

Yield and persistence of legume monocultures grown in the Lees Valley, South Island High Country

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Abstract

Six legume monocultures were established in the Lees Valley, North Canterbury (400 m a.s.l.), which has long cold winters. The stony soils have low pH, high aluminium concentration, and low water holding capacity, which can lead to severe summer soil moisture deficits. The aim was to identify legumes that would survive and persist in this environment and, therefore, increase the available nitrogen in the pastoral system.

Legume populations of 88 ± 12 seedlings/m² were established and ranged from 45 (sub clover) to 197 seedlings/m² (Caucasian clover). The highest yields were from 'Pawera' red clover at 2.5 and 2.9 t DM/ha in Years 2 and 3, 'Demand' white clover produced 1.7 and 2.6 t DM/ha, and 'Endura' Caucasian 1.8 and 1.7 t DM/ha. 'Kaituna' lucerne yields were low at 0.7 and 1.4 t DM/ha. Caucasian clover was the most persistent legume. A visual assessment in Year 5 found Caucasian was the only legume still dominating its plot (69%) with the lowest area of bare ground (11%). 'Leura' subterranean and 'Bolta' balansa annual clovers survived for four years but accumulated annual yields were low (<1.0 t DM/ha/yr), and the presence of unsoiled species was high (>50%). While red and white clover provided the highest yields for two years, Caucasian clover was the most persistent species and is therefore a legume recommended for this environment.

Keywords: Caucasian clover (*Trifolium ambiguum*), red clover (*T. pratense*), white clover (*T. repens*), sub clover (*T. subterraneum*), balansa clover (*T. michelianum*), soil aluminium

Introduction

The Lees Valley Farmer's Group was formed in January 2005 to discuss agronomic issues related to the intensification of hill and high country farms dominated by low-producing grass species, such as browntop (*Agrostis capillaris*), in this winter-cold, summer-dry environment. One objective was to increase available nitrogen (N) in the soil using legumes. In dryland pastures clovers can fix ~30 kg N/t of dry matter

(DM) (Lucas et al. 2010) and pastures with a high legume content have higher water-use efficiency than N deficient resident pastures (Moot 2012). At Lees Valley, Fasi et al. (2008) highlighted perennial grass growth responses of 8.3 to 20.1 kg DM/kg nitrogen (N) applied. This resulted in an average spring growth rate of 8.8 kg DM/ha/°Cd for grasses receiving 150 kg N/ha compared with 3.2 kg DM/ha/°Cd when no N was applied.

Monocultures of annual clovers can be more productive than perennial clovers in dryland systems (Olykan et al. 2021) and are favoured because of their higher growth rates in the North Island late winter (e.g., Hyslop et al. 2003) and South Island early spring (e.g., Teixeira et al. 2017). Where the effective rainfall is low or soil moisture is below wilting point for up to five months of the year, subterranean clover (sub, *Trifolium subterraneum*) can make a significant contribution to pasture production (Smetham 2003). At Lees Valley, experience suggested that annual clovers would suit the environment. However, the production and persistence of annual clover monocultures depends on a number of factors including: the initial establishment of hundreds of seedlings/m² (Zhang et al. 2004) and >50% clover groundcover (Teixeira et al. 2017), reducing weed competition (Taylor et al. 2020), with appropriate grazing management (Hyslop et al. 2003), to facilitate periodic reseeding to maintain a seed bank (Monks et al. 2008; Ates et al. 2012), and the amount and distribution of seasonal rainfall (Olykan et al. 2018). Cultivars with low hardseededness ratings (i.e., softer seed coats) are recommended in New Zealand (e.g., Lucas et al. 2015) for sub clover.

Pasture growth is influenced by altitude, aspect and soil depth (Anderson et al. 2014) and these factors can be highly variable across a hill country property. Moir and Moot (2010) found that, of all the variables measured at Lees Valley, lucerne (*Medicago sativa* L.) yields (0.7 to 1.2 t DM/ha/yr) were explained ($R^2 = 0.71$) by topsoil depth to gravel. Topsoil depth was extremely variable even over short distances of 1 to 2 m, impacting plant available water. Further, one of

the most limiting factors for legume performance in some hill and high country regions is the presence of toxic levels of soil aluminium (Al). Clover and lucerne growth is compromised when Al soil exceeds 3 to 4 mg Al/kg (Moir et al. 2016), which is associated with pH values <5.8 (Whitley et al. 2016), because root growth and nodulation are severely restricted, particularly in lucerne (Berenji et al. 2017).

Caucasian clover (*T. ambiguum*) has been successfully established and has persisted in many South Island High Country regions, including the lower sunny slopes of Tara Hills, Omarama, where it exhibited drought tolerance and spring vigour (Woodman et al. 1992). In contrast, white, red, and sub clovers showed poor survival and/or persistence at this site. Likewise, Scott (1998) reported that after a decade, Caucasian clover was the dominant species in mixed legume-grass pastures at Mt John, Lake Tekapo, under a higher phosphorus (P) fertility regime and an annual rainfall of 520 mm. Compared with white clover (*T. repens*), Caucasian has shown greater tolerance to elevated soil Al levels (i.e., >10 mg/kg) in tussock grassland sites (Caradus et al. 2001), where it spread by rhizomes from the original planted rows. At Lake Heron, Black et al. (2014) found that Caucasian persisted up to 10 years, at which time it contributed 66-76% of the total pasture DM yield.

The approach to the development of improved pastures in South Island hill and high country areas has been to test a range of legume and grass species and cultivars in the field to identify those that persist long-term (e.g., Woodman et al. (1992), Scott (1998), Berenji et al. (2018), Allan and Keogh (1994)). At Lees Valley a range of legume, perennial grass, and pasture mixture experiments were established and monitored from 2006 to 2012. This paper presents the results from the legume monoculture experiments. A separate paper focusses on white and sub clover yields in grass pasture mixture experiments, and Caucasian clover growing with or without herbs (Olykan et al. 2023).

Materials and Methods

Lees Valley is an intermontane basin in North Canterbury. The experimental site at Mt Pember Station (-43.1381, 172.1886; WGS1984) was on the valley flats (400 m a.s.l.), where the marginal grassland was dominated by fescue tussock (*Festuca novae-zelandiae*), blue tussock (*Poa colensoi*), browntop, and sorrel (*Rumex acetosa*), with matagouri (*Discaria tomatou*) scrub.

Soil characteristics

The Balmoral soil (Acid Orthic Brown) is characterised as being silty, very shallow, very stony, well drained, with a low to moderate profile of plant available water

(70 mm in top 100 cm). Below ~80 cm soil depth they are 'extremely gravelly' which creates a physical barrier to root penetration (Manaaki Whenua 2022). Without the addition of lime at this site, soil Al was >4 mg/kg below a depth of 75 mm ((Moir and Moot 2010), where 1 me Al/100 g was equivalent to ~3 mg Al/kg, J.L. Moir, pers. comm., 13/09/2022).

Initial soil test results (March 2005) showed the site had a pH of 5.5, Olsen P of 8 mg/L, and sulphate-sulphur (S) of 3 mg/kg (Table 1). This prompted the addition of lime and fertilisers during site preparation, and ongoing fertiliser applications. As a result, the pH, Olsen P, and sulphate-S were increased to adequate levels for clover growth (Table 1).

Site preparation

Site preparation was described by Fasi et al. (2008) and included herbicide applications (4 L/ha of Roundup, a.i. 360 ml glyphosate/L) in April and October 2005, 5 t lime/ha in April 2005, mob-stocking with cattle to breakdown the browntop mat in August 2005, and cultivation (discing, harrowing and heavy rolling) in January 2006, which incorporated 400 kg/ha superphosphate (P 9, S 11) and 300 kg/ha of diammonium phosphate (N 18, P 20, S 1) fertiliser.

Experiment details

The experiment was a randomised complete block (RCB) design with four replicates. Plots were 40 m long by 9 m wide. From 8 to 13 February 2006 five legume species were sown with a Duncan seed drill (coulters at 150 mm spacing). These were 'Demand' white, 'Pawera' red (*T. pratense*), 'Leura' subterranean, 'Bolta' balansa (*T. michelianum*) clovers (no inoculation), and 'Kaituna' lucerne ('Superstrike' coated). The following spring on 14th September 2006, plots for Caucasian clover were sprayed with 2 L/ha of Roundup Transorb® (a.i. 540 g glyphosate/L) mixed with 500 ml/ha of Pulse. 'Endura' Caucasian clover (inoculated with *Rhizobium* strain ICC148) was sown on 1 November 2006 because it is unlikely to establish successfully when autumn sown (Black et al. 2006). Table 2 contains details of the legumes and sowing rates.

The legumes were sown with a cover crop of oats (*Avena sativa*) at 15 kg/ha to provide seedlings with protection from the dominant Nor'west winds. The cover crop was grazed in Year 1 and, being an annual, died out. There was no evidence that the oats negatively affected legume growth.

Single superphosphate fertiliser was applied in October 2007 (750 kg/ha) and September 2008 (300 kg/ha). Herbicide applications included Garlon Fallowmaster® (a.i. 755 g Triclopyr/L, rate of 3 L/ha with Pulse penetrant) in February 2008 and Spinnaker (a.i. 700 g imazethapy/kg, rate of 300 ml/ha with

Table 1 Chemical analyses of soil samples (0-75 mm depth) from Lees Valley, Canterbury, taken March 2005 before site preparation (Fasi et al. 2008), and in August 2007 and May 2008. Recommended levels are for sedimentary soils.

Date	pH	Olsen P (mg/L)	K	Ca Quick tests values	Mg	Sulphate-S (mg/kg)
Mar 2005	5.5	8	8	2	15	3
Aug 2007	6.0	17	11	7	10	8
May 2008	5.9	19	16	7	12	30
Recommended:	5.8-6.0 [#]	20 [#]	5-8 [#]		8-10 [#]	10-12 [*]

References: [#] Morton and Roberts (2016), ^{*}Edmeades et al. (2005).

Table 2 Agronomic and experimental details for legume species sown in Lees Valley, North Canterbury, in 2006. TSW = Thousand seed weight of bare seed (estimated).

Legume species	Cultivar	Lifecycle	TSW (g)	Sowing rate (kg seed/ha)
Balansa	'Bolta'	Annual	1.0	3
Caucasian	'Endura'	Perennial	2.2	8
Lucerne	'Kaituna'	Perennial	2.4	10
Subterranean	'Leura'	Annual	7.9	10 (coated)*
Red clover	'Pawera'	Perennial	3.4	5
White clover	'Demand'	Perennial	1.0	4

* Equivalent to 5 kg bare seed/ha.

Codacide adjuvant oil) in May 2008 to reduce unsown species, particularly sorrel.

On 6 September 2006, the legume seedlings were counted in a 1.0 m length of drill row/plot and the number multiplied by 6.67 to give seedlings/m². Groundcover (%) was also visually assessed. On 15 November 2006 and 16 January 2007, Caucasian seedling populations were quantified by the same method.

Due to the summer dry, there were no annual clover seedling to count in the autumn of 2007. The number of balansa and sub clover seedlings were counted on 20 February 2008 (20 x 0.01 m² quadrats/plot) and 14 May 2009 (10 x 0.01 m² quadrats/plot).

Annual yield was accumulated from 1 July to 30 June for the perennials and from 1 January to 31 December for the annuals. The period from sowing until 30 June 2006 was considered the establishment phase. In Year 1 (2006-07), total pasture DM was calculated from capacitance probe readings (data not reported) and the site periodically grazed by sheep with the last grazing in June 2007. In Year 2 there were two harvests (on 20 November 2007 and 8 April 2008) representing 272 days of growth from 1 July 2007 and the three harvests in Year 3 (21 October 2008, 14 January 2009, and 21 April 2009), 343 days of growth from 10 April 2008. After each harvest, the site was mob grazed by sheep (ewes or weaned lambs) for an average of four days (stocking rate unknown, post grazing residuals <300 kg DM/ha). In Year 4, a harvest occurred on 24 November 2010, which represented 57 days of growth since last grazing. After Year 4 (2009-10) the annual clovers sub and balansa failed to regenerate. Harvest dates were affected by the difficulties of coordinating grazing times with host farm managers.

At all harvests, herbage biomass was cut using

motorised shears to a stubble height of ~20 mm from one 0.2 m² quadrat/plot. The samples were separated into sown legume; broadleaf weeds, herbs, grass, and volunteer clover (unsown species), and dead components. Samples were dried at 65 °C for 48 hours and weighed.

In Year 5 (10 November 2010), the lucerne and Caucasian, red and white clover plots were visually scored to estimate the percentage of bare ground, sown legume, unsown species, and dead material.

Climate

Daily climate data were obtained from the NIWA Virtual Climate Station (VCS) network site located at -43.125, 172.175 (NZDG 1949) at an elevation of 463 m a.s.l. (NIWAData 2022) that was ~1.9 km NNW of the experimental site. Because of the suspected overestimation of rainfall by the VCS due to its location nearer the foothills, daily rainfall was measured onsite with a Hobo rain gauge from November 2010 to June 2012. Calculations found that the daily VCS data should be multiplied by 0.88 (K. Pollock, unpublished) which resulted in a strong linear regression between the accumulated Hobo rainfall and adjusted VCS datasets ($R^2 = 0.99$). The adjusted VCS rainfall data were used.

Long-term mean (LTM, 30 years from 1992 to 2021) maximum and minimum air temperatures were 15.7 and 4.6 °C with a mean temperature of 10.1 °C. The LTM annual rainfall was 845 mm (Table 3). Because the top 1.0 m depth of Balmoral soils can store 70 mm of water, it was calculated that 300 mm of annual rainfall was lost via drainage or runoff resulting in an annual effective rainfall of 545 mm. LTM annual Penman potential evapotranspiration (PET) was 820 mm. Monthly PET values exceeded the effective rainfall for most of the

Table 3 Annual rainfall, drainage, effective rainfall, and potential evapotranspiration (PET); and dry season (Nov to Feb) rainfall, PET, and deficit at Lees Valley, North Canterbury, 2006-07 to 2010-11. Data from NIWA VCS at -43.125, 172.175 (~1.9 km NNW of the experiment, adjusted). Season from 1 July to 30 June. Long Term Mean (LTM) is 30 years from 1992 to 2021.

Year (Season)	Annual (mm)					Dry season (mm)	
	Rain	Drainage ¹	Eff rain ²	PET	Eff rain	PET	Deficit
1 (2006-07)	774	124	650	844	302	430	-128
2 (2007-08)	758	250	508	847	196	480	-284
3 (2008-09)	1077	559	518	867	260	496	-236
4 (2009-10)	919	374	545	872	190	466	-276
5 (2010-11)	902	300	602	868	272	493	-222
LTM	845	300	545	820	235	465	-230

¹ Daily drainage was quantified during SMD calculations.

² Effective rainfall = rainfall – drainage.

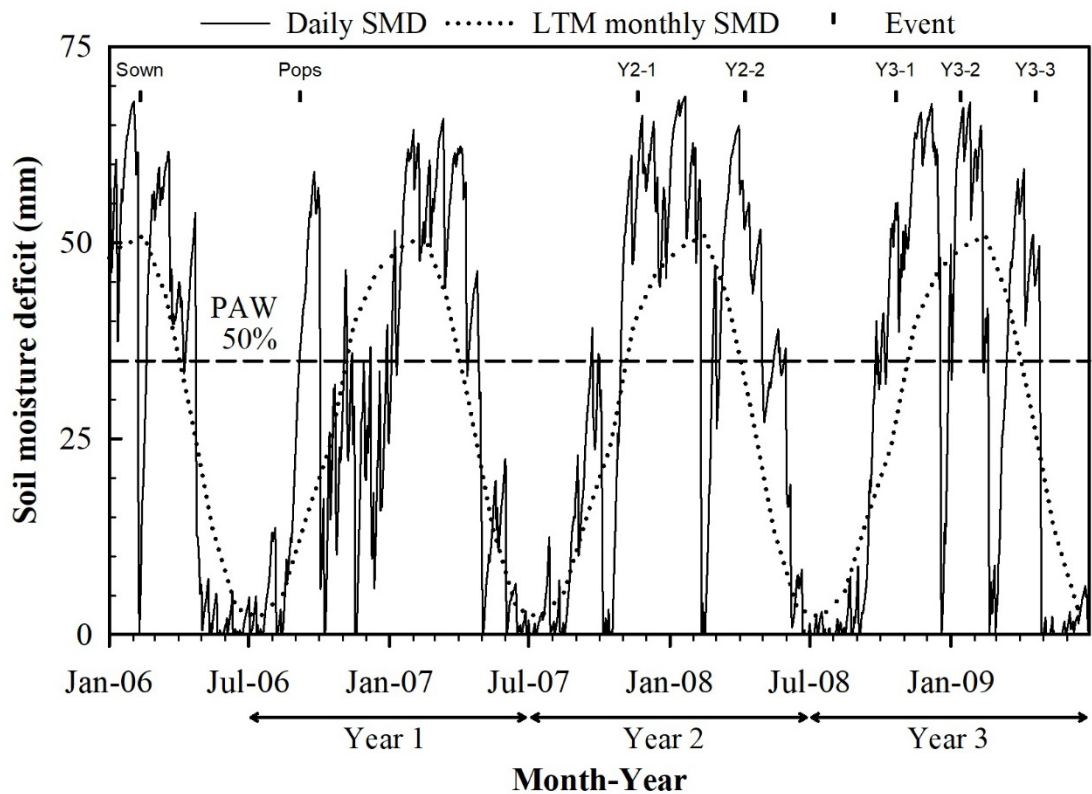


Figure 1 Daily soil moisture deficit (SMD) from January 2006 to December 2009 and LTM monthly SMD (1992-2021). Calculated using data from NIWA VCS at -43.125, 172.175 (~1.9 km NNW of the experiment, adjusted). Experimental events: sowing (Sown), Pops (population counts and ground cover assessment), Year 2 and 3 harvests (Y2-1 to Y3-3). PAW (plant available water) at 50% was equivalent to 35 mm of soil moisture.

year, particularly from November to February.

During the experiment, annual PET was consistently higher than the LTM while effective rainfall ranged from 508 to 650 mm (Table 3). The wettest 'dry season' was in Year 1, when the deficit (difference between effective rain and PET) was 128 mm, and the driest 'dry season' was in Year 2 with a deficit of 284 mm.

The LTM soil moisture deficit (SMD) was less than 50% plant available water (PAW, i.e., >35 mm SMD) from November to March (Figure 1). On a seasonal basis the SMD was highly variable, and the site could get very dry in the summer/autumn months when SMD approached 70 mm (i.e., 0% PAW). The SMD variability was highlighted in Year 3 when the dry

season (i.e., SMD > 35mm, therefore < 50% PAW) started on 10 October 2008 and continued until 26 April 2009. However, during this time two rainfall events returned the SMD to 0 mm (Figure 1).

Data analysis

Genstat (20th edition; VSN International Ltd.) was used for all statistical analyses. Data were analysed by one-way ANOVA (legume) with randomised blocks (rep) and orthogonal contrasts based on annual vs. perennial legume, and lucerne vs. perennial clover (see Table 2 for details) for Year 1 groundcover and plant population data, accumulated dry matter and growth rates at each harvest, and botanical components (legume, unsown and dead) in the final harvests for Years 2 to 4, and the Year 5 visual assessment data. When significant, means were separated by Tukey's HSD test at the $\alpha=0.05$ level.

Results

Seedling populations and early groundcover

Legume seedling populations and groundcover on 6 September 2006, seven months after sowing, were affected ($P<0.001$) by species. The average population was 66 ± 6 seedlings/m², ranging from 45 for sub clover to 92 for lucerne. Groundcover from the sown legumes was low, averaging $9.5\pm 1.5\%$. Balansa and lucerne had the lowest ($P<0.05$, ~6%), white clover the highest at 15%.

On 15 November 2006, two weeks after sowing, Caucasian clover averaged 197 ± 32 seedlings/m². By 16 January 2007, 11 weeks after sowing, there were 131 ± 12 Caucasian seedlings/m².

On 20 February 2008, an average of 100 ± 41 balansa seedlings/m² and 260 ± 71 sub clover seedlings/m² had re-established from the seed bank. On 14 May 2009 there were 25 ± 14 balansa seedlings/m² and 83 ± 33 sub clover seedlings/m².

Years 2 to 3: accumulated yields and botanical composition

In Year 2, the total (i.e., all species) spring yield was 1850 kg DM/ha and did not differ among legumes. Autumn accumulated yield showed the perennial legumes were more productive ($P<0.001$) than the annuals (2700 vs. 860 kg DM/ha).

In Year 2, legume affected accumulated legume yields in spring (20/11/2007, $P=0.002$) and autumn (08/04/2008, $P<0.001$). Caucasian and red clovers had higher ($P<0.05$) spring yields ($\sim 1500\pm 230$ kg DM/ha) than lucerne and sub clover (~ 310 kg) (Figure 2). In autumn, the red clover yield (2470 kg DM/ha) was almost triple that of lucerne (650 kg). Caucasian and white clover yields were not different in autumn (1800 ± 290 kg DM/ha). Balansa (144 kg DM/ha) and

sub clover (27 kg DM/ha) yields were minimal as seedlings were re-establishing. Mean daily spring growth rates of the Caucasian and red clovers were ~ 11 kg DM/ha/d. During the summer/autumn, red clover grew at 7 kg DM/ha/d.

In Year 3, the accumulated legume yields were affected by legume in spring (21/10/2008, $P=0.029$), summer (14/01/2009, $P=0.002$), and autumn (21/04/2009, $P<0.001$). In spring, white clover yield (1660 kg DM/ha) was higher ($P<0.05$) than from sub clover (300 kg) (Figure 2). White clover grew at 15 kg DM/ha/d. In summer, the red clover and white clovers accumulated $\sim 2500\pm 330$ kg DM/ha and were higher ($P<0.05$) than sub clover (363 kg DM/ha). Red and white clover growth rates from the spring to summer harvest were 18 and 11 kg DM/ha/d, respectively.

By the autumn harvest in Year 3, the red clover accumulated yield of 2920 ± 320 kg DM/ha was higher than lucerne (1390 kg DM/ha). At this time the annual balansa and sub clovers (< 50 kg DM/ha) were re-establishing. Growth rates of red clover (3.9 kg DM/ha/d) and lucerne (3.5 kg DM/ha/d) were higher ($P<0.05$) than balansa and sub clover (< 1 kg). White clover and Caucasian grew at ~ 2.8 kg DM/ha/d.

The total accumulated DM yield in the Year 3 autumn was affected by legume ($P<0.001$) because of the perennial vs. annual contrast (3260 vs. 230 kg DM/ha). The red clover total yield was 4100 kg DM/ha, no different to white clover (3500), but higher ($P<0.05$) than Caucasian and lucerne (2700 kg DM/ha).

In spring of Year 2, the % of unsown species (broadleaf weeds, grasses, volunteer clover) differed among legumes ($P<0.001$) and represented $70\pm 8\%$ of total DM yield produced by balansa, lucerne, and sub clover treatments, which was higher ($P<0.05$) than the $\sim 17\%$ contribution in the red, white, and Caucasian clovers. The dead component averaged $9\pm 4\%$.

In spring of Year 3, legume affected ($P=0.036$) the % sown legume, which was highest in white clover compared with sub clover (75 vs. 21%). Perennial clovers averaged $66\pm 12\%$ sown legume compared with 28% for the annual clovers ($P=0.002$). The % of unsown was $27\pm 11\%$ and dead material contributed $19\pm 4\%$.

Year 4 spring harvest

In Year 4, mean total yield for the harvest on 24/11/2009 was 2755 kg DM/ha from 57 days regrowth. Legume treatment affected ($P<0.001$) sown legume yield, growth rates, and % sown legume. Red and Caucasian clovers produced ~ 2300 kg DM/ha, which was higher than lucerne (740), sub clover (520) and balansa clover (190) (Figure 3A). The white clover yielded 1740 kg DM/ha. Caucasian and red clover growth rates were

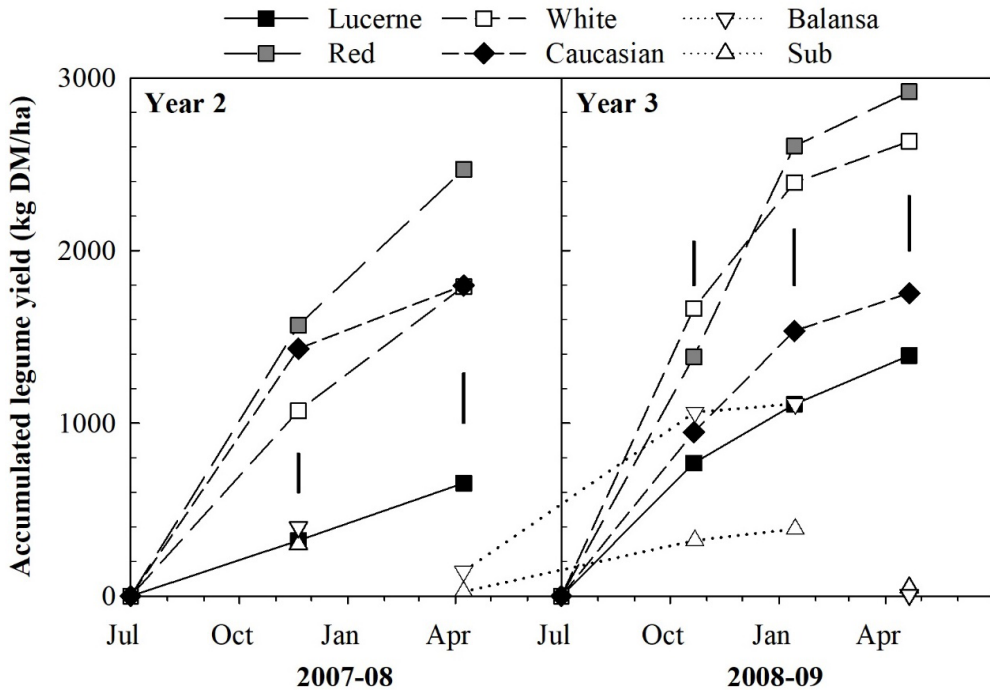


Figure 2 Accumulated perennial legume yield for Years 2 (2007-08) and 3 (2008-09) at Lees Valley, North Canterbury. Yield of annual legumes accumulated by calendar year. Bars are SEM for the harvest date.

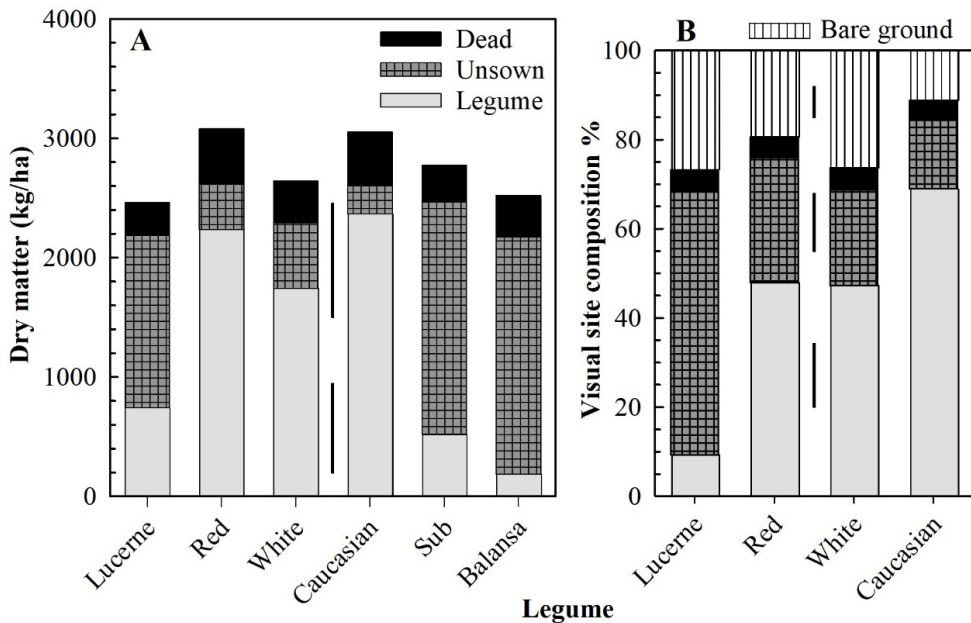


Figure 3 A: Component yield of legumes in Year 4 (2009-10) spring harvest (lines are LSD 5% for legume or unsown), B: visual composition of perennial legume plots in Year 5 on 10/11/2011 (lines are LSD 5% for legume, unsown or bare ground) at Lees Valley, North Canterbury.

40 kg DM/ha/d and higher than that of lucerne. White clover grew at 31 kg DM/ha/d. The sown legume was higher in the Caucasian, red, and white clover ($\sim 72 \pm 8\%$) monocultures compared with lucerne, sub clover and balansa clover ($\sim 16\%$).

Year 5 visual groundcover score

In Year 5, the late spring (10 November 2010) visual groundcover score showed that legume affected ($P=0.001$) the % bare ground, and sown legume and unsown percentages ($P<0.001$). The 69% of sown legume in the Caucasian clover monoculture was higher than that of red and white clovers ($\sim 48\%$), which were higher than the lucerne (9%) (Figure 3B). The 59% unsown species in lucerne exceeded ($P<0.05$) the contribution in the clover treatments. Caucasian clover bare ground (11%) was lower than the $\sim 26\%$ in the lucerne and white clover.

The unsown species were $\sim 50\%$ broadleaf weeds, 30% other clovers, and 20% grass.

Discussion

The highest total yield was 4100 kg DM/ha/yr in red clover in Year 3 of which 72% was the sown clover. Most of this herbage was grown in the six months from July to January (Figure 2). These are consistent with total yields of ~ 4500 kg DM/ha/yr found by Olykan et al. (2023) for grass and clover pasture mixtures at the same location. Fasi et al. (2008) reported maximum yields of 5700 kg DM/ha for the Year 1 growth of 'Aries' AR1 perennial ryegrass and 'Kara' cocksfoot grass monocultures (no N applied).

Success of the perennial clovers

Perennial clovers were the most productive and persistent legumes within this environment. Red clover was the highest yielding legume in Year 2 (~ 2400 kg DM/ha) and red and white clovers were highest in Year 3 (~ 2800 kg, Figure 2). These clovers persisted until Year 5 but were no longer the dominant groundcover in their plots (Figure 3B). Previous research has shown that red and white clovers may not persist in high country dryland environments (e.g., Woodman et al. 1992). For white clover this is due to the transition to clonal populations, 1 to 2.5 years after sowing. These have smaller fibrous root systems, which are more vulnerable to water stress (Brock and Hay 2001). Red clover stands frequently only persist for 2 to 3 years because carbohydrate replenishment of the taproot decreases when summer soil moisture is low and this slows regrowth (Brock et al. 2003).

At Lees Valley, lucerne yields were low (<1400 kg DM/ha/yr), less than the perennial clovers. Low lucerne yields were also found by Moir and Moot (2010) at an adjacent site which they attributed to the shallow nature

of the soils. This means the amount of plant available water is restricted and the benefits of the deep tap root of lucerne are negated. Lucerne root growth is also restricted by high soil Al (Berenji et al. 2017). The initial soil tests at this site highlighted potentially toxic levels of aluminium in the soil. These were partially rectified by the addition of 5 t of lime/ha that raised the soil pH to 6.0 (0-75 mm depth) after 2.5 years (Table 1). The addition of lime to address toxic aluminium levels has been successfully achieved in other South Island High Country environments (Kearney et al. 2010). The economics of these additions can only be determined on a case-by-case basis once the biological potential of the environment has been established, which was the aim of this research.

Initially, Caucasian clover yields were no different to red and white clovers, despite being sown nine months later. The vegetative spread of Caucasian by rhizomes contributed to its greater ground cover in later years. Thus, by Year 4 its yield was equivalent to red clover and by Year 5 it had the lowest proportion of bare ground. Caucasian clover therefore may prove to be the most productive legume in the long-term for this area of the Lees Valley. Berenji et al. (2017) highlighted Caucasian clover's ability to grow and spread on soils of low soil pH and high aluminium (pH 5.2, 15 mg Al/kg), as has Caradus et al. (2001) (pH 4.8, >10 mg Al/kg). Strachan et al. (1994) also noted that the extensive Caucasian clover root/rhizome system allowed it to withstand frost-heave and low photosynthesis in cold winter environments at Hakatere, Ashburton River catchment. Likewise, Scott (1998) concluded that the rhizomatous habit of Caucasian clover allowed it to be persistent in all situations.

Failure of the annual clovers

At this site 'Bolta' balansa clover and 'Leura' sub clover did not establish sufficient plant populations annually, failing to persist beyond Year 4, with lower DM yields (<1.0 t DM/ha/yr) than the perennial clovers. In the first year the plots were not grazed until late November, to allow the sub clover time to set seed. Populations of 100+ annual clover seedlings/m² were found in February 2008, however the relatively low annual clover yields in 2008, especially for balansa clover (Figure 2), suggest few of these seedlings survived the drier than normal autumn (Figure 1) when there was 94 mm of rain (March to May) compared with the LTM of 207 mm. Over time, the annual clover treatments became dominated by invading unsown weed species.

In the Lees Valley pasture mixture experiments described by Olykan et al. (2023), 'Leura' sub clover did not re-establish after the first season. Compared with other sub clover cultivars, 'Leura' is very late flowering and has been shown to re-establish low

populations of seedlings in monocultures (Teixeira et al. 2017) and cocksfoot pastures (Lucas et al. 2015). An earlier flowering sub clover may be more appropriate for this environment by allowing earlier seed set and the development of a seed bank in this location which is challenged by early spring water deficit. However, it should be noted that sub clovers ‘Denmark’ and ‘Woogenellup’ were sown in other pasture mixture experiments at this site (unpublished data) and also failed to persist.

Annual clovers are recommended for summer-dry hill and high country environments because they can utilise the winter moisture to grow forage during the spring before senescing and surviving summer as seed. At Lees Valley, the top flowering balansa annual clover failed to re-establish, this may be because it is susceptibility to hard grazing and trampling (Hyslop et al. 2003), which could compromise its ability to flower and reseed (Macfarlane et al. 2015). Balansa also failed to re-emerge after a hot dry summer at Lincoln (Olykan et al. 2021). For sub clover, early summer rain may result in a ‘false strike’ that affects soft-seeded cultivars (Teixeira et al. 2018) such as ‘Leura’. The Lees Valley environment is exposed to strong, dry Nor’west winds in the summer that were observed to desiccate small seedlings. For those that did establish, frost-heave was observed in the winter which dislodged small seedlings.

Nitrogen fixation

One of the objectives for investigating legumes at Lees Valley was to improve the N status of the soils. Adding N into the system would improve grass growth (Fasi et al. 2008) in a mixed legume-grass pasture and could increase total forage production. In this experiment, the highest annual yield of ~3 t legume DM/ha by red clover in Year 3 may have fixed ~90 kg N/ha (Lucas et al. 2010).

One reason for establishing legume monocultures was to provide temporal separation, before introducing any grass. These results suggest that it would take at least six years before contemplating overdrilling Caucasian clover with a companion grass.

Other legume options

Russell lupin (*Lupinus polyphyllus*) was not studied at this site but on-farm research found it was a persistent and productive legume in high country areas with high soil aluminium (i.e., >5 mg Al/kg, 0-75 mm soil depth) where lucerne (Hendrie et al. 2018) and other clovers (Berenji et al. 2018) have struggled to survive. Russell lupin yields of 8 t DM/ha/yr have been reported (Moot and Pollock 2014). As Russell lupins increase total and mineralisable N in the soil they can be an important species for the development of poor quality high-country soils (Che et al. 2018).

Conclusions

Summer soil moisture deficits, cold winters and highly variable shallow, infertile soils make Lees Valley a challenging site for establishing and growing productive and persistent legume monocultures. Caucasian clover was the most persistent and productive after 5 years, with red and white produced the highest yields in Years 2 and 3. The economics of establishing such legumes will also depend on the amount of lime and fertiliser required to enable the legumes to thrive.

Lucerne and annuals ‘Bolta’ balansa and ‘Leura’ sub clover had poor production and persistence and are not recommended for this environment.

Acknowledgements

The authors thank Vonny Fasi, Dr Saman Berenji, Dr Keith Pollock, Don Heffer, Dave Jack, and Dan Dash for their assistance with this research programme. This research was funded by the Ministry of Agriculture and Forestry (MAF) Sustainable Farming Fund (SSF 06/067 and 09/123). Funding for the preparation of this manuscript was provided by Beef + Lamb New Zealand, MBIE, Seed Force New Zealand and PGG Wrightson Seeds under the “Hill Country Futures” research programme (BLNZT1701).

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