Abstract

Four experiments were established to identify productive and persistent dryland pasture mixtures that included legumes to supply nitrogen and a suitable grass and/or herb companion species. There was a Caucasian clover-herbs (plantain and/or chicory) mixture experiment, and three grass-clover mixture experiments: ryegrass cultivars, dryland grass species (brome, cocksfoot, or tall fescue), or timothy +/- herbs (plantain and/or chicory), all sown with white and sub clovers. The site was in Lees Valley, an intermontane basin in North Canterbury (400 m a.s.l.), which experiences long cold winters, has soils of low pH and high aluminium, with low water holding capacity and severe summer soil moisture deficits.

In the first two years of the grass-clover mixtures, the ryegrass and dryland grass-clover pasture mixtures were the most productive with total yields of ~4,400 kg DM/ha. In the dryland grass mixtures, the yield of the brome and cocksfoot grass component increased from Year 1 to 2 (1350 to 2830 kg DM/ha) while tall fescue declined (970 to 800 kg DM/ha). The equivalent timothy grass yields were low averaging ~320 kg DM/ha/yr.

Across the grass-clover mixtures, the average white clover yield was 1800±210 kg DM/ha in Year 1 and represented 43% of total DM, compared with 8% sub clover. In Year 2, the white clover produced 930±90 kg DM/ha, which represented 29% of total annual yield. Sub clover did not re-establish. Grass cultivars/species in the mixture experiments had no effect on white clover yield. White clover yields peaked in October-November of both years with growth rates of ~16 kg DM/ha/d. At the start of the summer dry period, from November onwards, white clover growth rates declined resulting in lower yields.

In the Caucasian-herbs experiment, total yield in Years 1 and 2 was ~2750 kg DM/ha/yr. In both years Caucasian clover yields were lower when grown in herb-based mixtures compared with a monoculture (Year 1: ~400 versus 1800±270 kg DM/ha, Year 2: 920 versus 1750±210 kg DM/ha). Plantain contributed ~1740 kg DM/ha/yr to the total yield.

The persistence and productivity of grass-legume-herb mixtures for dryland pastures are discussed. Cocksfoot was a productive grass in Lees Valley because of its aggressive growth habit and resilience in dryland conditions. Caucasian clover was a productive when grown as a monoculture.

Key words: white clover (Trifolium repens), ryegrass (Lolium perenne), cocksfoot (Dactylis glomerata), Caucasian clover (T. ambiguum), soil moisture

Introduction

In January 2005 the Lees Valley Farmer’s Group was formed to discuss options for the intensification of hill and high country farms. These landscapes were dominated by low-producing grass species, such as browntop (Agrostis capillaris), in a winter-cold, summer-dry environment. Agronomic issues identified by farmers included pasture species combinations, supplying nitrogen (N) to pastures, and the establishment and management of legumes such as Caucasian and annual clovers.

In response, 10 experiments were conducted from 2006 to 2012. Published results showed the high soil aluminium was unsuitable for lucerne (Medicago sativa) without high inputs of lime and fertiliser (Moir and Moot 2010). Monocultures of the annual clovers balansa (Trifolium michelianum) and subterranean (sub, T. subterraneum) also produced low yields with poor persistence (Olykan et al. 2023). The most productive legumes were the perennial white (T. repens), red (T. pratense) and Caucasian (T. ambiguum) clovers, with Caucasian clover also being the most persistent (Olykan et al. 2023).

Fasi et al. (2008) found the most productive perennial grasses, sown as monocultures, were perennial ryegrass (Lolium perenne) cultivars in winter and spring, with cocksfoot (Dactylis glomerata) and tall fescue (Festuca arundinacea) more productive than ryegrass in summer. They reported that a mid-August application of 150 kg N/ha increased spring growth rates from 3.2 kg DM/ha/Cd to 8.8 kg DM/ha/Cd, highlighting the importance of N to maximise the most reliable period of pasture growth in spring.

These results suggested that perennial clovers, such
as white, red, and Caucasian, could fix nitrogen N and thereby improve the grazing preference (Edwards et al. 1993), production (Mills et al. 2006), and water-use efficiency (Moot 2012) of the non-legume companion grass species in a pasture mixture in Lees Valley. While cocksfoot and sub clover have been a productive and persistent dryland grass-clover pasture combination in Canterbury (Mills et al. 2014), sub clover has failed to thrive in the Lees Valley (Olykan et al. 2023). Plantain (Plantago lanceolata) is viewed as a promising alternative to ryegrass in mixed pasture systems (Golding et al. 2011). In North Island east coast dryland pastures, Macfarlane et al. (2015) found that plantain-white clover pasture mixtures produced ~20% more dry matter than the ryegrass-white clover, and had a higher clover content. Taylor et al. (2021) reported that ‘Tonic’ plantain replaced the failing ryegrass in Years 3 and 4 in the ‘MaxAnnuals’ dryland experiment at Ashley Dene, Canterbury, producing 1.5 and 2.4 t DM/ha, respectively. Plantain has also shown greater potential than chicory for persistence as a component of a pasture mix (Tozer et al. 2011a).

At Lees Valley, four pasture mixture experiments were established to examine the production and persistence of grass, clover, and herb species combinations in pasture mixtures for high country dryland conditions.

Materials and methods
From February 2006 to January 2007, four pasture mixture experiments were sown in Lees Valley: Caucasian clover-herb mixtures, two grass-clover mixtures, and a grass-clover-herb mixture. The Lees Valley site, soil details, climate, and site preparation for experimental work were described by Olykan et al. (2023).

Experiment 1: Caucasian-herb mixtures
The Caucasian clover and herb pasture mixtures were part of the legume experiment described by Olykan et al. (2023). They presented the legume monoculture results and provided details about the experiment’s establishment and maintenance. Cultivar names and sowing rates are presented in Table 1. The chicory and plantain were sown on 13 February 2006. Established herb seedlings were counted on 6 September 2006 in one 1 m length of row per plot and the groundcover (%) of the sown herbs was visually assessed.

On 1 November 2006, ‘Endura’ Caucasian clover was sown (8 kg seed/ha) as a monoculture (Cc-Mono) and also overdrilled into the chicory (Cc+Chic) and plantain (Cc+Plan) plots. Caucasian seedlings in all treatments were counted in four 1 m lengths of row per plot on 15 November 2006 but only in the Cc-Mono on 16 January 2007. There were two harvests in Year 1 (2007-08, 20 November 2007 and 8 April 2008, representing 272 days of growth from 1 July 2007), and three harvests in Year 2 (2008-09, 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 for an average of four days to rapidly remove all harvestable herbage (stocking rate unknown, post grazing residuals <300 kg DM/ha). At times, harvest dates were influenced by difficulties of post-measurement grazing with stock movement on-farm.

In Year 4 (10/11/2010) the original plots were visually scored to estimate the percentage of bare ground, Caucasian, herb, unsown species, and dead material.

Experiments 2 to 4: Grass-clover-herb pasture mixtures
After initial site preparation in 2005, the experimental site was sprayed with 2 L/ha of Roundup Transorb® (a.i. 540 g glyphosate/L) mixed with 500 ml/ha of Pulse penetrant (a.i. 800 g organomodified polydimethyl siloxane/L) in early November 2006 and left fallow for three months. Three grass-clover-herb based pasture mixture experiments were sown on 30 January 2007: Experiment 2) five cultivars of perennial ryegrass; Experiment 3) five dryland perennial grasses that included tall fescue, pasture brome, or cocksfoot; and Experiment 4) ‘Kahu’ timothy with chicory and/or plantain, and red clover. Cultivar names and sowing rates are presented in Table 1. Endophytes chosen were AR1 or LE (low endophyte) for ryegrass cultivars and MaxP for ‘Advance’ tall fescue (Table 1). All treatments in these three experiments had a basal clover mixture of ‘Leura’ sub clover sown at 10 kg coated seed/ha (equivalent to ~5 kg bare seed, Thousand Seed Weight (TSW) = 7.9 g) and ‘Nomad’ white clover at 2 kg /ha (TSW = 1.0 g). Both clovers were sown perpendicular to the grass. Plots were 6 m by 40 m with three replicates.

Seedling counts were carried out on 28 February, 21 March, and 4 April 2007 as the different pasture species established, counting a 1 m length of drill row/plot and the value multiplied by 6.67 to give seedlings/m².

The establishment phase was from sowing to 30 June 2007 and a harvest was carried out on 18/07/2007. In Year 1 (1 July 2007 to 30 June 2008, 2007-08) there were two harvests on 20/11/2007 and 08/04/2008, and in Year 2 (2008-09) there were four harvests on 10/09/2008 (not timothy mixtures), 21/10/2008, 22/01/2009, and 30/04/2009. In Year 3 (2009-10) there were two harvests, but they did not cover the whole year or the winter/early spring period of 2009.

After each harvest the experiments were grazed with sheep (August and November 2007, April 2008, November 2008, and January 2009) or mown (January...
Table 1  
Species, cultivars, endophytes, and sowing dates and rates (kg/ha) in the Lees Valley grass pasture mix experiments. Experiments 2 to 4 included 'Leura' sub clover and 'Nomad' white clover (+WC, sub).

<table>
<thead>
<tr>
<th>Expt., main cultivar, and species (sowing rate kg/ha)</th>
<th>Clover/herb cultivar and species (sowing rate kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Caucasian clover (8)</td>
</tr>
<tr>
<td>2. Ryegrass cultivars +WC, sub (sown 30/01/2007)</td>
<td>'Revolution AR1' (10)</td>
</tr>
<tr>
<td></td>
<td>'Samson AR1' (10)</td>
</tr>
<tr>
<td></td>
<td>'Cannon LE' (10)</td>
</tr>
<tr>
<td></td>
<td>'Revolution AR1' (20)</td>
</tr>
<tr>
<td></td>
<td>'Revolution' (10)</td>
</tr>
<tr>
<td>3. Dryland grasses +WC, sub (sown 30/01/2007)</td>
<td>'Advance' tall fescue (20)</td>
</tr>
<tr>
<td></td>
<td>'Advance MaxP' tall fescue (20)</td>
</tr>
<tr>
<td></td>
<td>'Bareno' pasture brome (20)</td>
</tr>
<tr>
<td></td>
<td>Agriseeds 'Dg25' cocksfoot (2)</td>
</tr>
<tr>
<td></td>
<td>'Ella' cocksfoot (2)</td>
</tr>
<tr>
<td>4. Timothy-herbs/red clover mixtures +WC, sub (sown 30/01/2007)</td>
<td>'Kahu' timothy (2)</td>
</tr>
<tr>
<td></td>
<td>'Kahu' timothy (2)</td>
</tr>
<tr>
<td></td>
<td>'Kahu' timothy (2)</td>
</tr>
<tr>
<td></td>
<td>'Kahu' timothy (2)</td>
</tr>
<tr>
<td></td>
<td>'Kahu' timothy (2)</td>
</tr>
</tbody>
</table>

Table 2  
Soil test (0-75 mm) results before site preparation in March 2005 (Fasi et al. 2008) and 19 May 2008 from the three pasture-mixture experiments at Lees Valley, Canterbury. Cation MAF units are in brackets. Recommended levels are for sedimentary soils.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>2005</th>
<th>Ryegrass</th>
<th>Dryland</th>
<th>Timothy</th>
<th>Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (H2O)</td>
<td>5.5</td>
<td>6.0</td>
<td>5.7</td>
<td>5.9</td>
<td>5.8-6.0#</td>
</tr>
<tr>
<td>Olsen P (mg/L)</td>
<td>8</td>
<td>12</td>
<td>23</td>
<td>12</td>
<td>20#</td>
</tr>
<tr>
<td>K (me/100 g)</td>
<td>(8)</td>
<td>0.42 (8)</td>
<td>0.75 (14)</td>
<td>0.51 (10)</td>
<td>(5-8)#</td>
</tr>
<tr>
<td>Ca (me/100 g)</td>
<td>(2)</td>
<td>6.2 (7)</td>
<td>5.6 (6)</td>
<td>5.7 (6)</td>
<td></td>
</tr>
<tr>
<td>Mg (me/100 g)</td>
<td>(15)</td>
<td>0.41 (8)</td>
<td>0.47 (10)</td>
<td>0.42 (9)</td>
<td>(8-10)#</td>
</tr>
<tr>
<td>Sulphate-S (mg/kg)</td>
<td>3</td>
<td>22</td>
<td>32</td>
<td>30</td>
<td>10-12*</td>
</tr>
</tbody>
</table>


and September 2008 - ryegrass and dryland mixtures only). Because of difficulties with coordinating grazing times, there were times when grazing was delayed until stock were available so some herbage yield may not have been recorded. Superphosphate (P 9, S 11) was applied in October 2007 (750 kg/ha) and September 2008 (300 kg/ha). In February 2008, 100 kg/ha urea (46% N) was applied.

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 species (grass, clover, or herb), unsown herbage (e.g., broadleaf weeds and grass), and dead components. Samples were dried at 65 °C for 48 hours and weighed. In the ryegrass mixture, the ‘Revolution’ with cocksfoot treatment was analysed as total sown grass.

Establishment rates for the pasture species used seed sowing rates (Table 1) and standard TSW values to calculate seeds sown/m², which was divided by average seedlings established/m². Growth rates (kg DM/ha/d) were calculated for the pasture species between consecutive harvests but were not statistically analysed.

Soil fertility
Initial soil analysis results in 2005 indicated that pH, Olsen P, and sulphate-S were low (Table 2) and these were used to formulate the application of lime, and superphosphate and diammonium phosphate (DAP; N 17.6, P 20) fertilisers during site preparation (Olykan et al. (2023)). In May 2008, 20 soil cores (depth 0-75 mm) were bulked for each pasture-mixture experiment and analysed by Hill Laboratories Ltd. Across the three pasture mixture experiments the soil pH was ~5.9, Olsen P had increased to 12 mg/L in the ryegrass and timothy experiments and 23 in the dryland experiments (Table 2) and sulphate-S levels increased to 22 to 32 mg/kg.
The Lees Valley climate during the experimental period is detailed in Olykan et al. (2023). In the dry season of 2006-2007, the combination of higher effective rainfall and lower potential evapotranspiration (PET) resulted in a below average soil moisture deficit of -110 mm (Table 3) when the experiments were sown. In the following two growth seasons, the dry season moisture deficits exceeded the long-term mean (LTM) (Table 3).

Data analysis
Genstat statistical software (20th edition; VSN International Ltd.) was used for all statistical analyses. In Experiment 1, the Caucasian-herb mixture annual accumulated total and component dry matter yields and proportions in Years 1 or 2 were analysed by one-way ANOVA (Cc treatment) with randomised blocks (reps). Accumulated yields in Years 1 and 2 were compared using a two-way ANOVA (Year*Cc treatment) with randomised blocks (reps).

Within each grass-clover-herb pasture mixture experiment, total and component dry matter yields were analysed by one-way ANOVA with randomised blocks (reps) used to compare treatments with the following orthogonal contrasts a) ryegrass mixtures: sowing rate (10 vs. 20 kg/ha), cocksfoot (+ or -), or ‘Revolution’ vs others (‘Samson’ and ‘Cannon’), b) dryland mixtures: tall fescue vs. others, cocksfoot vs. others, or brome vs. others, and c) timothy mixtures: chicory (+ or -), plantain (+ or -), red clover (+ or -), or timothy (alone vs. rest).

When significant, means were separated by Tukey’s HSD test at the α=0.05 level or, if only two means, by LSD at 5%.

Results
Seedling populations
Experiment 1: Caucasian clover- herbs
In the Caucasian-herb plots, herb populations on 6 September 2006 were 31±5 chicory and 47±9 plantain seedlings/m². The groundcover of the herbs was 4.5 and 6.3%, respectively. On 15 November 2006, the average Caucasian population was 200 ± 26 seedlings/m² (55% establishment of seed sown) and was unaffected by the presence of herbs. In the monoculture plots the Caucasian seedling population declined (P=0.012) from 217 to 125 seedlings/m² between 15 November 2006 and 16 January 2007.

Experiments 2 to 4: Grass-clover-herb mixtures
On 28 February 2007, four weeks after sowing the grass-clover-herb pasture mixtures, there was an average 143 to 217 white clover and 50 to 57 sub clover seedlings/m². On average 89% of white clover and 85% of sub clover seed that was sown established. Grasses that established by this date were the ryegrass cultivars, and brome in the dryland mixture, both with 300+ seedlings/m² (Table 4), and cocksfoot in the ryegrass mixture (44 seedlings/m²). There were 161 tall fescue seedlings/m² in the dryland mixtures on 21 March. Those grasses with greater than 75% establishment of the seed sown were ryegrass cultivars and brome.

In the timothy mixtures there were <50 seedlings/m² of plantain (96% establishment), chicory (43%), or red clover (14%) on 21 March and an average of 62 timothy seedlings/m² on 4 April (12%, Table 4).

Experiment 1: Caucasian-herb pasture mixtures
Caucasian clover yields were higher when grown as a monoculture. When grown with plantain, total pasture yield was unaffected, but the Caucasian clover component was reduced.

Total yields in Year 1 (P=0.039) and 2 (P=0.077) were affected by the Caucasian-herb treatments. In Year 1, the total yield of 3190 kg DM/ha in Cc+Plan was 56% higher than Cc+Chic (2040 kg DM/ha) and...
Table 4  Average seedling populations (± SEM) of white and sub clovers, grasses and herbs sown on 30 January 2007 in the Lees Valley pasture mixture Experiments 2 to 4. Date indicates when first seedling count could occur for a grass/herb species.

<table>
<thead>
<tr>
<th>Date:</th>
<th>28 Feb Clovers</th>
<th>28 Feb Grasses or herbs (seedlings/m²)</th>
<th>21 Mar</th>
<th>4 Apr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ryegrass</td>
<td>White 217±40</td>
<td>Ryegrass 382±21</td>
<td>Cocksfoot 44±14</td>
<td></td>
</tr>
<tr>
<td>Sub</td>
<td>57±11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dryland</td>
<td>White 170±33</td>
<td>Brome 364±48</td>
<td>Tall fescue 161±25</td>
<td></td>
</tr>
<tr>
<td>Sub</td>
<td>50±7</td>
<td></td>
<td>Cocksfoot 58±10</td>
<td></td>
</tr>
<tr>
<td>Timothy</td>
<td>White 143±34</td>
<td>Red clover 27±3</td>
<td>Timothy 62±5</td>
<td></td>
</tr>
<tr>
<td>Sub</td>
<td>55±17</td>
<td>Plantain 36±5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chicory 48±8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

in Year 2 was 36% higher (3330 kg vs. 2440 kg DM/ha) (Figure 1).

Across the three Caucasian treatments, there was an increase (P<0.10) in Caucasian clover yield from Year 1 (870 kg DM/ha) to Year 2 (1200 kg DM/ha) and the % Caucasian of total DM increased (P<0.05) from 31 to 44%. Caucasian clover yield in Year 1 was reduced (P<0.05) by the presence of chicory or plantain from 1800 kg DM/ha in the monoculture to ~400 kg DM/ha (Figure 1). In Year 2, the Cc+plan mixture had a lower (P<0.05) Caucasian clover yield than the Caucasian monoculture: 810 vs. 1750 kg DM/ha (Figure 1).

The decline (P<0.05) in total herbs, in Years 1 to 2, from 910 to 600 kg DM/ha, respectively, was due to the reduction (P<0.10) in chicory yield from 780 to 250 kg DM/ha. In Year 1 the plantain yield of 1950 kg DM/ha was more than twice the chicory yield and in Year 2 was five times greater at 1540 DM/ha (Figure 1).

In spring of Year 4 (10/11/2010), the Cc-treatments affected the groundcover of Caucasian clover (P<0.001), herbs (P<0.001), and unsown components (P=0.094). The 69% Caucasian in the monocultures was higher (P<0.05) than found in Cc+Chic (62%), which in turn was higher than Cc+Plan (50%). In the Cc-herbs, there was more (P<0.05) plantain than chicory (13 vs. 2%). Bare ground was ~14% across the Cc-treatments. On average, the 16% unsown species comprised of 6% other clovers, 3% grass and 7% broadleaf weeds.
Figure 2  Accumulated yield and botanical composition of ryegrass (Rye), dryland grasses (Dry) and timothy (Tim) pasture mixtures in Years 1 (2007-08, two harvests) and 2 (2008-09, 4 harvests) at Lees Valley, North Canterbury. All pasture mixtures included basal white and sub clovers. In the timothy mixtures, Herbs/RC was an average of herbs (plantain and chicory) or red clover (RC) components.

Figure 3  Accumulated yield and botanical composition of dryland grasses or timothy pasture mixtures in Year 2 (2008-09) at Lees Valley, North Canterbury. All pasture mixtures included white clover, but sown sub clover was no longer present.
Experiments 2 to 4: Grass-clover-herb pasture mixture yields and botanical composition

Total DM yields, and sown grass and white clover yields differed among the pasture mixture experiments and was affected by grass treatments within the experiments.

Total yield

Across the grass-pasture mixtures, total yield was affected by pasture mixture in Years 1 (P=0.021) and 2 (P<0.001). In Year 1 the ryegrass mixtures yield of 4550 kg DM/ha was higher (P<0.05) than the timothy mixtures (3440 kg DM/ha) (Figure 2). Total yield in Year 2 was ~60% higher (P<0.05) in the ryegrass and dryland mixtures (~4400 kg DM/ha) than timothy mixtures (2650 kg DM/ha) (Figure 2). Average total DM across the two years was not different (~3970 kg DM/ha).

Average dead material in the total yields was 640 kg (16%) in Year 1 and 960 kg (25%) in Year 2. The average amount of unsown herbage (species not recorded) was ~20 kg DM/ha in Year 1 and ~50 kg DM/ha in Year 2.

Within the ryegrass mixture experiments, cultivar did not affect total yield in Year 1 or 2. In Year 2, the dryland grass treatment effect (P<0.001) on total yield was predominantly due to the contrast (P<0.001) between tall fescue (2680 kg DM/ha) and cocksfoot and brome (5720 kg DM/ha, Figure 3). In the timothy mixture treatments, the presence of plantain (P=0.002) increased total yield to 3315 kg DM/ha compared with 2060 kg in the timothy monoculture (Figure 3).

Sown pasture grass

Year affected (P<0.001) the sown grass content across the pasture mixtures and increased (P<0.05) from 1120 kg DM/ha in Year 1 to 1610 kg in Year 2.

In the ryegrass mixtures, the cultivar did not affect the sown ryegrass yield in Year 1 or 2, which was 42 and 57% of the total DM, respectively. In the dryland pasture mixtures, the sown grass yield was affected by an interaction (P<0.001) between grass treatment and year. Specifically, from Year 1 to Year 2, average tall fescue yields declined from 970 to 800 kg DM/ha, while the average for brome and cocksfoot increased from 1350 to 2830 kg DM/ha.

Timothy production was low, averaging 260 and 380 kg DM/ha in Years 1 and 2, with the total pasture yield dominated by white clover in Year 1 and white clover and/or herbs in Year 2 (Figure 2).

Clover in the grass mixtures

In Year 1, the average white clover yield of 1800 kg DM/ha was unaffected (P=0.43) by the pasture mixture and represented 43% of the total DM compared with 8% sub clover (340 kg DM/ha), which was only present in the first harvest (20 November 2007). In Year 2 the white clover yield declined (P<0.01) across the mixtures and was 930 kg DM/ha or 29% of total DM. Sub clover was not present.

In Years 1 and 2, white clover yield was unaffected by the treatments within the three grass-based pasture mixtures but there were several contrasts of interest in Year 2. In the dryland mixtures there was more (P=0.068) white clover in tall fescue treatments (1340 kg DM/ha) than the cocksfoot and brome (870 kg DM/ha, Figure 3A). In the timothy mixtures in Year 2, white clover yield was higher (P<0.05) in the timothy-only treatment than timothy+Ch+Pl (1350 vs. 660 kg DM/ha) (Figure 3B) and the presence of plantain reduced (P=0.014) white clover yield compared with the other treatments (710 vs. 1110 kg DM/ha).

Seasonality of pasture species growth rates

The focus of seasonal growth rates was on those grass, clover, and herb species that were productive and persistent in the pasture mixtures.

In Year 1, white clover growth rates peaked on 20 November at 15 kg DM/ha/d and were 5 kg DM/ha/d on 10 April (Figure 4). Ryegrass and plantain growth rates plateaued through the January to May period. Cocksfoot and brome growth rates were 3 and 6 kg DM/ha/d, respectively, in November and increased to 12 kg DM/ha/d in April.

In Year 2, brome, cocksfoot, and plantain (+Cc) had winter growth rates of 4 to 6 kg DM/ha/d (Figure 4). Growth rates peaked for ryegrass (21 kg DM/ha/d), white clover (17), and brome (18) in October and then declined to ~6 kg DM/ha/d for the two grasses and 2 kg DM/ha/d for white clover by January. Cocksfoot growth rates were 11 to 12 kg DM/ha/d from October to April (Figure 4). Plantain (Tim) growth rates increased from 3 to 9 kg DM/ha/d from October to April.

Of note, Caucasian clover growth rates, when in a mixture with herbs, were comparatively low in Years 1 and 2. The highest growth rate was in January of Year 2 (5 kg DM/ha/d; Figure 4).

Discussion

Establishment

In the four pasture mixture experiments at Lees Valley, some of the sown pasture species had seedling establishment rates of >75% (e.g., ryegrass cultivars, brome, white and sub clovers, and plantain). This successful establishment was due to several factors including extensive site preparation, and the high sowing rates. Importantly, prior to sowing, a chemical fallow was used. This was successful due to the effective rainfall from November to December 2006 which was higher than normal (302 vs. 235 mm, Table 3) and led to successful emergence. Across the pasture
mixtures, white clover established 177 seedlings/m² and was the dominant pasture plant in Year 1. The ryegrass cultivars and pasture brome established >300 seedlings/m² during February (Table 4) and were among the most productive treatments. The early establishment of a range of sown pasture species could provide a competitive advantage against unsown weed species (Tozer et al. 2011b). By mid-autumn 2007, there were 500 to 1000 established sown pasture seedlings/m² across the three grass pasture mixture experiments suggesting that sown species dominated the plots. This was confirmed by the low yield of unsown species that amounted to ~1% of total DM in Years 1 and 2 (Figure 2).

‘Leura’ sub clover had an establishment rate of 85%, however the number of seeds sown was half the recommended rate of 10 kg bare seed/ha and seedling numbers were ~54/m². Tall fescue, timothy, and red clover had seedling establishment rates <30% of seed sown and were not productive components of the pasture mixtures. Sharifiamina et al. (2016) found that ‘Finesse Q’ tall fescue seed germination rapidly declined under moisture stress levels beyond -0.37 MPa, which are typical of dry soils. While the cocksfoot seedlings emerged later and at lower numbers, it was a productive grass in the Lees Valley dryland pasture mixtures (Figure 3) because of its aggressive growth habit and resilience in dryland conditions (Mills et al. 2006).

The initial establishment of ~200 Caucasian seedlings/m² in mid-November, two weeks after sowing, declined to 125 seedlings/m² in Cc-Mono two months later. A lack of soil moisture over the 2006-07 summer dry period was the likely cause (Figure 1 in Olykan et al. (2023). Caucasian clover is slow to establish, and the seedlings are poor competitors with other vegetation (Black et al. 2002) until the plants develop their rhizomatous root system (Black and Lucas 2000), which is why initial establishment as a monoculture is recommended.

**Pasture production**

The focus of the following discussion will be on ryegrass cultivars, dryland brome and cocksfoot, and Caucasian pasture mixtures as these were the most productive.

In the Lees Valley pasture experiments, total yield was ~4.5 t DM/ha/yr in the ryegrass and dryland mixtures in Years 1 and 2. This was more than the highest clover monoculture total yield of 4.1 t DM/ha (red clover in Year 3) (Olykan et al. 2023) but less than
the 5.7 t DM/ha reported by Fasi et al. (2008) for Year 1 ryegrass or cocksfoot monocultures.

Grasses

The ryegrass and dryland pasture mixtures were the most productive and contained 30-40% sown grass in Year 1, which increased to 45-55% in Year 2. The increased grass growth in Year 2 may have been a response to clover-fixed N coming into the pasture systems. Fasi et al. (2008) highlighted the responsiveness of grass monocultures at Lees Valley to N applied in mid-August with the DM responses being highest for the ryegrass and cocksfoot monocultures (~20 kg DM/kg N). Legumes can fix ~30 kg N/t of DM yield (Lucas et al. 2010). Therefore, based on the Year 1 total clover yield of ~2 t DM/ha, ~60 kg N/ha may have been fixed. In Year 2 the average increase in the sown grass yield of the ryegrass mixtures was 530 kg DM/ha. Within the dryland mixtures, the sown grass yields of ‘Bareno’ brome and the cocksfoot cultivars ‘Dg25’ and ‘Ella’ increased 1480 kg DM/ha, which indicated that these grasses may be more suited to the Lees Valley environment once established. The grass mean daily growth rate data (Figure 4) reinforce what was known about these species when grown in summer-dry environments (e.g., Stewart et al. 2022) – that ryegrass was most productive in spring and growth rates declined during summer-dry periods, while cocksfoot growth rates were lower in spring but increased and were maintained during the summer. Brome growth rates at Lees Valley were similar to ryegrass. While ryegrass pasture mixtures were comparatively productive at Lees Valley, they are not expected to persist beyond three years (Mills et al. 2014; Lee et al. 2017; Taylor et al. 2021).

Clovers

Clove was the dominant species in the Year 1 grass-pasture mixtures, with some clover growth occurring late winter (sub clover) but mostly in spring (white clover). The Year 1 ryegrass and dryland mixtures contained ~40% clover, mostly white clover, and in Year 2 this declined to ~24% from white clover only. White clover growth rates were consistent in both springs, but the growth period was shortened in Year 2 as the date when soil moisture decreased below 50% profile available water, (i.e., the start of the summer dry), occurred on 25 September 2008 compared with 30 October 2007 (Olykan et al. 2023). It is likely that low soil moisture, increased grass competition and the failure of ‘Leura’ sub clover to re-establish contributed to the lower clover yield in the Year 2 spring. The low persistence and productivity of annual clovers at Lees Valley, including ‘Leura’ sub clover’, was discussed by Olykan et al. (2023).

White clover is not a preferred clover species for dryland pastures because its spring growth starts later than sub clover (Evans and Mills 2008; Olykan et al. 2021). In these experiments, white clover declined over the two years, probably due to the loss of its tap root (Brock and Hay 2001) and interspecific competition from associated grasses and herbs. Olykan et al. (2023) reported that ‘Demand’ white clover monocultures were productive for four years at Lees Valley but by Year 5 occupied ~48% of the plot area, with unsown species and bare ground starting to dominate. In the same experiment, the ‘Pawera’ red clover monoculture produced >2.5 t DM/ha/yr in Years 2 and 3. However, in the timothy + red clover pasture mixture reported here, the Year 2 red clover yield was 160 kg DM/ha (Figure 3) after producing 600 kg DM/ha in Year 1.

Perennial clovers, particularly Caucasian clover, have shown higher yields and greater persistence at this site. However, in the Year 1 Caucasian-herb pasture mixtures with plantain resulted in lower Caucasian clover yields (Figure 1). In Year 2, Caucasian clover yields and growth rates (Figure 4) increased in the Cc+herb treatments. With time, and the decline of the herbs, as indicated by the groundcover scores in Year 4, Caucasian clover is expected to persist and become the dominant pasture species (Scott 1998; Black et al. 2014). Results from legume monocultures in the Lees Valley indicated that Caucasian clover production increased over time, while white clover declined (Olykan et al. 2023).

Herbs

At Lees Valley, plantain was a productive component of pasture mixtures. In contrast, chicory was not, with yields of less than 250 kg DM/ha by Year 2. Plantain made a significant contribution to total DM yields in the Caucasian mixtures (Year 1 = 1950 kg DM/ha, Year 2 = 1540 kg, Figure 1) and timothy mixtures (Year 1 = 850 kg DM/ha, Year 2 = 1700 kg, Figure 3). Plantain growth rates were maintained during the summer period (Figure 4). At Lees Valley, plantain was not grown in mixtures with the more competitive ryegrass and dryland grasses. Stewart (1996) found that plantain in sward mixtures with persistent grasses contributed 5 to 15% after three years.

Best pasture options

The results from these experiments suggest that cocksfoot-white clover was the most productive grass-legume mixture to maximise clover content and pasture dry matter yield in the first two years. Cocksfoot is a preferred dryland grass species however, its ability to thrive in the long-term and provide palatable feed requires the provision of N (Edwards et al. 1993; Mills et al. 2014). As white clover is unlikely to persist in Lees
Valley in the medium-term, an alternative companion legume needs to be considered.

Caucasian clover persisted in this environment as a monoculture, and the Caucasian-plantain mix, with a low plantain seed rate, looked promising as the Caucasian will spread once established. Ideally, the Caucasian clover would be sown in October and the plantain overdrilled ~17 months later in March.

In the Lees Valley and similar environments, a cocksfoot-Caucasian clover pasture may warrant further investigation as it has been shown to be a productive and persistent pasture mixture (Black and Lucas 2000).

Acknowledgements
The authors thank Vonnly Fasi, Dr Saman Berenji, Dr Keith Pollock, Don Heffer, Kim Barnes, Dave Jack, Dan Dash and numerous interns, students, and visitors 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).

REFERENCES


