

# Subterranean clover growth responded to grass suppression, phosphorus and molybdenum fertilisers in a summer dry hill environment

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## Abstract

Pastures on the north-facing slopes of the Port Hills, Canterbury, are summer-dry, grass dominant, with soils low in phosphorus and sulphur. The aim of this experiment was to assess the effect of P, S and Mo fertiliser and grass-suppressing herbicide on the establishment and growth of oversown subterranean (sub) clover. Fertiliser treatments were first applied in 2021, with P and S reapplied in 2023, and herbicide applied in 2022 and 2023. Pasture yields were measured from 2021 to 2023. Total pasture yield in 2021 was not affected by fertiliser treatment and averaged 3650±83 kg DM/ha with 770±43 kg of sub clover. In 2022, pasture yield increased from 2900 to 3270 kg DM/ha with P. The sub clover yield doubled from 310 to 645 kg DM/ha when herbicide reduced the grass from 1650 to 1410 kg DM/ha. However, in 2023, the total accumulated pasture yield (10180±160 kg DM/ha) was not affected by herbicide but sub clover content increased from 10 to 25% as grasses were reduced from 63 to 47%, with ~4% white clover. Where herbicide was applied without fertiliser (+H), total clover yield increased from 1460 to 2930 kg DM/ha. The application of P and Mo increased it further to 4010 kg DM/ha. There was no yield response to +S or +Mo unless added with P. Applying herbicide or phosphorus increased total metabolisable energy from 38.5 to 42.6 GJ ME/ha and crude protein from 500 to 595 kg/ha in pastures sampled in November 2023. The highest feed quality values were from treatments that had herbicide suppression of the grass and additional P and Mo fertilisers. These results suggest a pasture sub clover content of 25% on the Port Hills can be achieved using grass suppression followed by P fertiliser, if indicated by soil tests, along with molybdenum.

**Keywords:** dryland, herbicide, sub clover, sulphur, *Trifolium subterraneum* L.

## Introduction

On New Zealand's dryland hill country, subterranean (sub) clover (*Trifolium subterraneum* L.) was oversown in the 1930s to 1960s to increase the legume content of

grass dominant pastures where white clover (*T. repens* L.) failed to thrive (Smetham 2003). The winter annual lifecycle of sub clover means it is well suited to north-facing hill slopes that dry out for 2-4 months in the summer.

In clover-grass pastures Cosgrove et al. (2002) found that sheep and cattle prefer clover, as when given choice they spent 75% of their time grazing on clover and 25% on grass. Mills et al. (2014) demonstrated that best management practices on dryland grass-clover pastures can produce annual clover dry matter (DM) of ~40% of total sward yield. Clover content during spring has a major influence on sheep live weight production (Brown et al. 2006). Compared with other legumes, sub clover produces high quality feed in the early spring (Brown et al. 2006; Mills et al. 2008) and the ~30 kg of nitrogen (N) it fixes per tonne of DM (Lucas et al. 2010) may improve both the grazing preference of associated grasses (Edwards et al. 1993), pasture productivity and water-use efficiency (Tonmukaykul et al. 2009).

Maximising the legume content of mixed species pastures in summer dry hill country has challenges including the variable seasonal rainfall, low soil fertility, strong competition for resources (i.e., soil nutrients and water, and sunlight) from the grass component, and preferential grazing of the legume, particularly in set stocked situations. The soils of New Zealand's hill and high country tend to be acidic (Moir & Moot 2014) with low plant available phosphorus (P) and sulphur (S) (Morton et al. 2021). Molybdenum (Mo) is also deficient in many soils (Sherrell & Metherell 1986). The management of legume nutrition in hill country pastures focuses on maintaining a pH above 5.4 through adding lime (Moir et al. 2016), an Olsen P of 12 mg/L and sulphate-S of 6 to 8 mg/kg (Morton & Roberts 2016). Pasture Mo status is currently assessed by testing clover foliage with the aim of maintaining foliar Mo concentrations above 0.1 mg/kg (Sherrell & Metherell 1986).

For a given yield, sub clover has a higher P requirement than cocksfoot (*Dactylis glomerata* L.) (Haling et al. 2016) with which it is frequently recommended to be sown (Mills et al. 2014). In New Zealand the effect of

P fertiliser on white clover in mixed-species swards has been investigated (e.g., Morton et al. 2021), but has not for sub clover.

In a legume-grass pasture, competing grasses can be controlled by grazing and/or herbicide suppression to maximise the legume content and persistence. For example, in the summer dry Wairarapa hill country (annual rainfall 810 mm) reducing grass competition by grazing at key times in the sub clover lifecycle increased sub clover ground cover to 60% after two seasons (Olykan et al. 2019). At Tempello farm in Marlborough (annual rainfall ~500 mm), a range of management strategies (e.g. grazing, paddock subdivision, fertiliser applications) have been used to increase spring pasture sub clover content to 50%. This contributed to increased pre-weaning lamb growth rates from 258 to 350 g/head/day (Grigg et al. 2008).

Herbicide suppression of grass to encourage clovers has also been used. At Waipawa (Hawkes Bay, annual rainfall 850 mm, Olsen P 18), Hepp et al. (2003) applied late autumn herbicide to suppress grasses, such as browntop (*Agrostis capillaris* L.), which increased ( $P < 0.01$ ) legume content from 23 to 51%, about half of which was sub clover.

Jackman and Mouat (1970) investigated the effect of 15 rates of superphosphate (0 to 897 kg/ha) applied in spring on white clover yield when grown alone or with browntop on a P deficient soil (Olsen P of 2 to 8 mg/L) in Manawatu. They found that an additional 580 kg/ha superphosphate was needed to grow 800 kg white clover DM/ha when grown with browntop than when grown alone. Browntop did not respond to increasing superphosphate rates with yields <200 kg DM/ha. In discussing this research, Scott (1973) noted the competitiveness of grass and its 'depressive effect' on clover growth, and therefore N fixation. The P demand of the grasses needed to be fulfilled first and thus competition for P was an important inefficiency in the grass/clover association, which depends solely on N fixed by clovers.

The aim of this research was to increase the total yield and sub clover content in summer dry pastures, through use of P, S and Mo fertilisers, and herbicide suppression of the grass. Treatments were applied strategically over a three-year period based on expected growth responses in relation to seasonal rainfall.

## Materials and methods

### Location and site details

The experiment was located on the Port Hills to the south of Christchurch (GPS -43.6252, 172.5836). The site was 35.5 m wide (across slope) and 19 m long on a northwest facing slope (~10°) at an elevation of ~200 m a.s.l. The existing pasture was dominated by grasses, mainly browntop, as well as sweet vernal

(*Anthoxanthum odoratum* L.) and clumps of cocksfoot. There were low populations of resident white and sub clovers. Other species identified were suckling clover (*T. dubium* Sibth.), small gorse (*Ulex europaeus* L.) bushes, plantain (*Plantago lanceolata* L.), yarrow (*Achillea millefolium* L.), and vulpia hair grass (*Festuca bromoides* L.). Historically, the pasture has received minimal fertiliser inputs.

### Soil characteristics

The soils are predominantly a Timaru stoneless silt (mottled fragic pallic), developed from hard sandstone rock loess parent material, characterised as moderately deep (50-70 cm) and imperfectly drained, with high profile available water (93 mm in 0-60 cm depth) and low P retention (21%) (Manaaki Whenua 2021).

A bulk soil sample of 20 random cores (0-75 mm) from across the experimental area was taken on 14 October 2020, analysed by Hill Laboratories, and showed the site was low in phosphorus (Olsen P 8 mg/L), sulphate-sulphur (S) and organic-sulphur (Table 1).

An analysis of bulk resident sub clover lamina samples taken at the same time confirmed the low soil P and S status of the site with foliar P at 0.13% and S at 0.17%, i.e. below the marginal deficiency values of 0.30% and 0.18% reported for sub clover (lamina+petiole), and molybdenum (Mo) concentrations were marginally deficient at 0.10 mg/kg (Reuter & Robinson 1997). Therefore, P, S and Mo fertiliser treatments were included in the experimental design.

### Site preparation and basal treatments

The experiment was established in autumn 2021, after below average rainfall (42% of long-term mean) in January and February (Figure 1). On 31 March 2021, rotary lawn mowers were used to remove the mature grass from the site and leave ~30 mm residual herbage. Small gorse bushes were grubbed out. The perimeter was fenced with a solar powered two wire electric fence to exclude cattle. The area, approximately 0.0675 ha, was oversown with a 50:50 mix by weight, of 'Woogenellup' and 'Denmark' sub clover seed at the rate of 120 kg seed/ha using a hand spreader on 14 April 2021. A high rate was used to represent an established sub clover seed bank, which can contain from <100 kg (Smetham et al. 1994) to >1000 kg seed/ha (Teixeira et al. 2018). The standard sowing rate is 10 kg/ha.

Plots for fertiliser treatments were pegged out on 6 May 2021. These were 1.5 x 5 m with 0.5 m gaps between plots and a 1 m gap between replicates.

### Experimental details and general methods

The experimental design was a 2<sup>4</sup> factorial, with 0 or 60 kg P/ha (-P or +P) x 0 or 50 kg S/ha (-S or +S) x 0 or 0.06 kg Mo/ha (-Mo or +Mo) x minus or plus herbicide (-H or +H). The 16 treatments were allocated randomly within each of three replicates.

The aim of the P fertiliser application rate was to raise soil Olsen P levels from 8 to 20 mg/L (Morton & Roberts 2016). Sulphur was applied at 50 kg S/ha because of the initial low soil levels (Table 1). Recommended initial rates of Mo application are 0.05 to 0.10 kg/ha (Morton 2019). The herbicide treatment was used to suppress grass growth because regular controlled grazing as a treatment was not an option at this site.

## Measurements and management

### Year 1 – 2021

Emerged sub clover seedlings, two-cotyledon to spade leaf stage, were observed on 6 May 2021. Germination was probably triggered by rainfall events of 14 mm and 15 mm on 16<sup>th</sup> and 24<sup>th</sup> April, respectively. On 11 May the P (triple super, P 19, S 1) and S (gypsum granules, S 16) fertiliser treatments were applied to each plot by hand after mixing in a container with 300 ml of river sand. On 20 May the Mo treatment was applied as a dilute sodium molybdate ( $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$ , Unilab) solution in ~4 L water using a watering can.

No herbicide application was needed to suppress grass growth in 2021 prior to winter because of the dry autumn (Figure 1). On 25 June, sub clover populations were assessed based on Teixeira et al. (2017) scoring, adapted for the low density pasture population. The sub clover populations were scored in three 0.1 m<sup>2</sup> quadrats along the middle of each plot using: 0 = no seedlings, 1 = 1 to 10 (average is 5.5), 2 = 11 to 50 (30.5), 3 = 51 to 100 (75.5), 4 = 101 to 150 (125.5), and 5 > 150 seedlings/quadrat. The polynomial (order 2) equation  $y=77.86^2 - 9.57 - 12.29$  ( $R^2 = 0.998$ ) was used to convert scores to seedling numbers. Seedling growth stage ranged from cotyledon to three-trifoliate leaves, indicating that several germination events had occurred since early May.

On 19 October, a harvest of herbage was taken from each plot (see details below). On 1 November the site was mown to 50 mm stubble height and the clippings removed (i.e., cut and carry). The mowing was used to simulate a ‘best practice’ grazing for sub clover. On 9 December, there was a second harvest of herbage. However, a dry spring (Figure 1), meant there was insufficient herbage to justify the logistics of mowing the site afterwards as it was drying off. Total yield represented the 253 days from 31 March, when site was first mown, to 9 December 2021.

### Year 2 - 2022

On 17 February, sub clover seedlings were observed with growth stages ranging from cotyledon to a multi-trifoliate stage suggesting germinations had started pre-February. Younger seedlings were probably the result of three >20 mm rainfall events in early February (i.e., 22 mm on 5, 29 mm 9, and 37 mm on 12 February).

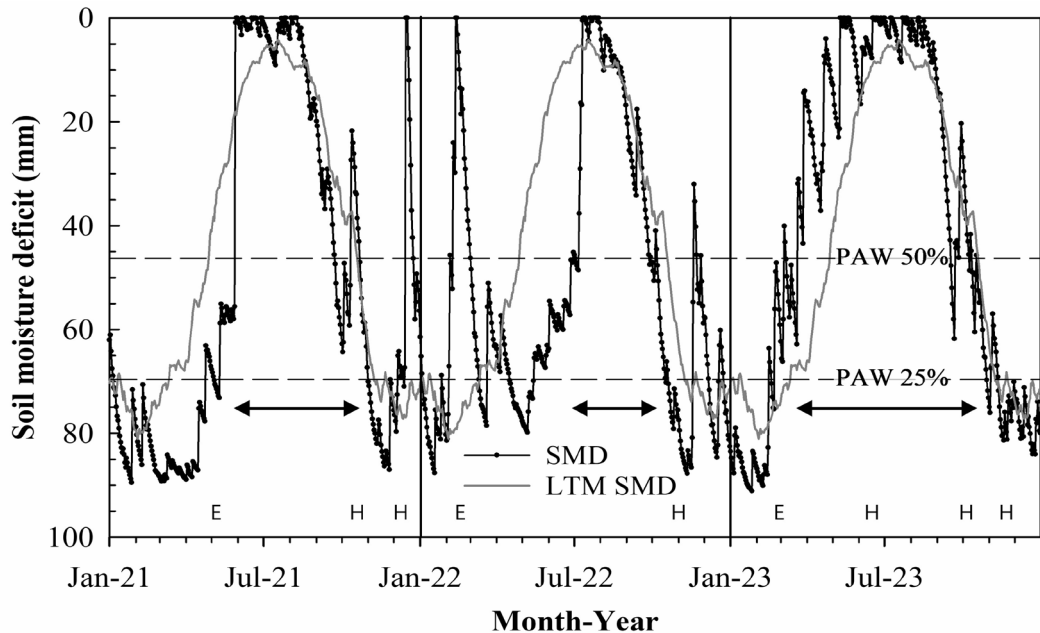
Because of the range of seedling ages, counting at this stage was difficult and not attempted. Because of the wet summer (312 mm rainfall from December to February), the grasses had not dried off so on 21 February the site was mown (50 mm height, cut and carry) to reduce grass competition. Following this on 15 March the grass suppressing herbicide Centurion® Xtra (a.i. 360 g clethodim/L) was applied at 330 ml / ha + oil using a knapsack sprayer (two overlapping passes per plot) to the plus herbicide (+H) plots, at half the rate of herbicide recommended for annual grass control (UPL New Zealand Limited 2022). The autumn rainfall was low (71 mm from March to May), less than the long-term mean (LTM) of 185 mm, meaning there was insufficient growth to warrant a late autumn yield assessment. An electric netting fence was put up on 16 September 2022 to exclude sheep that had been intermittently grazing the site during the winter. At the time, the sub and white clover were 2 to 5 cm in height, but not grazed out and there was little evidence of any recent grazing. On 1 November the herbage was harvested. The site was not mown to facilitate sub clover seed set.

### Year 3 – 2023

The electric fence was removed on 18 January to allow the stock (sheep and cattle) to graze the site. On 27 February sub clover seedlings were observed at cotyledon stage (rainfall of 20 mm on 15 February and 34 mm from 21 to 24 February). There was evidence of grazing, but dead standing grass was also present. The area was mown on a high setting of 100 mm on 2 March to remove the grass (cut and carry) but leave the clover seedlings. The electric netting fence was reinstated on 14 March. The autumn rainfall and low soil moisture deficit (Figure 1) encouraged grass growth, so the herbicide was reapplied on the 24 March, and P and S fertiliser were reapplied on 2 May at the same rates to their respective treatment plots. A harvest cut was taken on 16 June after which the site was mown (50 mm height, cut and carry). On 5 October there was a harvest cut and the site mown (50 mm, cut and carry). A final harvest was taken on 21 November. Total yield represented the 263 days from 21 March to 20 November 2023.

### Herbage harvest methods

Herbage biomass was cut using motorised shears to a stubble height of ~20 mm from one 0.2 m<sup>2</sup> quadrat/plot from a representative area along the centre line of the plot, except for the first harvest on 19 October 2021 when sampling aimed to include sub clover because plant populations were uneven in this first year. The samples were separated into sub clover, volunteer white clover, grasses, broadleaf weeds, and dead components. Samples were dried at 65°C for 48 hours and weighed.



**Figure 1** Calculated daily soil moisture deficit (SMD) from January 2021 to December 2023 using rainfall and PET data from NIWA VCS 19552 (NIWA 2024) and 93 mm of profile available water (PAW) (Manaaki Whenua 2021). Port Hills, Canterbury. E = sub clover establishment first observed, H = harvest date. ↔ = estimated length of sub clover growing season when PAW >50%.

It was assumed that the distribution of volunteer white clover was even across the site and therefore had also responded to the treatments.

#### NIR analysis

Metabolisable energy (ME), crude protein, and digestibility (organic matter that can be digested) were determined on a representative sub-sample of the bulk pasture, from the 21 November 2023 plot harvest, using near-infrared (NIR) spectroscopy (FOSS NIRSystems 5000).

#### Soil chemistry

On 3 November 2022, 18 months after the initial fertiliser application, five 0-75 mm cores/plot were taken from the control, S alone, P alone, and P+S plots, where no herbicide had been applied (from three replicates) and bulked by treatment. On 3 November 2023, six months after the reapplication of P and S fertiliser treatments, soil samples were taken from the same four treatments, as noted above. Samples were analysed by Hill Laboratories.

#### Climate

Climate data were accessed from NIWA Virtual Climate Station (VCS) agent number 19952 located at -43.635 172.575 (NZGD1949 positioning system) (NIWA 2024) approximately 700 m west of the experimental site at an elevation of 26 m. The 30-year LTM (1990-2019) temperature was 12.1°C, and annual rainfall and potential evapotranspiration (PET) were 687 and 934

mm, respectively. LTM annual drainage/runoff was calculated as 182 mm, with 75% occurring during the winter when LTM monthly rainfalls were ~72 mm and PET was ~26 mm, resulting in a LTM effective annual rainfall of 506 mm. In summer the LTM monthly rainfalls averaged 46 mm and PET 136 mm. Based on the calculated LTM soil moisture deficit (SMD), using daily rainfall and PET data (NIWA 2024) and profile available water (PAW) of 93 mm (Manaaki Whenua 2021), the Port Hills site was typically 'summer dry' with minimal growth expected (i.e., PAW <50%) from 20 October to 27 April (Figure 1).

For sub clover, the climate details of interest were rainfall events from February to May that would facilitate germination and subsequent autumn/winter/spring rainfall that would enable seedlings to survive and grow. In 2021, sub clover emergence started in late April and PAW was >50% from 29 May until 21 October, giving a 'growing season' of 145 days (Figure 1). After this, PAW was <50%. In 2022, the autumn March to May rainfall was 71 mm, 38% of the LTM, and SMD was <50% PAW from 2 March to 29 June. This was followed by 99 days with >50% PAW up to 6 October. In 2023, the autumn rainfall was 241 mm and PAW was >50% from 21 March to 17 October, a growing season of 210 days.

**Table 1** Soil nutrient test results in October 2020 (pre-fertiliser addition) and for treatments in November 2022 and 2023, on the Port Hills, Canterbury. MAF Quick Test units for cations in brackets. SO<sub>4</sub>-S = sulphate-sulphur, Org-S = organic-sulphur.

Date/treatment	pH	Olsen P (mg/L)	K	Ca (me/100 g)	Mg	SO <sub>4</sub> -S (mg/kg)	Org-S
<b>October 2020</b>	5.7	8	0.74 (11)	5.7 (5)	3.2 (52)	4	7
<b>November 2022</b>							
Control	5.6	8	0.58 (9)	5.4 (5)	3.2 (56)	3	6
P alone	5.7	12	0.56 (8)	6.3 (5)	3.5 (53)	4	8
S alone	5.5	7	0.43 (6)	5.6 (5)	3.1 (50)	5	7
P+S	5.7	12	0.49 (7)	6.8 (6)	3.5 (55)	6	7
<b>November 2023</b>							
Control	5.6	9	0.93 (15)	5.6 (5)	3.3 (57)	8	6
P alone	5.6	26	0.75 (11)	6.6 (6)	3.7 (59)	7	7
S alone	5.6	10	0.63 (10)	5.9 (6)	3.2 (54)	14	6
P+S	5.8	22	0.62 (10)	7.1 (7)	3.5 (59)	16	6
<b>Recommended:</b>	5.8-6.0 <sup>1</sup>	12 <sup>1</sup> 20-30 <sup>2</sup>	0.3-0.4 <sup>2</sup> (4-5) <sup>1</sup>	4-9 <sup>2</sup>	0.4-0.6 <sup>2</sup> (8-10) <sup>1</sup>	6-8 <sup>1</sup> >10-12 <sup>3</sup>	>10-12 <sup>3</sup>

<sup>1</sup> Morton and Roberts (2016) for hill country, <sup>2</sup> Hill Laboratories 'medium range', <sup>3</sup> Edmeades et al. (2005).

## Data analysis

Genstat software (Version 22, VSN International Ltd 2022) was used for all statistical analyses. The 2021 total dry matter yield and harvest components (sub clover, white clover, grasses, broadleaf weeds and dead) at each harvest were analysed by one-way ANOVA of fertiliser (orthogonal contrasts based on applied nutrients P, S and Mo) and randomised blocks (replicates). For the 2022 and 2023 data, a two-way ANOVA of fertiliser (with orthogonal contrasts noted above) by herbicide (all interactions) and randomised blocks (replicates) was used to analyse total dry matter yield and harvest components (sub clover, white clover, grasses, broadleaf weeds and dead) at each harvest, accumulated total and component yields for the year, and 21 November 2023 NIR data. For the 2022 harvest and the accumulated 2023 data, a two-way ANOVA of P (+ or -) by herbicide (+ or -), with randomised blocks (replicates) analysed sub clover DM. The following skewed data in 2023 were square root transformed (Ireland 2010) for statistical analysis: sub clover DM (harvested 16 June, 5 October), white clover DM (16 June, 5 October), sub clover % (5 October), and white clover % (5 October). The untransformed means are presented. When significant, fertiliser means were separated by Tukey's HSD test at  $\alpha=0.05$  and fertiliser x herbicide interactions using LSD  $\alpha=0.05$ . Grand means are presented with  $\pm$  standard error of the mean.

## Results

### Soil phosphorus and sulphur

In November 2022, 18 months after fertiliser applications, the addition of P lifted the Olsen P from 8 to 12 mg/L and S addition increased sulphate-S from 3 to ~5.5 mg/kg but had no effect on organic-S (Table 1). In November 2023, six months after the reapplication of P and S fertilisers, P addition lifted Olsen P from 10 to ~24 mg/L and the addition of S increased sulphate-S from 8 to 15 mg/kg but had no effect on organic-S, which averaged 6 mg/kg across the four treatments (Table 1).

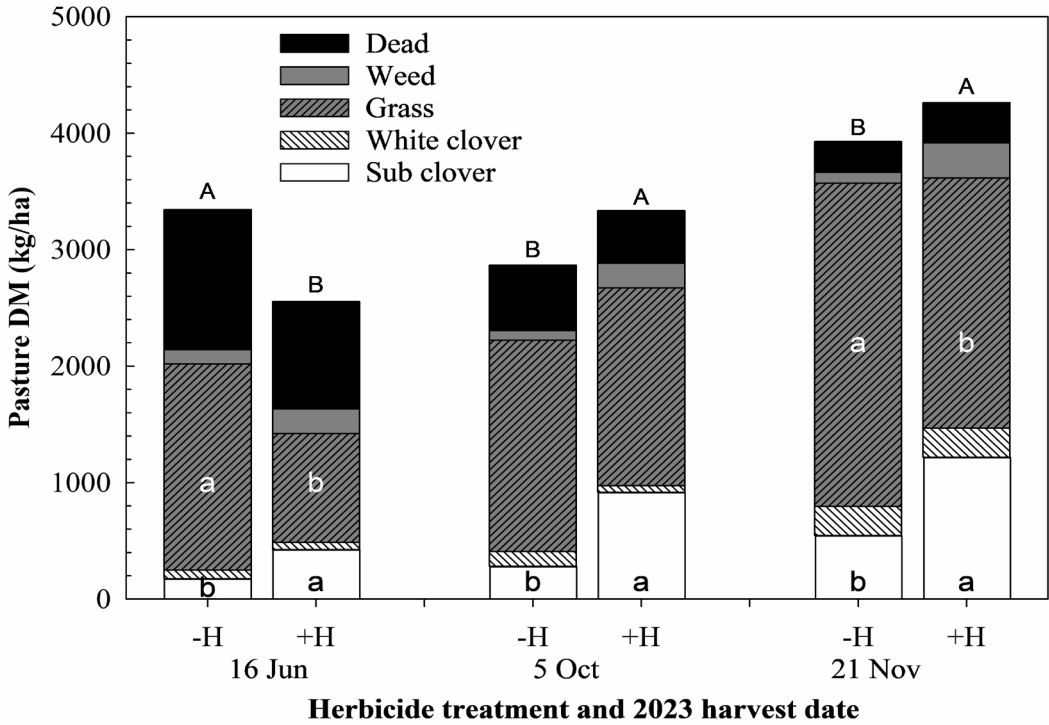
### Sub clover populations

The initial establishment of the sub clover seedlings was observed on 6 May 2021, 22 days after sowing. By 25 June there were 267 $\pm$ 7.5 sub clover seedlings/m<sup>2</sup> across the experimental plots representing an emergence of 19% of the estimated 1400 seeds/m<sup>2</sup> sown. The number of reestablished sub clover seedlings in 2022 and 2023 was not quantified due to the multiple germination events through late summer/autumn. In 2022, seedlings at the spade-leaf stage were first observed on 17 February, and in 2023 at the cotyledon stage on 27 February 2023.

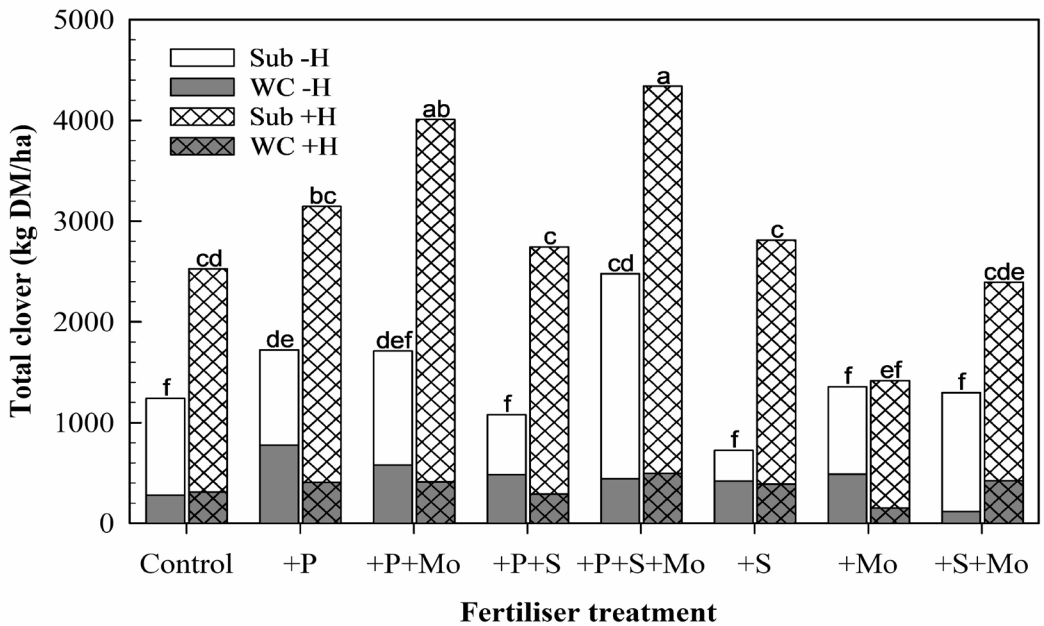
### Dry matter yields

#### 2021: Year 1

Total pasture yield for 2021 was 3,650 $\pm$ 83 kg DM/ha including 770 $\pm$ 43 kg of sub clover (21%) with no



**Figure 2** Effect of herbicide (-H or +H) on pasture component yields for three harvest dates in 2023, Port Hills, Canterbury. For each harvest date, sub clover, grass or total dry matter (DM) means with different letters are significantly different (LSD,  $\alpha=0.05$ ).



**Figure 3** Total clover (sub + white) yield against fertiliser (P= phosphorus, S = Sulphur, Mo = Molybdenum) and herbicide (-H or +H) treatments in 2023, Port Hills, Canterbury. Total clover yields with the same letters are not different (LSD,  $\alpha=0.05$ ).

**Table 2** Feed quality values (ME = metabolisable energy, CP = crude protein) in pasture samples harvested 21 November 2023, Port Hills, Canterbury in response to herbicide (-H or +H) and fertiliser P (-P or +P) treatments. Probability = P value. Comparison of best treatment (+H+P+Mo) with the control. Means with same letter are not significantly different ( $\alpha=0.05$ ).

	ME MJ/kg DM	CP %	Digestibility %	Total ME GJ/ha	Total CP kg/ha
<b>Herbicide</b>					
-H	9.7	12.6	62.7	38.0	495
+H	10.1	14.0	65.7	43.1	598
P value	<0.001	0.002	<0.001	0.003	<0.001
<b>Fertiliser contrast</b>					
-P	9.8	12.5	63.1	39.0	499
+P	10.1	14.1	65.3	42.2	594
P value	0.016	<0.001	0.009	0.055	0.002
<b>Treatment comparison</b>					
Control	9.4 b	11.0 b	60.6 b	35.0 b	408 b
+H+P+Mo	10.5 a	16.4 a	67.8 a	48.2 a	764 a

differences among treatments at either harvest on 19 October or 9 December. The December harvest included  $18 \pm 5$  kg volunteer white clover DM/ha.

### 2022: Year 2

The sub clover yield was affected by the interaction ( $P=0.047$ ) between the herbicide and P fertiliser level. The sub clover yield was 790 kg DM/ha in the +P+H treatment which was higher ( $P<0.05$ ) than herbicide alone (-P+H) with 500 kg DM/ha, and the  $\sim 300$  kg DM/ha with no herbicide regardless of P addition.

Herbicide reduced ( $P=0.050$ ) grass from 1,650 to 1,410 kg DM/ha (decrease of 15%) and dead material ( $P<0.001$ ) from 860 to 510 kg DM/ha. There was no effect of the fertiliser treatments on any of these components.

Pasture yield was affected by P fertiliser ( $P=0.018$ , -P = 2,900 kg vs. +P = 3,270 kg DM/ha) but not the herbicide treatment. White clover yield was increased by the P treatment ( $P<0.001$ , -P = 110 vs. +P = 360 kg DM/ha). The +P+S+Mo fertiliser treatment increased white clover yield to 560 kg DM/ha which was greater ( $P<0.05$ ) than the Control (120 kg DM/ha), +Mo (40), and +S+Mo (60) treatments.

### 2023: Year 3

Herbicide affected ( $P<0.001$ ) sub clover yields in all three 2023 harvests (Figure 2). The accumulated sub clover yield was 2,560 kg DM/ha for +H and 1,000 kg in -H treatment. Herbicide affected grass yields on 16 June ( $P<0.001$ ) and 21 November ( $P=0.012$ ) with less grass in the +H treatment (Figure 2). Accumulated grass yield for 2023 was higher ( $P<0.001$ ) in the -H than the +H treatment (6,360 vs. 4,780 kg DM/ha, respectively).

White clover accumulated yield was  $410 \pm 40$  kg DM/ha (4% total DM). The total accumulated pasture yield was  $10,200 \pm 160$  kg DM/ha in 2023.

The P fertiliser treatment affected the accumulated yields of sub ( $P=0.018$ , +P = 2,170 vs -P 1,400 kg DM/ha) and white ( $P=0.051$ , +P = 490 vs -P = 330 kg DM/ha) clovers.

Herbicide doubled ( $P<0.001$ ) the accumulated total clover yield from 1,460 to 2,930 kg DM/ha (Figure 3). The addition of P increased ( $P=0.002$ ) total clover from 1,720 (-P) to 2,660 kg DM/ha (+P). Sub clover content was higher ( $P<0.05$ ) in the +P+S+Mo+H treatment, at 36% of total DM, than the other fertiliser treatments with no herbicide (3 to 18%). As a result, total clover in this treatment was 4,340 kg DM/ha with the +P+Mo+H treatment yielding 4,010 kg DM/ha (Figure 3).

### Feed quality

Herbicide application increased ( $P<0.01$ ) pasture ME, crude protein, and digestibility (Table 2) in the November 2023 harvest. Total ME/ha was increased by 13% (38.0 to 43.1 GJ/ha) and total crude protein by 21% (495 to 598 kg/ha).

Fertiliser treatment only affected crude protein ( $P=0.008$ ), which was lower ( $P<0.05$ ) in the control and +Mo treatment (12.1%) than in +P+Mo (15.3%). Within the fertiliser treatments, +P increased ME, crude protein, and digestibility as well as total ME and crude protein/ha (Table 2). A combination of fertilisers and herbicide (i.e., +H+P+Mo) consistently increased ( $P<0.05$ ) ME and crude protein values compared with the control (Table 2).

## Discussion

The aim of this experiment was to increase the yield and sub clover content of a summer dry hill country pasture. To do this herbicide and fertilizer treatments were applied strategically based on the summer and autumn rainfall and initial soil fertility conditions. This meant that in the establishment year (2021), fertiliser treatments were applied but no herbicide was necessary because the grass was limited by summer dry conditions (Figure 1). However, after summer rains in 2022, herbicide was used to suppress the grass, but no fertiliser was applied. In 2023, both herbicide and fertilizer were applied because of a wet autumn which gave a high growth potential (Figure 1). In hindsight the fertiliser application was probably unnecessary because the Olsen P had increased to over 20 by the end of 2023.

### Pasture yields

#### Sub clover

In 2021, the dry autumn (Figure 1) delayed sub clover establishment until May. Accumulated sub clover yield was 770 kg/ha and did not respond to fertiliser additions. In 2022, the autumn conditions were dry and there was insufficient sub clover growth to harvest until spring. Then sub clover yield increased from ~300 to 500 kg DM/ha with the application of herbicide alone and to 790 kg with the addition of P as well (+P+H). Without herbicide addition to suppress the grass there was no sub clover response to the P applied in 2021.

The highest total clover content of ~4,200 kg in 2023 was equivalent to ~40% of the total DM and provided an extra 3,000 kg clover DM/ha compared with the control (-H). The steps necessary to obtain this increase in a pasture with established sub clover are highlighted in Figure 3: applying herbicide increased ( $P<0.05$ ) total clover yield from 1250 to 2,530 kg DM/ha, and then applying +P+Mo increased ( $P<0.05$ ) yield to 4,010 kg DM/ha. This clover content would be fixing ~120 kg N/ha/yr into the pasture system. In the same experiment, Olykan et al. (2024) reported that the herbicide treatment increased ( $P<0.01$ ) grass foliar N% in 2022 and 2023 presumably because this treatment increased the clover content and therefore soil N availability.

The length of the sub clover 'growing season' on the Port Hills, defined as PAW>50% (Figure 1B), was dictated by seasonal rainfall and ranged from 99 days in 2022 to 210 days in 2023. While reestablished sub clover seedlings were observed in February of both years, it is possible that 'false strikes' affected the 2022 sub clover population. False strikes are most likely from January to March when rain, that initiates germination, is followed by dry weather resulting in the death of some emerged seedlings (Dodd et al. 1995), and dry autumn conditions prevailed on the Port Hills in 2022 (Figure 1). In contrast, an early winter harvest

was possible in 2023 because of higher than normal autumn rainfall (Figure 1) resulting in a lower soil moisture deficit.

The white clover yields in 2022 and 2023 represented a 'revival' of the resident population. The observed 'background' presence of white clover was typified by the  $18\pm 5$  kg DM/ha (0.5%) in December 2021. White clover yields increased when P was applied (Figure 2) and in 2023 the +P yield was 490 kg DM/ha (4.7%). While white clover can survive on the Port Hills and respond to P fertiliser, these north and west facing slopes typically dry out in summer, negatively affecting its productivity and persistence (Knowles et al. 2003). Therefore, these areas are more suitable for sub clover or lucerne.

### Pasture composition

On this dryland hill site, the annual increase in clover production was not at the expense of total pasture production. The autumn application of herbicide in 2022 and 2023 provided more sub clover and less grass. In the November 2022 pasture yield of ~3,100 kg DM/ha, +H contained 22% sub clover and 47% grass while -H had 10% and 52%, respectively. The 2023 accumulated pasture yield of 10,200 kg DM/ha contained 25% sub clover and 47% grass in +H compared with 10% and 63% in -H treatment. The effect of herbicide more than doubling the clover proportion was also found by Hepp et al. (2003). In addition, the feed quality of the pasture, when measured as ME and crude protein in spring 2023, was increased by the herbicide treatment (Table 2) because of increased clover content and higher foliar N% (see Olykan et al. 2024).

Increasing clover content to ~30%, which included 4% white clover, was a positive result, however grass was still the dominant vegetation where herbicide was applied. While the ideal is to offer a ratio of 75% clover and 25% grass, Cosgrove et al. (2002) believed this proportion of clover could not be sustained in mixed pastures. Olykan et al. (2019) increased sub clover ground cover to 60% after two seasons utilising appropriate grazing management rather than herbicide. Highest sheep live weight gains for a dryland grass-legume pasture were on a cocksfoot-sub clover mixture (Mills et al. 2015) which, over nine years, averaged 25% sub clover and 14% volunteer white clover content (i.e., total clover 39%) when best grazing management practices were utilised (Mills et al. 2014). Those results show that best grazing practices can provide mixed pastures containing 40 to 60% clover and can be an alternative approach to controlling pasture grass with herbicides. For lactating ewes and their lambs, this clover growth is required from late winter into spring which is why sub clover is favoured in dryland hill country pastures.

## Response to fertiliser additions

### Phosphorus

In 2023, P fertiliser application to the low Olsen P soils on the Port Hills lifted the Olsen P levels (Table 1), increased sub and white clover DM yields (Figure 3), increased pasture feed quality (Table 2), and increased ( $P < 0.001$ ) foliar P% in grass and sub clover (Olykan et al. 2024). To maximise the positive effect of P addition on sub clover yield it was essential to control the grasses first so that the sub clover could respond (Figure 3). This result confirms for sub clover what Jackman and Mouat (1970) found for white clover, namely that a clover yield response to P fertiliser occurs once the competing grass demand for P is met. On the Port Hills, this happened because grass competition was reduced using herbicide.

### Molybdenum

In this experiment there was no sub clover yield response to applied Mo unless P was also applied (Figure 3). Olykan et al. (2024) found that Mo application increased ( $P < 0.001$ ) grass Mo concentrations in foliage samples taken in the spring of 2021, 2022 and 2023 but only increased ( $P = 0.011$ ) sub clover Mo concentrations in 2022.

### Sulphur

Adding S did not significantly increase clover yield further despite soil S levels being less than recommended (Table 1). This lack of sub and white clover response has been found before by Morton et al. (1998), where clover yield was increased at only one of the five sites they studied where both soil sulphate-S and organic-S were  $< 10$  mg/kg. In dryland hill and high country, Smith et al. (2004) suggested that sub clover was tolerant of low soil S supply because there was no yield response to S application at soil levels  $> 3$  mg/kg. Olykan et al. (2024) found that foliar S% was affected by a range of treatments, most often P addition, and the year of sampling.

### Management strategies

The priority for optimising the clover content of dryland hill pastures is to oversow with sub clover, control the competing grasses, and then apply P fertiliser, if Olsen P is low, and apply Mo. The best treatment combination from a total clover yield and feed quality perspective was +H+P+Mo (Table 2). This experiment, and previous dryland grazing experiments, have shown that reducing grass competition promotes clover growth. This is possible using herbicide as a grass suppressant or grazing if larger paddocks were subdivided and grazing stock were available when required during key periods of the sub clover lifecycle.

## Conclusions

Herbicide application to suppress grass competition

was the primary treatment influencing sub clover yield, which more than doubled in response. Where herbicide was applied the sub clover then responded to the addition of P fertiliser.

Total pasture yield was not impacted by the herbicide, but the proportion of sub clover increased, and the proportion of grass decreased. Feed quality parameters, e.g., total ME and crude protein/ha, and digestibility were increased by applying herbicide and phosphorus. Beyond this experiment, it is acknowledged that best grazing management practices can be used instead of herbicides to maximise pasture clover content.

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