Roy on 26 September 2012 (Experiment 3).

Plate 4.6 Lupin seedlings in a spring broadcast plot at Bog Roy on 29 January 2013 (Experiment 3). Flower-heads are from resident haresfoot clover.

Plate 4.7 Subterranean clover plants in a spring broadcast annual clovers plot at Bog Roy on 29 January 2013 (Experiment 3).

Site 5 – Omarama Station

Over-sowing of annual clovers at Omarama station (uncontracted)

Primary Objective

To increase the clover content of pasture on sunny and shady slopes by OSTD (over-sowing/topdressing).

Goals

- Establish annual clovers through over-sowing on faces with contrasting aspects.

Site descriptions

1. The shady face block (approximately 25 ha) generally faces east but folds in the slope to create SE and NE faces which influence the soil moisture regime. The slope varies between 15 and 20 degrees. The soil surface is rubbly in places, it is intensively modified by stock tracks and moist bare ground sites where over-sown seed may establish are relatively common. Pasture species present include cocksfoot and perennial ryegrass and a small amount of white clover. Shrubs cover about 20% of the block. Haresfoot clover is the most common legume. There are however large strips on dry mini-ridges where vegetation is less vigorous.
2. The sunny face block (approximately 25 ha) has about 2 ha of stony flat, a 10 to 15 degree north slope plus a west facing rocky slope. The flat area and the north face are dominated by danthonia and rip-gut brome but there are areas where haresfoot clover is common. Briar rose bushes are common on the west face.

Investigated Species

- Subterranean clover cv. 'Seaton Park'
- Balansa clover cv. 'Bolta'
- Balansa clover cv. 'Frontier'
- Cocksfoot cv. 'Greenly'
- ***Note** - gland clover was the first choice for this site, but no seed was available.*

The following seed mixture was flown on to 15 ha of each block on 8 March 2012. 'Seaton Park' sub clover (4 kg/ha), 'Bolta' balansa clover (3 kg/ha), 'Frontier' early flowering balansa clover (3 kg/ha), coated 'Greenly' cocksfoot (2 kg/ha, equivalent to 1 kg/ha bare seed). Sulphur super 20 was applied with the seed at 350 kg/ha.

Results

On 17 May 2012 seedlings from broadcast seed were common on the south east facing areas (shady) which had disturbed surfaces. Balansa seedlings in particular had adequate populations in small patches with up to 50/m^2. Sub clover plants were less common with only about one per m^2. This means that only about 30% of the 15 ha oversown in the block is likely to have a balansa plant population sufficient to justify closing the block in late October/early November to get maximum reseeding.

On the sunny face; only two balansa and no sub clover seedlings were found after one person hour searching on 17 May 2012. In general the competition from resident grass for water on the north face would have been excessive. Subsequent information from the farmer indicated that this area of the block had not actually been over-sown.

Both shady and sunny blocks were spelled until balansa clover seed had matured. Intensive summer grazing will ensure balansa and subterranean clover seeds have optimum conditions to germinate and establish when autumn rains finally come

In the sunny face block on a small NE area where soil surface conditions were suitable, haresfoot clover seedlings were common. There a start was made to develop a 0 to 10 scoring system to describe volunteer and improved annual clover populations. A 10 score indicates > 1000 seedlings/m^2. Photographs were taken to illustrate the scoring system which is required to hasten field observations on all MerinoNZ pasture improvement sites (e.g. Figure 5.2 = 8/10 score).

Plate 5.1 Ripgut brome and haresfoot cloverl on the 'North Face' at Omarama Station on 8 December 2012

Plate 5.2 Quantifying legume content on the 'East slope' at Omarama Station on 17 May 2012. (8/10 score for haresfoot clover population).

Plate 5.3 Excellent patch of balansa clover in flower on east facing slope at Omarama Station on 8 November 2012.

Plate 5.4 General shot of east face slope with balansa clover in flower at Omarama Station on 8 November 2012.

Plate 5.5 Rip-gut brome dominating balansa clover on north face at Omarama Station on 8 November 2012.

2013

A visit to the over-sown clover site confirmed that some balansa clover seedlings were re-establishing on the hill side (Photo 5.6).

Plate 5.6 Re-establishing balansa clover seedling in the over-sown slope at Omarama Station, taken on 9 May 2013.

A paddock of balansa clover was sown for the purpose of seed production to be distributed up the hill. The crop established well, however pigs discovered the legume seedlings and did major damage in one night (Plates 5.7 and 5.8) before being eliminated with lead poisoning.


Plate 5.7 Pig damage to balansa clover crop at Omarama Station, taken on 9 May 2013


Plate 5.8 Surviving balansa clover seedlings after pigs damaged a large area of the balansa clover crop at Omarama Station, taken on 9 May 2013.

Site 6 – Mt Grand Station

Large-scale annual clover over-sowing (uncontracted)

Primary Objective(s)

To introduce more productive annual clover species to sunny face pastures by conventional over-sowing and topdressing.

The dominant legume in lower altitude sunny face pasture on Mt Grand is striated clover. If earlier flowering more productive annual clover species could be introduced the feeding value of pasture on offer to ewes and lambs in spring would be significantly improved. Additionally, if a wider range of clover species can be established they will be able to exploit hill country site variability more efficiently.

Goals

- The use of intensive grazing to improve establishment of sown legumes through the dual-effects of trampling and removal of resident vegetation competition.
- Improve knowledge and management of annual clovers.
- Observe effect of fertiliser application on resident clovers (e.g. striated).
- Quantify the success of improved annual clover species establishment when oversown/top-dressed (OSTD).

Experimental Design

Over the next three years it is proposed that three or four lower altitude, Mt Grand sunny face blocks will be sub-divided and over-sown with annual clovers. One half of each block will be OSTD while the other half will be have the same amount of fertiliser applied but without broadcasting clover seed. In some cases the lower altitude area of a block may be OSTD in anticipation of the higher altitude, summer grazing, snow tussock area being fenced off. Assessment of this programme will be difficult to quantify precisely; changes in botanical composition, nitrogen content of grasses, sheep and cattle grazing days and possibly lamb and ewe weaning weights may be measured.

Measurements and dates

2011

8 Apr — Patterson's block divided in half with both sides being fertilised with 200 kg/ha Maxi Sulphur Super.

8 Apr — Eastern upper half of Patterson's block oversown with sub clover (6 kg/ha), balansa clover (4 kg/ha), gland clover (4 kg/ha) and plantain (1 kg/ha). Block was intensively grazed before (1400 ewes) and after over-sowing (750 ewes).

2012

9 Mar — Lower western half of Patterson's was oversown with sub clover (6 kg/ha) and balansa clover (4 kg/ha).

The lower altitude zone of the 60 ha Castle Rocks Block was OSTD with sub clover (2 kg/ha), balansa clover (4 kg/ha) and 250 kg/ha sulphur super 30. This was in anticipation of sub-dividing the snow tussock area from the warmer gully which has the potential to produce high quality feed in spring when the tussocks should be spelled for summer grazing.

Patterson's Block was inspected several times by LU staff with the manager, Evan Gibson, over the last 18 months and Evan was in regular contact regarding grazing management decisions in relation to the growth and development of the annual clover species.

Results and Discussion

An average of over 1000/m^2 seedlings of the resident striated clover established and thrived in Patterson's East in 2011. The striated clover appeared to benefit from the fertiliser application and it dominated the three annual clover species which were over sown. The two top flowering clovers, gland and balansa, grew taller than the 10 to 20 cm high striated clover canopy. The gland and balansa clover plant populations varied widely over the 12 ha block but neither species exceeded an average of 1 flowering plant/m^2. There were fewer sub clover plants than the smaller seeded top flowering species.

Issues which require further investigation are: timing of seeding, intensity of winter/early spring grazing, the need for Rhizobium inoculation, clover seeding rate and quantification of the production advantages of top flowering annual clovers.

1. Timing: The striated clover germinated before the additional clover seed of was flown on and striated seedlings had about a month's early autumn establishment and growth advantage. Earlier seeding before the autumn break should give new clover species an improved chance to compete with resident clovers. Early seeding would be assisted only if suitable rhizobium strains were resident in the soils Rhizobia on inoculated or coated seed would be unlikely to survive on hot, dry soil surfaces in late summer.
2. Grazing in early spring until the first indications of flower development (stem elongation) would reduce the intensity of resident grass and clover competition.
3. Rhizobia strains from soil and nodules from resident clovers could be isolated and tested on 'improved' clover species to determine the need for clover seed inoculation.
4. Very high seeding rates of more productive species to counter the large resident striated clover population may be successful but would be unacceptably expensive.
5. Comparisons between volunteer resident annual clovers such as striated and haresfoot versus gland, balansa and sub clovers will enable quantification of differences between species at a range of sites.
6. Spring sowing of annual clovers on a large scale.

Outlook for 2013

Further work is planned to develop initial investigations into the possibility of using very high seeding rates on hill blocks from seed produced on farm from cultivated paddocks. Several methods will be compared on different parts of Mt Grand and attempts made to manage adjacent paddocks 'normally' as 'controls' without any heavy rates of seed application.

1. Balansa clover hay was made in the Mt Grand Cottage paddock in late December 2011 (60 x 230 kg square bales from 4 ha). Each bale contained between 6 and 30 kg balansa

seed and when bales were rolled down south facing, steep slopes they disintegrated over a swath of up to 60 m x 10 m. Salt spread on the seed rich hay encouraged intensive grazing and under-grazed tall oat grass and cocksfoot 'tussocks' were reduced to short clumps with bare ground between. Very high populations of balansa clover (>1000/m^2) and some plantain seedlings have established in these heavily grazed areas.

Improvements to this "haying" technique may be achieved by:-

- Making hay when it is less mature to get higher ME material which is more attractive to sheep.
- Feeding hay to cattle rather than, or as well as, sheep.
- Increasing the area "hayed" by making round bales, which can be more successfully rolled down hill pastures.
- Introducing small amounts of granular salt to hay through an attachment on the baler.
- Increasing the proportion of individual grazing blocks "hayed" by fencing off treated areas. These smaller areas can be spelled to set seed the following spring.
- Developing one small block each year by grazing intensively with cattle through dry summer/early autumn periods to the point where the seed rich hay is up to half the animal intake will ensure that seed is spread before significant autumn rain. Winter hay feeding would result in less desirable spring germination of annual clovers.

2. Harvest seed from paddocks on the flat which are grown specifically for seed production for use on farm for aerial over-sowing (e.g. red and Caucasian perennial clovers; balansa, gland and sub clovers). Note: perennial clovers should be sown in early spring and annuals in autumn, and it would be illegal to sell seed off farm unless the cultivar was "out of PVR".
3. Grow clover patches for seed on flat to rolling areas of hill blocks or on paddocks at the base of steep hill blocks. Use electric/temporary fencing where necessary to control cattle grazing when seed crops are mature. Manipulate stock movement on and off seed crops with salt, water, dogs etc. and the natural inclination of sheep to camp on higher ground.

Notes: These methods assume suitable Rhizobia are present in the soil where seed is broad-cast or spread in hay or by livestock. For instance it may not work for lucerne or Caucasian clover which have specific rhizobium requirements.

Plate 6.1 Balansa clover seedlings growing after a seed-rich hay bale was rolled down a steep slope at Mt Grand, Hawea on 28 April 2012 (circular quadrat = 0.1 m^2).

Plate 6.2 Site of autumn 2012 “hay avalanche” used to distributed seed-rich hay at Mt Grand. Photo taken on 12 December 2012 shows damage by sheep due to high preference resulting

from excess salt application (about 300 kg NaCl/ha) and the area therefore being over-grazed.

Site 7 – Lake Heron Station

Experiment 1 – Establishment of cocksfoot and Caucasian clover in tussock lambing blocks at Lake Heron Station

Background

Caucasian clover is a persistent legume that tolerates drought and infertile soils, and is a potential alternative to white clover and lucerne in high country regions of New Zealand. Philip Todhunter, at Lake Heron Station in Canterbury, has an impressive 11-year-old pasture of 'Endura' Caucasian clover and was keen to direct drill a mix of Caucasian clover and cocksfoot into another low lying tussock lambing paddock (Figure 7.1). However Caucasian clover is normally very slow to establish particularly in competition with other pasture plants. Inoculation with effective rhizobia, which enables legumes to fix atmospheric N_2 in the soil, is essential for the successful establishment of Caucasian clover. There are two commercial *Rhizobium* strains available to inoculate Caucasian clover: ICC 148 is recommended in New Zealand and CC283b is recommended in Australia but is also available in New Zealand.

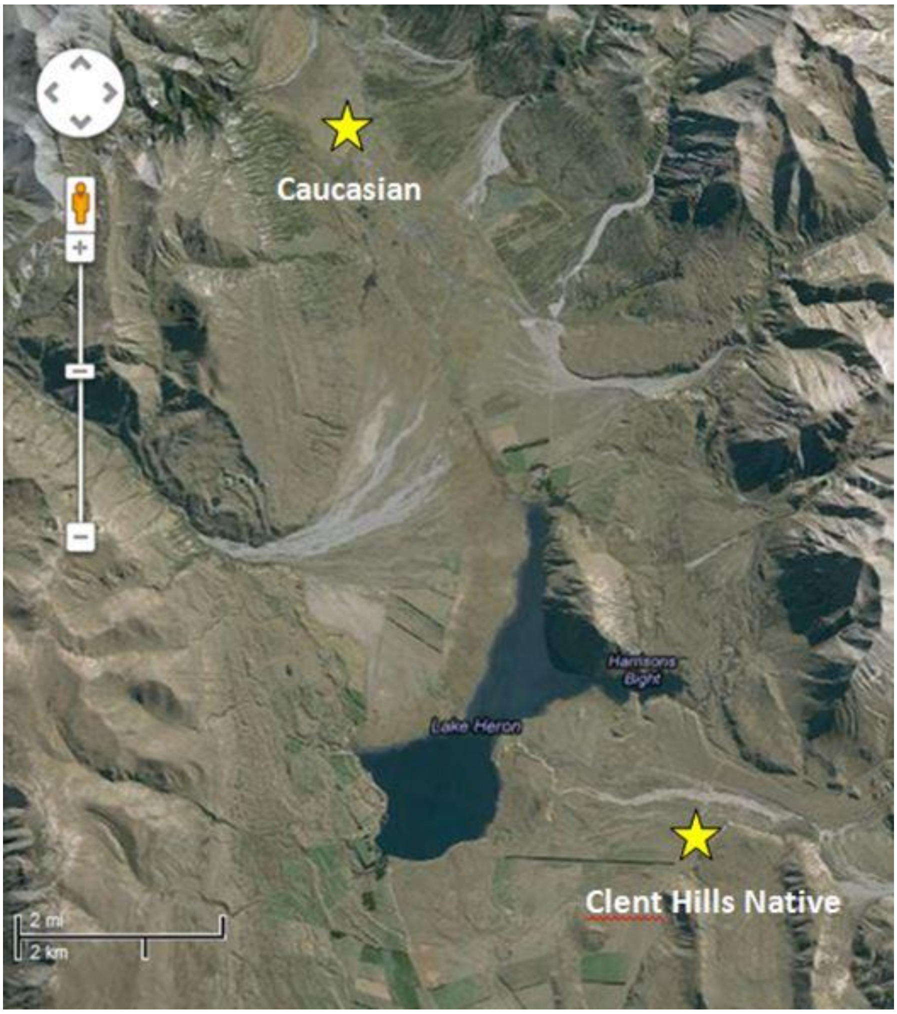

Figure 7.1 Locations of the established (Caucasian) and new (Clent Hills Native) Caucasian clover pastures at Lake Heron Station.

Primary Objective(s)

- *Determine whether cocksfoot and Caucasian clover can successfully establish in low lying tussock lambing blocks at Lake Heron Station.*
- *Investigate whether N fertiliser applied at drilling improves plant establishment, growth and survival.*
- *Determine the superphosphate requirements of the new Caucasian clover/cocksfoot sward and whether liming affects these requirements.*
- *Investigate in pots the effects of nutrients and Rhizobium inoculant on the growth of Caucasian clover seedlings.*

Goals

- Gather plant population data at establishment then twice in growing season.
- Determine the yield response to fertiliser/lime twice in the growing season.
- Analyse the soil nutrient status.
- Determine the growth responses of Caucasian clover to nutrients and inoculant in pots.

Site and soil

The two field trials were located in an undeveloped 11.5 ha paddock of fescue tussock in the Clent Hills block (43°29'27.08"S and 171°13'11.61"E, elevation 756 m) of Lake Heron Station. A pre-treatment soil test in December 2011 indicated Olsen P was very low at this site, but S was within optimum levels (Table 7.1). The pH was moderately acid and as a result soil exchangeable Al was moderate, approaching toxic levels. P, perhaps in combination with some Al issues, was likely to limit growth of Caucasian clover. It was expected that this site would be very responsive to P fertiliser applications.

Table 7.1 Pre-treatment (December 2011) soil test for the new Caucasian clover/cocksfoot sowing at Clent Hills, Lake Heron Station.

Sample	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
Clent Hills	5.5	7	14	5	16	10	3	2.1

Soil samples were collected on 10 December 2012 after the application of fertiliser treatments and drilling. The site was sampled as follows:

- Key plots were sampled (15 x 2.5 cm diameter cores per plot) and bulked on a treatment basis for 0 – 7.5 and 7.5 – 15 cm horizons.
- Deep (auger) samples were also taken at 20 cm intervals on the 0 (control) treatment at six sites, to a maximum depth of 1 m. Samples were bulked on a horizon basis.

Table 7.2 Soil test results for bulked 25 mm diameter core samples taken from the 'Native' site (Clent Hills) at Lake Heron Station.

Sample	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
1 (0-7.5)	5.9	8	3	5	15	9	4	2.1
2 (0-7.5)	5.9	9	3	5	15	10	3	1.4
3 (0-7.5)	5.7	9	5	5	12	9	3	2.1
4 (0-7.5)	5.8	18	8	5	12	9	2	1.9
5 (0-7.5)	5.9	8	3	7	14	8	2	1.2
6 (0-7.5)	6.2	11	4	9	17	10	3	<0.5
7 (0-7.5)	6.0	8	4	7	14	9	3	0.6
8 (0-7.5)	6.3	16	5	9	13	10	3	<0.5

Table 7.3 Soil test results for auger samples collected from the 'Native' site (Clent Hills) at Lake Heron Station.

Sample/Depth	pH	Exch Al (mg/kg)
1: 0-20 cm	5.7	3.1
1: 20-40 cm	5.7	4.9
1: 40-60 cm	5.7	5.3
1: 60-80 cm	5.7	4.4
1: 80-100 cm	5.8	4.3

- In the A horizon safe levels of exchangeable Al were found but with depth increased to toxic levels. The auger samples down to 1.0 m had toxic levels of exchangeable Al that would be difficult for lucerne establishment.
- Olsen P was variable across soils at Lake Heron Station. Sulphur levels were variable and in some cases deficiencies occurred.
- Caucasian clover may be an appropriate species at this site.

Experimental design

Field experiment 1 (Objectives 1 and 2):

The paddock was sprayed with 2 L/ha of 480 glyphosate and grazed hard with about 1800-2000 wethers for 2 days in mid-December 2011. On 20/21 December a mix of 'Endura' Caucasian clover (6 kg/ha) and 'Vision' cocksfoot (2 kg/ha) was direct drilled with two starter fertilisers, either 110 kg/ha of superphosphate (9% P, 12% S) or 100 kg/ha of Cropmaster 20 (19.5% N, 10% P, 12.5% S), by a local contractor with a triple disc drill. This was done according to a randomised block design with three replicates and plots 30 m by the length of the paddock (Figure 7.2). The Caucasian clover seed was inoculated with rhizobia before sowing. The paddock was top-dressed with 250 kg/ha of Sulphur Super 20 in late February 2012.

Field experiment 2 (Objective 3):

Combinations of four rates of superphosphate (0, 100, 200 and 400 kg/ha) and ± 5 t of lime/ha were applied to 12 x 20 m plots according to a 4 x 2 factorial randomised complete block design with four replicates (Figure 7.3). The two rates of lime were chosen to create two pH environments because we suspected the superphosphate response would depend on pH. The super was applied on 31 January and the lime on 28 February, 2012. This experiment was avoided when the rest of the paddock was top-dressed with Sulphur Super 20 in late February 2012.

To test whether the Caucasian clover and cocksfoot seedlings would respond to a second dressing of N fertiliser, we applied 100 kg of urea/ha to a 5 x 20 m subplot in each of the 32 plots of the super x lime experiment on 9 May 2012 and looked for a growth response in October and November.

Figure 7.2 Layout of starter N fertiliser experiment and superphosphate x lime experiment in the new Caucasian clover pasture at Lake Heron Station.

Block 3 (plots 17–24) and Block 4 (plots 25–32)

S3 L1	S1 L2	S4 L2	S4 L1	S3 L2	S2 L1	S2 L2	S1 L1	S4 L2	S2 L2	S3 L2	S2 L1	S1 L2	S1 L1	S4 L1	S3 L1
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32

Block 1 (plots 1–8) and Block 2 (plots 9–16)

S1 L1	S2 L1	S3 L1	S4 L1	S1 L2	S2 L2	S3 L2	S4 L2	S2 L2	S3 L2	S2 L1	S1 L1	S3 L1	S1 L2	S4 L2	S4 L1
Plot 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Figure 7.3 Design of the superphosphate x lime factorial experiment at Clent Hills, Lake Heron Station. Abbreviations are: L1 – no lime; L2 – 5 t lime/ha; S1 – no superphosphate; S2 – 100kg/ha superphosphate; S3 – 200 kg/ha superphosphate; S4 – 400 kg/ha superphosphate.

Pot Experiment 1 (Objective 4):
To study in more detail the effects of P, S, N and trace element (TE) fertilisers and the effect of Caucasian clover *Rhizobium* inoculant (CC283b) on the growth of Caucasian clover seedlings, we carried out a pot experiment at Lincoln University. On 9 May 2012 we collected 32 cores of individual Caucasian clover plants from an area outside of the super x lime experiment and potted them in a glasshouse. The treatments in the pot trial were all possible combinations of ±P, ±S, ±N, ±TE (Mo + B) and ± inoculant, applied using a single replicate of a 2^5 factorial experimental design (32 pots). Shoots were harvested four times, and the yields of Caucasian clover were measured at the final harvest on 26 February 2013.

Pot Experiment 2 (Objective 4):
To confirm some of the results from Pot Experiment 1 we have started a second pot experiment at Lincoln University as part of an Honours student (Alan Harvey) project. The treatments were all possible combinations of ± *Rhizobium* inoculant, ± 2.5 t of lime/ha and three nutrient treatments (P, P+S and 'all nutrients') and two legume species (Caucasian clover compared with lucerne) grown on Lake Heron Station soil. The soil (0-20 cm) was collected from the new pasture in April 2013 and taken back to Lincoln University. Caucasian clover and lucerne were grown in the pots from seed and the treatments were applied according to a 2 x 2 x 2 x 3 factorial experiment with four replicates (96 pots). This trial is still in the early stages but treatment effects are already obvious (see Plates 7.4 and 7.5).

<u>Measurements and dates</u>

2012

7 Mar Measured plant population and size in Field experiment 1 by counting the number of seedlings along a 1 m length of two adjacent drill rows at five random sampling sites near the southern end of each plot. After counting the seedlings were dug to about 10 cm depth and taken back to Lincoln University to determine their dry weight.

11 Apr Took photos of plots and seedlings.

9 May Urea was applied to Field experiment 2

Collected 32 cores of individual Caucasian clover plants for Pot experiment 1

5 Oct Observed Field experiment 2 for plant responses to urea and took photos of plots and seedlings.

28 Nov Observed Field experiment 2 for plant responses to urea and took photos of plots and seedlings.

Measured plant population and size in Field experiment 2 by digging a 1 m strip of drill row at two random points in each of the four negative and positive control plots (± 400 kg of super/ha and ± 5 t of lime/ha).

Soil sampling:

- Sampled all plots in block 1 of Field experiment 2 (15 cm x 25 mm diameter cores) and bulked on treatment for 0-7.5 cm and 7.5-15 cm horizons.

- Deep (auger) samples were also taken at 20 cm intervals at 6 sites on the negative control treatment in Field experiment 2 to a maximum depth of 1 m. Samples were bulked on a horizon basis.

2013

22 Feb Paddock was recently grazed by cattle so took photos of plots.

Apr Collected soil (0-20 cm depth) from Clent Hills Native for a second pot experiment.

Note: There was insufficient yield to measure during the 2012/13 growing season.

Results

Field experiment 1:

Cropmaster 20 improved the early growth of Caucasian clover and cocksfoot (Table 7.4). However most plants did not establish well and many Caucasian clover seedlings in particular failed to survive after 12 months.

Table 7.4 Mean plant population and size on 7 March 2012 in response to two starter fertilisers at Clent Hills, Lake Heron Station.

	Superphosphate	Cropmaster 20	Level of sig.	SED
Caucasian clover				
Plants per 2 m of drill row	12.9	12.2	NS	2.37
Plant dry weight (mg)	12.9	39	***	7.15
Cocksfoot				
Plants per 2 m of drill row	14.3	12.2	NS	4.32
Plant dry weight (mg)	13.7	76.4	***	9.51

NS = not significantly different; *** = significantly different

Field experiment 2:

Plant population was unaffected but seedlings were bigger in the plots without super and lime than the plots with super and lime (Table 7.5).

Table 7.5 Mean plant population and size on 28 November 2012 in response to superphosphate and lime at Clent Hills, Lake Heron Station.

	Negative control (- Super/- Lime)	Positive control (+ Super/+ Lime)
Caucasian clover		
Plants per 2 m of drill row	10	11
Plant dry weight (mg)	18.4	8.1
Shoot dry weight (mg)	4.1	1.9
Root dry weight (mg)	14.3	6.2
Cocksfoot		
Plants per 2 m of drill row	34	34
Plant dry weight (mg)	223.8	116.2
Shoot dry weight (mg)	173.9	85.4
Root dry weight (mg)	49.9	30.8

Urea strips and pot trial

By April it was obvious the Caucasian clover was failing to establish. The seed was inoculated before sowing with the specific strain of rhizobia Caucasian clover needs to fix N_2 (ICC148), but it was suspected that the inoculation was ineffective and the soil N at the site was insufficient to support early plant growth. To test this theory it was decided to;

1) Apply strips of urea to the plots and look for a growth response in spring to determine whether soil N was deficient at the site.
2) Take individual plants of Caucasian clover back to Lincoln University and treat them with ± inoculant and ± different nutrients in a glasshouse pot trial.
3) Apply inoculant and nutrients to the plots if necessary based on the pot trial results.

On 9 May 2012 the urea (100 kg/ha) was applied over a 5 m strip in each of the 32 small plots, and cores of individual plants were collected for the pot trial. The treatments in the pot trial were all possible combinations of ± inoculation, ± P, ± N, ± S and ± trace elements (boron and molybdenum). These were applied using a single replicate of a 2^5 factorial experimental design (32 pots). Shoots were harvested four times, and the Caucasian clover dry matter results of the final harvest on 26 February 2013 are presented in Table 7.6.

Table 7.6 Main effects on Caucasian clover dry matter production (g/pot) of ± Caucasian clover rhizobium, ± sulphur, ± phosphorus, ± nitrogen (urea) and ± molybdenum and boron.

Main effect	Nil	+	SEM	P value	CV%
P	2.43	2.19	0.264	0.534	45.6%
S	2.17	2.46	0.295	0.502	51.1%
N	1.99	2.64	0.187	0.027	32.3%
TE (Mo + B)	2.32	2.31	0.225	0.969	39.0%
Inoculation	1.67	2.96	0.167	<0.001	28.9%

The urea strips on the field plots were observed on 5 October and 28 November 2012, but, although the cocksfoot and some of the resident grasses (browntop, sweet vernal, etc.) had 'greened up' in response to the urea, the Caucasian clover hadn't improved.

The plants in the pot trial responded immediately to the warm conditions in the glasshouse, but any responses to the treatments were less obvious. The results of the pot experiment, along with the field evidence, indicate that the major reason for the failure of Caucasian clover at Clent Hills was inadequate rhizobia on the seed at sowing. Nitrogen was the only nutrient to give a response in the pot experiment (Table 7.4) and that was expected given the large response to the addition of Caucasian clover rhizobium inoculant.

On 24 January 2013 a strip of Caucasian clover inoculant was sprayed across each of the small plots to see whether the Caucasian clover plants will respond.

<u>Outlook for 2013/14</u>

- New sowing onto the existing super x lime plots in Field experiment 2 to investigate the establishment and yield of different legume species (white clover, Caucasian clover, red clover, lucerne, lotus) with timothy at Lake Heron Station.

Plate 7.1 Caucasian clover and cocksfoot seedlings on 7 March 2012 after drilling with Cropmaster 20 on 20/21 December 2011 at Lake Heron Station (Field Experiment 1).

Plate 7.2 Typical Caucasian clover and cocksfoot seedlings in a Cropmaster 20 plot on 14 April 2012 at Lake Heron (Field Experiment 1).

Plate 7.3 A Caucasian clover seedling (indicated within yellow circle) and cocksfoot seedling in the new pasture on 5 October 2012 at Lake Heron Station (Field Experiment 2).

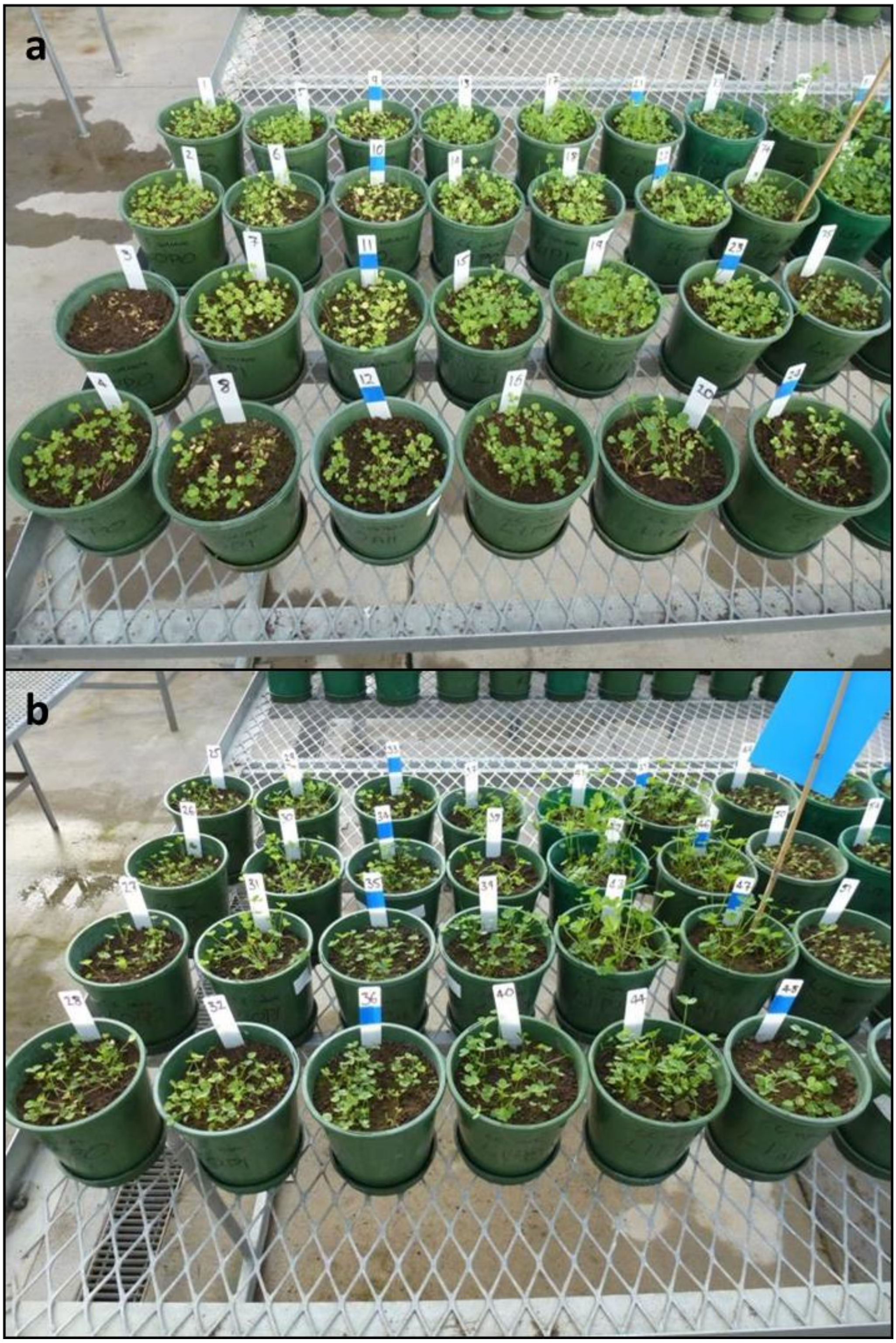

Plate 7.4 Uninoculated (a) and inoculated (b) Caucasian clover grown without lime (12 pots on the left of (a) and (b)) and with 2.5 t/ha of lime (12 pots on the right of (a) and (b)) in soil from Lake Heron Station (Pot Experiment 2).

Plate 7.5 Uninoculated (a) and inoculated (b) Caucasian clover grown without lime (12 pots on the left in (a) and (b)) and with lime (12 pots on the right of (a) and (b)) in soil from Lake Heron Station (Pot Experiment 2).

Experiment 2 – Superphosphate requirements of an established stand of Caucasian clover at Lake Heron Station

Objective

The objective of this trial was to determine the superphosphate requirements of a mature stand of Caucasian clover at Lake Heron Station and whether liming affects these requirements.

Goals

- Determine the yield response to fertiliser/lime twice in the growing season.
- Analyse the nutrient status of the Caucasian clover.
- Analyse the soil nutrient status.

Site and soil

A field experiment was carried out in the established Caucasian clover pasture beside Lake Stream (43°23'31.47"S, 171°9'5.89"E, elevation 680 m) at Lake Heron Station (Figures 7.1 and 7.3). The pasture was direct drilled with 'Endura' Caucasian clover and fertilised with 150 kg/ha of superphosphate in 2002. A pre-treatment soil test in January 2012 indicated Olsen P was very low but S was within optimum levels (Table 7.7). The pH was moderately acid and as a result soil exchangeable Al was moderate. P, perhaps in combination with some Al issues, was likely to limit growth of Caucasian clover. We expected this site to be very responsive to P fertiliser.

Table 7.7 Pre-treatment (January 2012) soil test for the established Caucasian clover sward near Lake Stream, Lake Heron Station.

Sample	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
Caucasian	5.5	5	11	7	10	8	3	1.7

Figure 7.3 Location of the superphosphate x lime experiment in the established Caucasian clover pasture beside Lake Stream at Lake Heron Station.

The four rates of superphosphate were applied on 31 January and the lime on 28 February, 2012.

Soil samples were again collected on 10 December 2012 after the fertiliser treatment applications. Samples were collected as follows:

- All plots were sampled (15 x 2.5 cm diameter cores per plot) and bulked on a treatment basis for 0 – 7.5 cm and 7.5 – 15 cm horizons (Table 7.8).

Table 7.8 Soil test results for bulked 2.5 cm diameter core samples taken from the established Caucasian clover site (Lake Stream) at Lake Heron Station.

Treatment	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
S1L1	5.6	9	8	8	12	8	3	2.3
S2L1	5.8	12	11	11	12	9	3	1.2
S3L1	5.4	10	9	8	10	8	3	3.9
S4L1	5.6	15	9	9	12	10	3	2.0
S1L2	6.1	13	8	15	15	9	4	<0.5
S2L2	5.9	10	9	12	12	7	3	0.7
S3L2	6.0	12	9	14	13	9	3	0.5
S4L2	6.0	12	11	13	13	9	5	0.6

Design

Combinations of four rates of superphosphate (0, 100, 200 and 400 kg/ha) and ± 5 t of lime/ha were applied to 12 x 20 m plots according to a 4 x 2 factorial randomised complete block design with four replicates (Figure 7.4). The two rates of lime were chosen to create two pH environments because we suspected the superphosphate response would depend on pH. The super was applied on 31 January and the lime on 28 February 2012.

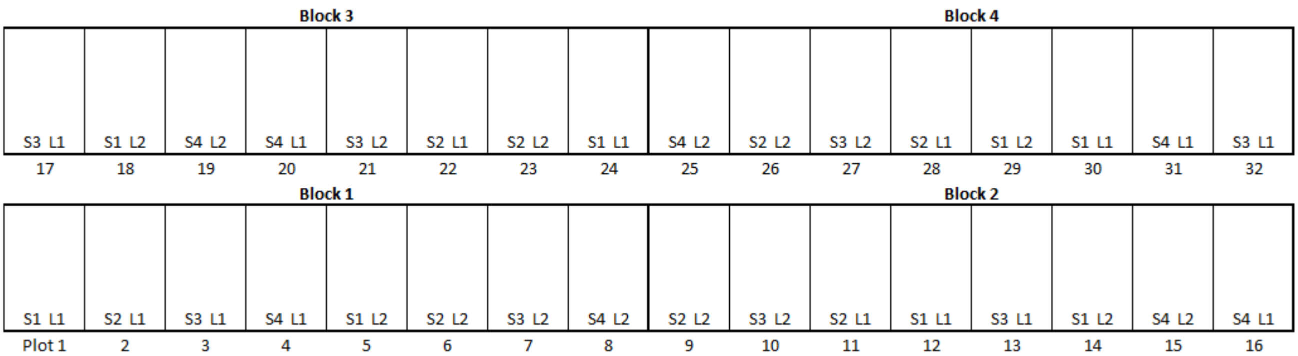

Figure 7.4 Location of the superphosphate x lime experiment in the established Caucasian clover pasture beside Lake Stream at Lake Heron Station.

Measurements and dates

2012

14 Apr — Yield was limited and there were no obvious responses to super and lime so took photos only.

9 May — Sampled leaves and petioles of Caucasian clover from each plot for herbage nutrient analysis.

5 Oct — Limited yield so only photos were taken.

28 Nov Measured yield responses by cutting a random 5 x 0.46 m strip in each plot to a height of 2 cm using a lawn mower and taking samples back to Lincoln.

Collected soil samples from each plot (15 cm x 2.5 cm diameter cores) and bulked on treatment for 0-7.5 cm and 7.5-15 cm horizons.

Sampled leaves and petioles of Caucasian clover from each plot for herbage nutrient analysis.

Note: After November, growth was limited by low summer rainfall and yield was insufficient for a second harvest in 2012/13. When we visited again on 22 February 2013, the Caucasian clover was wilted and there was no obvious lime effect, but the plots dressed with 400 kg/ha of super were greener than those without or with 100 kg/ha super.

Results

Total yield and Caucasian clover yield were affected by superphosphate ($P<0.001$) and lime ($P<0.05$), and the response to superphosphate was the same for both levels of lime (Figure 7.5).

There was some evidence of increases in Olsen P and Sulphate S with increasing rates of superphosphate, and lime increased pH and lowered exchangeable Al (Table 7.6).
On 9 May herbage P and N levels in Caucasian clover were affected ($P<0.001$) by super, but S content was not and lime had no effect (Figure 7.6). On 28 November, P content was affected ($P<0.001$) by super as were S and N ($P<0.05$), but lime continued to have no effect (Figure 7.7).

Autumn 2012

In the first autumn after top-dressing there were no obvious responses to superphosphate and lime so yield and botanical composition were not measured. On 9 May 2012 samples of leaf and petiole of Caucasian clover were collected from each plot for herbage analysis to estimate the nutrient status. P and N contents were affected ($P<0.001$) by superphosphate but not S content, and neither were affected by lime (Figure 7.5).

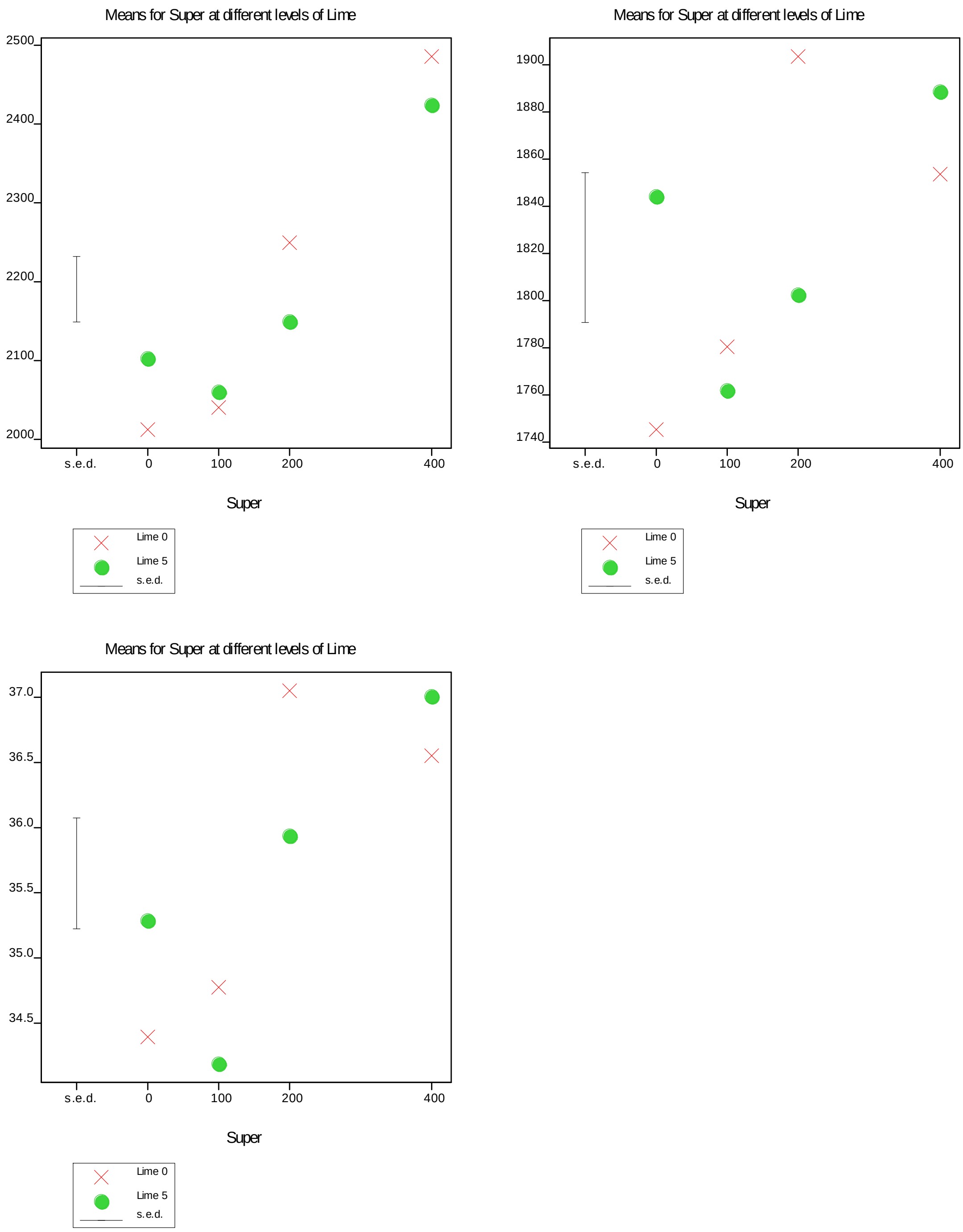

Figure 7.5 Mineral concentrations of Caucasian clover herbage on 9 May 2012 in response to superphosphate and lime applied in Jan/Feb 2012 at Lake Heron Station.

Spring 2012

On 28 November 2012 the yield, composition and nutrient status of the Caucasian clover stand was estimated in response to the four rates of superphosphate and ± lime. Dry matter yield was estimated by cutting a 5 x 0.46 m strip at a random point in each plot to a height of 2 cm using a lawn mower. The cut herbage was weighed in the field and a subsample of approximately 200-400 g was kept for each plot for dry matter % determination. Botanical composition was estimated by collecting another random sample from each plot to 2 cm height using battery operated sheep shears. Samples of leaf and petiole of Caucasian clover were also collected from each plot for chemical analysis, and soil samples were collected from each plot and pooled into the eight treatments. The samples were taken back to Lincoln University where 100 g of each mown subsample was dried at 65°C to determine dry matter percentage, and approximately 200 g of each of the clip samples was separated into Caucasian clover and other species, and dried to determine botanical composition. Total herbage yield (fresh weight*DM percentage/100*10000/[5*0.46]) and herbage yield of each fraction (fraction dry weight/total fraction dry weight*total herbage yield) were calculated. The leaf and petiole samples were dried and ground and will be analysed for nutrient content.

Total yield and Caucasian clover yield were affected by superphosphate ($P<0.001$) and lime ($P<0.05$), and the response to superphosphate was the same for both levels of lime (Figure 7.6).

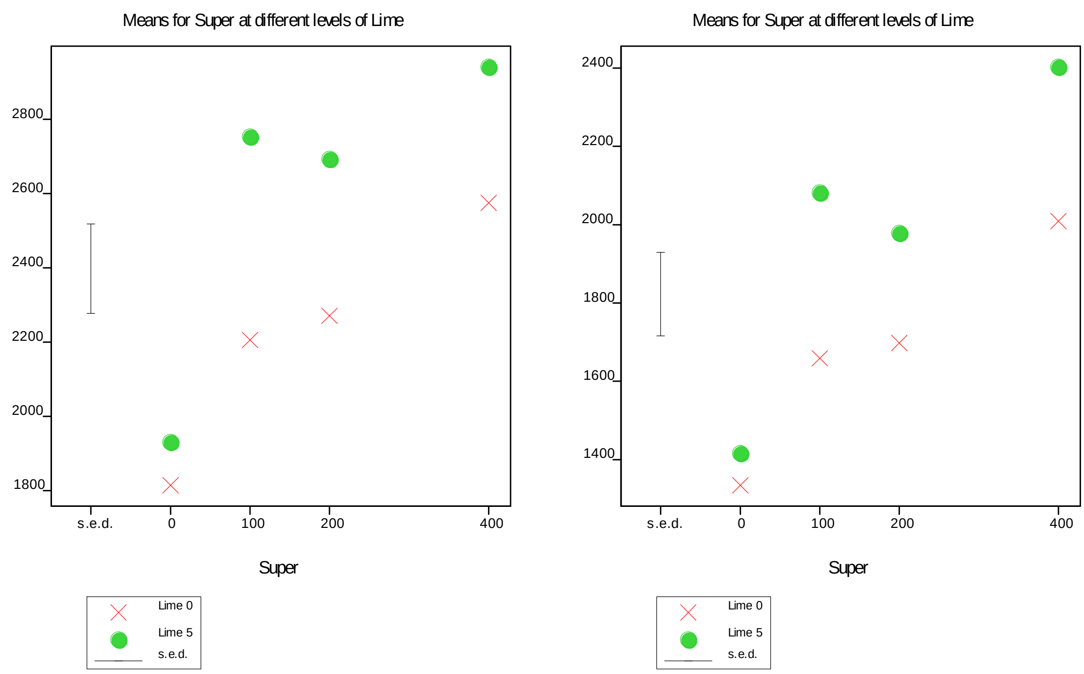

Figure 7.6 Total yield and Caucasian clover yield on 28 November 2012 in response to superphosphate and lime applied in Jan/Feb 2012 at Lake Heron Station.

P content was affected ($P<0.001$) by superphosphate as were S and N contents ($P<0.05$), but these mineral contents were not affected by lime (Figure 7.7).

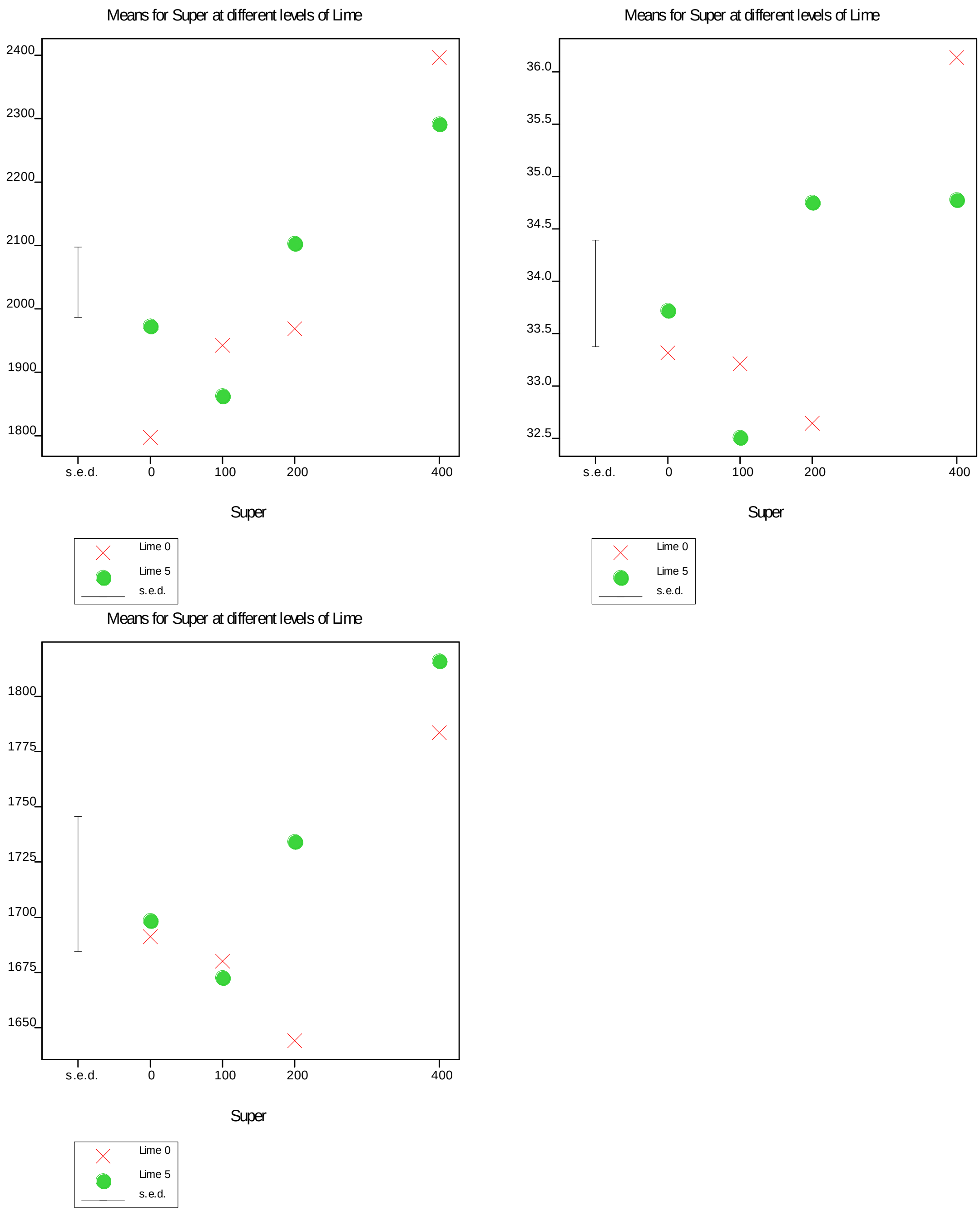

Figure 7.7 Mineral concentrations of Caucasian clover herbage on 28 November 2012 in response to superphosphate and lime applied in Jan/Feb 2012 at Lake Heron Station.

<u>Summer 2013</u>

On 22 February 2013 the trial was visited with a plan to measure the yield response, but the Caucasian clover was wilted and the herbage mass was insufficient to sample so it was decided to postpone this measurement until mid-March. Nevertheless the plots dressed with 400 kg/ha of superphosphate were noticeably greener than those not dressed or with 100 kg/ha. There was still no obvious response to lime.

Plate 7.6 Superphosphate x lime experiment in the established Caucasian clover pasture on 5 October 2012 at Lake Heron Station.

Plate 7.7 Superphosphate x lime experiment on 28 November 2012 in the established Caucasian clover pasture at Lake Heron Station.

Plate 7.8 Caucasian clover without superphosphate and lime (left) and with 400 kg of superphosphate/ha and 5 t/ha of lime (right) on 22 February 2013 in the established pasture at Lake Heron Station.

Site 8 – Ashley Dene/Lincoln University – Capability development

The need to intensively monitor pasture responses to the environment at more frequent intervals has led to some parallel experiments being established using Lincoln University post-graduate students.

Literature review

A literature review on the grazing of 'Blue' and 'Russell' lupin which summarised the relevant literature from work done in the 1980's through to the present was completed and submitted in October 2012. Revised based on comments from Dr Scott.

Armadale soil pot trial

Armadale Station was visited on 16 and 17 October 2012 and soil was sampled at two sites. The low fertility acid soil was sieved and a glasshouse experiment has been established at Lincoln to investigate the pH/Al tolerance and nutrient requirements of several forage legume species grown in a high Al high country soil.

Methodology and progress to date are as follows;

- Bulk soil (2.5 T) was collected from a high country site (Armadale Station – hill site) in Central Otago on 16 October 2012, and transported to Lincoln University.
- The field-moist soil was prepared by passing through a 4 mm sieve to remove all plant and root material, and mixing thoroughly to homogenise.
- A chemical analysis was then conducted on the soil to characterise soil fertility.
- Various nutrient/lime treatments were then added to 1.3 L of soil, thoroughly mixed, and then the soil was gently packed into pots.
- A fully replicated complete factorial experiment was established in mid-November 2012, involving combinations of:
    - four levels of phosphorus (0, 50, 150 and 500 mg P/kg of soil),
    - four levels of lime (0, 2, 4 and 8 t lime/ha),
    - a minus sulphur (S) treatment,
    - a 'complete' nutrient/trace-element treatment.
- The 528 pots were then transported to a glasshouse, and seed of the species under investigation was sown, covered with a thin layer of soil, and lightly watered.
- The six sown species were monocultures of:
    - Caucasian clover (*Trifolium ambiguum*),
    - Subterranean clover (*Trifolium subterraneum*),
    - Lotus (*Lotus pedunculatus*),
    - Lucerne (*Medicago sativa*),
    - Blue lupin (*Lupinus angustifolius*),
    - French serradella (*Ornithopus sativus*).
- Pots were watered regularly to a soil gravimetric water potential of 40%.
- Following seedling germination and establishment, a rhizobia inoculant specific to each legume species was added to all pots using a peat slurry to ensure nodulation.

- Plants were then thinned to 'field' plant densities in the pots in late December 2012. This meant that all species were thinned to 5 plants per pot with the exception of lupins which were thinned to one plant per pot.
- By mid-January 2013 the glasshouse experiment was fully established.
- Herbage samples were harvested on a species basis over a period of six months.
- These samples were dried, weighed and ground for acid digested analyses to be carried out in order to determine a full suite of elemental concentrations.
- Final soil pH will be measured in all limed pots and phosphorus fertilised pots at the completion of the experiment
- In 2013, Amy Whitley, a B.Agr.Sc. Honours student, was involved with the pot trial.

Soil sampling was conducted at the two sites as follows:

Soil sampling was conducted 16 and 17 October 2012 at two sites as follows:

1) High altitude hill site:

- A large quantity of bulk soil was collected and transported to Lincoln University for establishment of a glasshouse experiment.
- Several spots were sampled across the block by digging and collecting soil from the 0 – 20 cm horizon. A total of 2.5 t of soil was collected.
- In addition, the block was core sampled (80 cores) for 0 – 7.5 cm and 7.5 – 15 cm horizons.

2) Flats:

- Two sites were sampled on the flats: a developed well producing lucerne site and an adjacent 'native' site which may be developed for lucerne in the near future.
- Each block was sampled (30 cores) for 0 – 7.5 cm and 7.5 – 15 cm horizons.

Soil test results

Table 8.1 Bulked 2.5 cm diameter core sample soil test results for Sites 1 and 2 on 16 October 2012.

Site	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
1 (0-7.5)	5.1	18	6	4	21	12	11	7.6
1 (7.5-15)	5.1	-	-	-	-	-	-	16.5
2 (0-7.5)	5.7	6	<1	7	30	11	10	<0.5
2 (7.5-15)	5.6	-	-	-	-	-	-	<0.5

*Note; Site '1' = Hill block native, '2'= Flats native

Table 8.2 Soil pH and aluminium from auger samples collected from Sites 1 and 2 at Armadale Station on 17 October 2012.

Site/Depth	pH	Exch Al (mg/kg)
1: 0-20 cm	5.0	10.7
1: 20-40 cm	4.9	21.3
1: 40-60 cm	5.1	22.6
1: 60-80 cm	5.1	19.6
2: 0-20 cm	5.6	<0.5
2: 20-40 cm	5.9	<0.5
2: 40-60 cm	6.5	<0.5
2: 60-80 cm	-	-

*Note; Site '1' = Hill block native, '2'= Flats native

- Site 1 (hill block) has very low pH from 0-80 cm, and extremely toxic Exch Al levels. A very challenging site in terms of establishing and growing legumes.
- Site 2 (flats) has very favourable pH and very low Exch Al levels to depth. A perfect site for lucerne development.

Lime x legume species

Lime (3 rates) x species (lupins, Caucasian clover, lucerne) experiment on a low pH medium aluminium soil with moderate P levels – Saman Berenji – PhD student.

Sowing rate x sowing date report

Lupin block – an experiment of perennial 'Blue' vs 'Russell' lupin was established on a 2 ha block at Ashley Dene.

<u>Primary Objectives</u>

- *Define the optimum sowing rate and date of perennial lupins, in a dryland environment.*
- *Examine the impact of grazing on lupin seedlings of different sizes.*

<u>Investigated species/cultivar</u>

- Perennial lupin, cv. 'Russell'
- Perennial lupin, cv. 'Blue'
- Caucasian clover, cv. 'Endura'
- Cocksfoot, cv. 'Kara'

<u>Experimental design</u>

A split-plot factorial design was sown in four replicates with 18 October, 13 December 2012, and 15 February 2013 sowing dates as main plots. Five sowing rates (4, 8, 12, 16 and 20 kg seed/ha) of 'Russell' lupin and one rate (12 kg/ha) of 'Blue' lupin were sown as sub-plots, with 'Kara' cocksfoot (2 kg/ha) and 'Endura' Caucasian clover (5 kg/ha). Sub-plots are 2.1 × 10 m direct-drilled with an Oyjoord cone seeder at 150 mm row spacing, and a target depth of 15 mm.

Prior to sowing, the experimental area was sprayed with 'Roundup 360' (1800 g/ha a.i.). Before each sowing, 'Buster' (glufosinate-ammonium) was sprayed (1200 g/ha a.i.) to kill annual grasses and perennial clovers. Caucasian clover was inoculated with *Rhizobium trifolii* strain ICC148, immediately prior to sowing.

Immediately after sowing, soil temperature probes (2 x 100 mm and 1 x 15 mm) and a single air temperature probe, were placed central to all blocks. Temperatures are logged on an hourly basis.

Measurements

Plant population for each species was determined six weeks after sowing by randomly placing a 1 m rule between two drill rows (2 m) twice in each sub-plot. Also at this time, five lupin plants were dug from each plot, dried and weighed for shoot and root characteristics. Leaf appearance is counted twice weekly (when plants are actively growing i.e. not wilted) on five marked plants in 2 sub-plots of each block. Lupin leaves are considered to be fully emerged when the petiole is visible. Soil moisture (upper 12 cm) is measured in each sub-plot on a weekly basis.

Soil Test

A soil test was conducted to a depth of 7.5 cm on 20 October 2012. This soil is considered acidic with a pH of 5.3, and has a soluble aluminium level of 2.7 mg/kg, which is below the toxic threshold (3 mg/kg) for plants (Table 8.3). Most nutrients remain in the recommended range, with a slight deficiency of sulphate sulphur.

Table 8.3 Soil test from paddock H2 at the Lincoln University Research farm "Ashley Dene" on 20/10/12.

	pH	Olsen P	K	Ca	CEC	TBS%	Sulphate S	Soluble Al
Result	5.3	49	0.73	7.2	18	52	7	2.7
Optimum range	5.8-6.2	20-30	0.4-0.6	4-10	12-15	50-85	10-12	0-3

Results

The mean plant dry weight of 'Russell' lupin was 162.1 g/plant compared with 137.9 g/plant for 'Blue' lupin (Table 8.2). Shoot weight, root weight and shoot to root ratio were not significantly different between cultivars.

Table 8.4 Shoot and root weights (g) of 'Russell' and 'Blue' (perennial) lupins on 19 November 2012 at Ashley Dene, Springston. NS = Not significant, * = $P < 0.05$.

	Shoot Wt (g)	Root Wt (g)	Plant Wt (g)	Shoot:Root
Russell	139.4	22.7	162.1	6.29
Blue	118.3	19.6	137.9	6.27
SEM	7.7	1.2	8.3	0.3
Significance *(P < 0.05)*	NS	NS	*	NS

Soil moisture data for the period 30/10/12 – 17/12/12 is presented in Figure 8.1. Soil moisture percentage (SM%) was not significantly affected by lupin sowing rate for observation dates 2 (33 ± 0.81), 3 (22 ± 0.7), 4 (19.3 ± 1.95), and 5 (12 ± 0.51). Soil moisture was significantly (*P* <0.05) higher in plots sown at 4 kg/ha (31 % SM) than those sown at 20 and 8 kg/ha with 28 and 27 %SM, respectively.

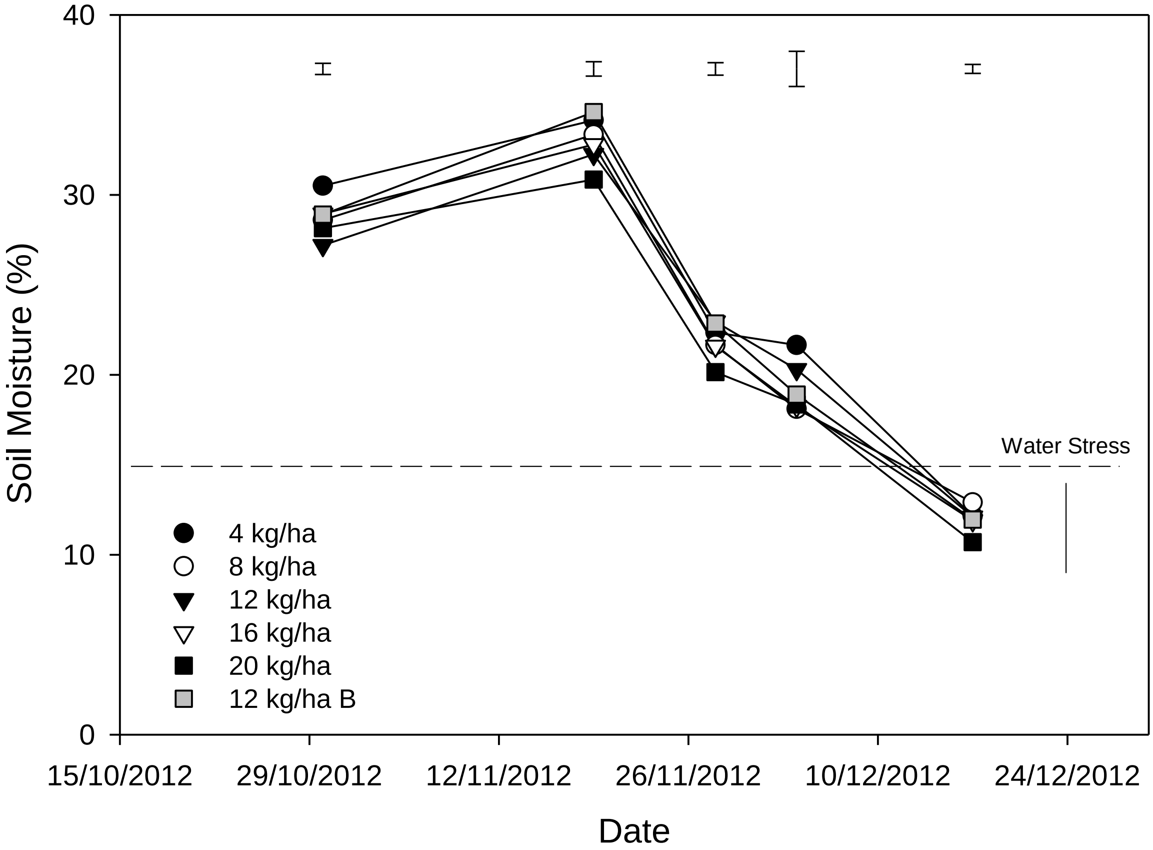

Figure 8.1 Soil moisture percentage of perennial lupin plots sown at 4, 8, 12, 16 and 20 kg seed/ha; over a period of 49 days. Level at which plant growth is limited by water (approximate) is represented by dashed line (- -). B = perennial 'Blue' lupin, all other sowing rates are 'Russell' lupin. Error bars represent SEM (standard error of mean).

Lupin population, 32 days after sowing, was significantly affected by sowing rate (*P* < 0.001). The mean plant population of 16 and 20 kg/ha sowing rates was 10.4 plants/2 m and 1.8 plants/2 m for the lowest sowing rate of 4 kg/ha (Figure 8.2). Plant population of 'Blue' lupin sown at 12 kg/ha did not significantly differ from 'Russell' lupin sown at 12 kg/ha, with a means of 5.9 and 6.9 plants/2 m, respectively.

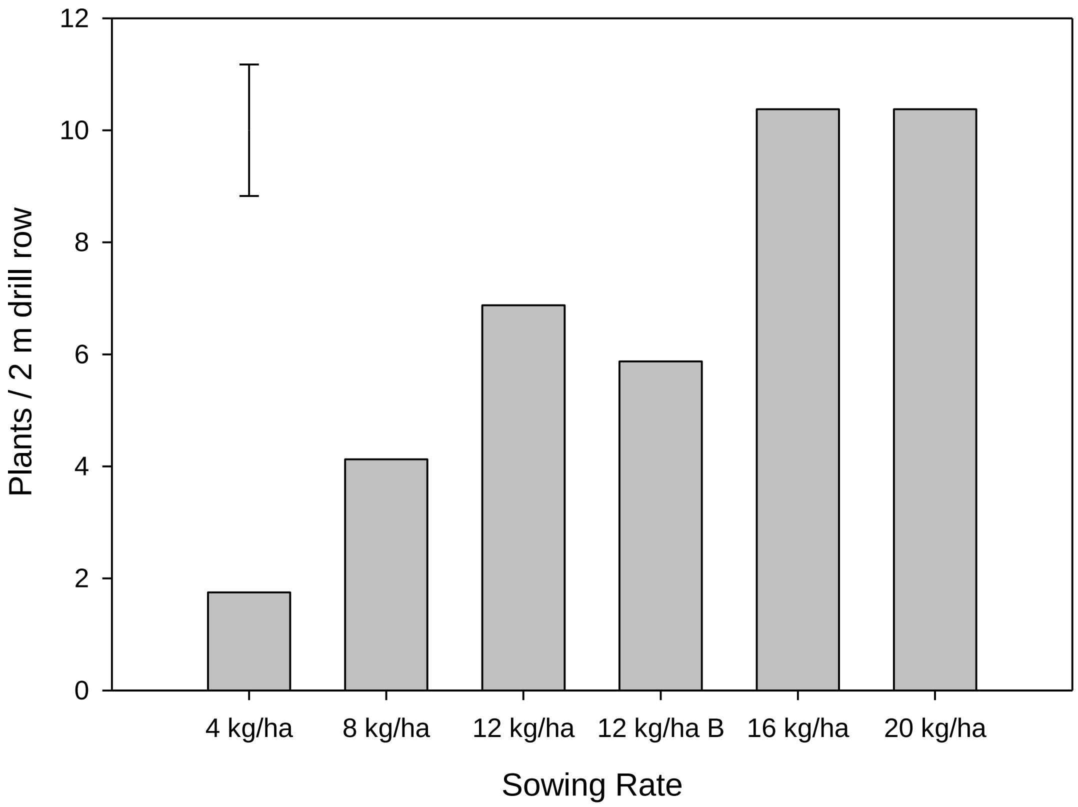

Figure 8.2 Plant population (plants/2 m drill row) of lupins 32 days after sowing, on 19 November 2012 at Ashley Dene, Springston. B = perennial 'Blue' lupin, all other sowing rates are 'Russell' lupin. Error bar represents LSD ($P < 0.05$).

Limitations/Future data

Data collection has been limited by dry soil conditions in the establishment year. Plant growth has been minimal over the summer period, and germination of sowing dates two and three has been delayed.

Future reports will include:

- Leaf appearance rate (in response to temperature).
- Biomass assessment.
- Plant survival and regeneration in the second growing season.
- Physiological cultivar comparisons (root/shoot weights, and growth rate).

Note: this experiment has been abandoned and replaced with the lupin experiments at Glenmore Station and Simon's Hill.


Plate 8.1 Cotyledons of 'Russell' lupin and 'Endura' Caucasian clover 12 days after sowing on 30 October 2012 at Ashley Dene, Springston.


Plate 8.2 Leaflet of 'Russell' lupin, sown on 13 December 2012, showing water stress by folding along the midrib. Taken on 22 February 2013 at Ashley Dene, Springston.

Plate 8.3 Inflorescence of 'Russell' lupin sown on 13 December 2012. Taken on 22 February 2013 at Ashley Dene, Springston.

Establishment of lupin seedlings from December and February sowing was poor and the experiment was discontinued and replaced with lupin survival and grazing experiments at Simon's Hill and Glenmore Station.

Plate 8.4 Unhealthy-looking lupin seedling, sown on 30 October 2012, surrounded by re-invading twitch, in early November 2012.

Plate 8.5 Re-invasion of twitch affected lupin establishment from later sowings (December and February).

PhD Project – Travis Ryan-Salter
Overcoming soil pH and aluminium toxicity in high country grazing systems; novel use of machinery and *Lupinus polyphyllus*.
Completion: February 2016

The Merino NZ/Lincoln University high country forage project commenced in 2011, and its goal was to improve the productivity/sustainability of high country grazing systems. To achieve this, strong emphasis was placed on introducing appropriate legumes into these environments. The rejuvenation of declining legume populations would initiate nitrogen cycling and improve productivity per unit area of land; thus improving environmental and financial sustainability of the fine wool industry.

Initially, the project investigated a large range of species, including: annual clovers, perennial clovers, lucerne and perennial lupins. Following the first year of experiments, it became evident that lucerne and perennial lupins would offer the largest contribution to increasing productivity in the Mackenzie basin, and similar high country areas. However, the sensitivity of lucerne to acidity (and more importantly; plant-available aluminium), and lack of knowledge around lupins' ability to thrive under adverse soil conditions, has facilitated the need for further research.

The research project has three main experimental objectives that form a comprehensive approach to the introduction of lupins and lucerne into high country grazing systems.

Objective 1 – *Effectiveness of rhizobial strains that nodulate Lupinus polyphyllus.*
Little knowledge exists around the specific inoculation requirements of *L. polyphyllus*, and commercially available inoculants have been developed for the nodulation of annual species. This objective will evaluate the effectiveness of several strains of rhizobium that nodulate wild populations of lupin. Their ability to fix nitrogen (efficiently) under stressful soil conditions will be compared against commercially available inoculants.

Objective 2 – *Ability of lupins, lucerne and cocksfoot to utilise soil nitrate.*
Legumes are introduced into N depleted pastures to initiate nitrogen cycling, and improve the productivity and quality of resident species (mainly grasses). However, it is important that soil nitrates are utilised by the pasture to reduce adverse environmental effects (leaching). This objective will quantify the ability of lucerne, lupins and cocksfoot to utilise soil nitrate, and evaluate the ability of each legume to respond to increasing soil nitrate by reducing their N fixation rate.

Objective 3 – *Comparison of lupins, lucerne, cocksfoot and legume/grass mixtures under high country conditions; importance of grass companion species and soil pH/aluminium.*
The adverse effect of soil acidity/aluminium on the root growth, productivity and persistence of lucerne, has become evident at multiple field sites. Soil tests have indicated that acidity is localised in the subsoil; approximately 15 – 30 cm below the soil surface. At this depth, effective amelioration with surface applied lime, would take substantial time to take effect. This objective will develop and evaluate the effectiveness of a unique liming implement, which is capable of delivering lime to acidic subsoil layers. The goal is to improve rooting depth of tap rooted legume species, so that a greater volume of soil can be exploited (depth) for the uptake of nutrients and water.

Site 9 – Bright spots

Ben Dhu Station

Three blocks at Ben Dhu Station were soil sampled: one established lucerne site (doing well) and two large blocks, one of which will be considered for lucerne in the future. Each block was sampled (60 cores) for 0-7.5 cm and 7.5-15 cm horizons. Deep auger samples were taken at 20 cm intervals at six spots to a maximum depth determined by striking gravels. These samples were bulked on a horizon basis within each area.

Soil test results

Table 9.1 Bulked 2.5 cm diameter core samples collected from Ben Dhu Station on 10 December 2012.

Sample	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
1 (0-7.5)	5.2	9	14	4	8	8	7	10.1
1 (7.5-15)	5.4	-	-	-	-	-	-	8.2
2 (0-7.5)	5.6	16	2	4	19	11	6	1.3
2 (7.5-15)	5.6	-	-	-	-	-	-	3.1
3 (0-7.5)	6.4	11	21	10	9	10	10	0.5
3 (7.5-15)	5.5	-	-	-	-	-	-	2.7

*Note; Sample '1' = Deer fence block, '2'=Back block, '3'=Established Lucerne block.

Table 9.2 Soil pH and Al levels from bulked auger samples collected at Ben Dhu Station on 11 December 2012.

Sample/Depth	pH	Exch Al (mg/kg)
1: 0-20 cm	5.2	12.2
1: 20-40 cm	5.6	4.5
1: 40-60 cm	5.6	2.5
1: 60-80 cm	-	-
2: 0-20 cm	5.3	8.4
2: 20-40 cm	5.4	9.2
2: 40-60 cm	5.6	8.0
2: 60-80 cm	-	-
3: 0-20 cm	5.9	0.7
3: 20-40 cm	5.5	1.9
3: 40-60 cm	5.6	1.8
3: 60-80 cm	-	-

*Note; Sample '1' = Deer fence block, '2'=Back block, '3'=Established Lucerne block.

- The 'Deer fence' block showed lower soil Exch Al with depth, indicating that this is the best site for lucerne development on this property.
- The large 'Back block', although having deep topsoil, may be problematic for lucerne. Exch Al levels are around 8-9 down to 60 cm, indicating that a more Al tolerant legume species may be better suited to this block. Development with lime would be expensive, and probably uneconomic on this block.

- The 'Established lucerne' block has been developed well, and has no pH or Exch Al issues. It should be noted that this block has a different (heavier textured) soil from the other 2 blocks/sites sampled.

Omarama Station (uncontracted)

Soil test results

Soil sampling was conducted at 2 sites.

Site 1:

- A large block on the western side of SH8 was soil sampled.
- The block was split into 4 areas, following the road, with each area sampled individually.
- Each area was sampled (30 x 2.5 cm diameter cores) for 0-7.5 and 7.5-15 cm horizons (where possible).
    - Deep (auger) samples were also taken at 20 cm intervals at 3 spots, to a maximum depth determined by striking gravels. These samples were bulked on a horizon basis within each area.

Table 9.3 Soil test results for bulked 2.5 cm diameter core samples taken from Site 1 at Omarama Station.

Sample	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
1 (0-7.5)	5.5	12	2	3	10	6	7	2.7
1 (7.5-15)	5.4	-	-	-	-	-	-	8.3
2 (0-7.5)	5.6	10	<1	3	10	6	6	3.0
2 (7.5-15)	5.4	-	-	-	-	-	-	7.8
3 (0-7.5)	5.6	9	1	3	9	6	5	3.2
3 (7.5-15)	5.3	-	-	-	-	-	-	11.2
4 (0-7.5)	5.9	14	4	6	8	5	6	<0.5
4 (7.5-15)	5.4	-	-	-	-	-	-	6.6

Table 9.4 Soil test result for auger samples collected from Site 1 at Omarama Station.

Sample/Depth	pH	Exch Al (mg/kg)
1: 0-20 cm	5.4	4.6
1: 20-40 cm	5.4	8.8
1: 40-60 cm	5.9	1.5
1: 60-80 cm	6.1	1.4
2: 0-20 cm	5.5	4.5
2: 20-40 cm	5.5	6.1
2: 40-60 cm	5.6	6.5
2: 60-80 cm	-	-
3: 0-20 cm	5.6	3.5
3: 20-40 cm	5.4	8.0
3: 40-60 cm	5.6	6.8
3: 60-80 cm	-	-
4 0-20 cm	5.4	5.2
4: 20-40 cm	5.4	6.0
4: 40-60 cm	5.5	2.6
4: 60-80 cm	-	-

- Soil pH is low (5.4) in the top 40 cm across this block. Exchangeable Al is at high levels.
- This block may be well suited to lupins rather than lucerne.

Site 2

A new trial site was selected on the eastern side of SH8 at Omarama Station. On 14 December 2012 soil was sampled (60 x 2.5 cm diameter cores) for 0-7.5 cm and 7.5-15 cm horizons. Deep auger samples were also collected at 20 cm intervals at eight spots to a depth of 1 m. These samples were then bulked on a horizon basis.

Table 9.5 Bulked 2.5 cm diameter core samples collected from the new trial site at Omarama Station on 14 December 2012.

Sample	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
0-7.5 cm	5.9	16	<1	3	34	9	8	1.4
7.5-15 cm	5.6	12	2	<1	19	4	6	7.1

Table 9.6 Soil pH and Al levels from bulked auger samples collected at Omarama Station on 14 December 2012.

Sample	pH	Exch Al (mg/kg)
0-20 cm	5.7	1.8
20-40 cm	5.7	2.1
40-60 cm	5.7	3.5
60-80 cm	5.8	4.2
80-100 cm	6.0	1.7

- Soil pH and Exch Al levels are more favourable at this site than at the other Omarama Station site.
- With adequate S fertiliser at establishment, it will be a very good trial site for lupin.

Quailburn Station (Greenfields)

- 3 large blocks were soil sampled; 1 established lucerne site, doing poorly (Sample 1), 1 'native' block which is being developed for lucerne in the near future (Sample 2), and 1 established lucerne/cocksfoot site, doing well (Sample 3).
- Each block was sampled (60 x 2.5 cm diameter cores) for 0-7.5 and 7.5-15 cm horizons (where possible).
    - Deep (auger) samples were also taken at 20 cm intervals at 6 spots, to a maximum depth determined by striking gravels. These samples were bulked on a horizon basis within each area.

Table 9.7 Soil test results for bulked 2.5 cm diameter core samples taken from Quailburn Station. Note: Sample 1 = Basin block; Sample 2 = Native; Sample 3 = Middle block.

Sample	pH	Olsen P (mg/L)	Sulphate S (mg/kg)	Exch Ca (QTU)	Exch Mg (QTU)	Exch K (QTU)	Exch Na (QTU)	Exch Al (mg/kg)
1 (0-7.5)	6.5	20	17	12	11	9	7	<0.5
1 (7.5-15)	6.1	-	-	-	-	-	-	<0.5
2 (0-7.5)	5.8	16	31	10	17	12	6	0.7
2 (7.5-15)	5.3	-	-	-	-	-	-	<0.5
3 (0-7.5)	6.4	25	20	13	16	14	7	<0.5
3 (7.5-15)	6.0	-	-	-	-	-	-	<0.5

Table 9.8 Soil test results for auger samples collected at Quailburn Station. Note: Sample 1 = Basin block; Sample 2 = Native; Sample 3 = Middle block.

Sample/Depth	pH	Exch Al (mg/kg)
1: 0-20 cm	6.6	<0.5
1: 20-40 cm	5.8	0.6
1: 40-60 cm	5.6	1.7
1: 60-80 cm	5.7	2.0
1: 80-100 cm	5.6	2.3
1: 100-120 cm	5.8	1.8
2: 0-20 cm	5.5	1.9
2: 20-40 cm	5.2	5.5
2: 40-60 cm	5.6	6.2
2: 60-80 cm	-	-
2: 80-100 cm	-	-
2: 100-120 cm	-	-
3: 0-20 cm	6.5	<0.5
3: 20-40 cm	5.7	0.6
3: 40-60 cm	5.4	3.6
3: 60-80 cm	5.4	4.8
3: 80-100 cm	5.4	7.1
3: 100-120 cm	5.6	5.0

- At the ‘Basin’ site, soil pH was reasonably high, and exchangeable Al low. Factors other than pH (e.g. light soils / poor RAWC) may be limiting lucerne growth in this block. However, further investigations are required at this site, as lucerne roots seem to be turning horizontal at around 5 cm depth in some places.
- The ‘Middle’ block showed decreasing soil pH and increasing exchangeable Al below 40 cm. Regardless, the lucerne and cocksfoot mix in this block seem to be producing well.
- The higher ‘Native’ block has shallower soils, lower pH and higher exchangeable Al levels. With development (lime), the Al should not be an issue for plant growth to at least 0.5 m.