Productivity and seedling recruitment of naturalised annual clovers versus sown clovers *Trifolium repens* and *Trifolium subterraneum*

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Abstract

Naturalised annual clover (NAC) species (suckling clover, cluster clover, striated clover, and haresfoot clover) are commonly present to locally abundant in summer dry hill and high country areas where white and subterranean (sub) clover abundance is limited. This field trial investigated NAC species dry matter production and seedling regeneration compared to white and sub clover. Autumn seedling recruitment was measured in response to low (75 kg/ha) or high (200 kg/ha) superphosphate (SP) application. Over two growing seasons, NAC species contributed >90% to pasture legume content while white and sub clover contributed <10%. Striated, suckling, and cluster clovers showed greater recruitment under low SP with 996, 978, and 227 seedlings/m^2 respectively compared to high SP with 635, 466, and 123 seedlings/m^2 respectively. Collectively, NAC species were superior to white and sub clover on north-facing slopes. Spreading NAC species seed via livestock dung dispersal and aerial broadcasting would further increase their contribution to total pasture DM and nitrogen input.

Keywords: annual legumes, striated clover, *Trifolium striatum*, cluster clover, *T. glomeratum*, suckling clover, *T. dubium*, white clover, subterranean clover, superphosphate, phosphorus, sulphur, seedling recruitment, hill and high country.

Introduction

The opportunity exists to increase the productivity of South Island hill and high country grazing land of lower–middle altitude (300–900 m a.s.l.). Retirement of higher altitude land (>900 m a.s.l.) to conservation and recreation resulting from land tenure review (O'Connor 2003; Gillespie *et al*. 2006) has reduced grazing areas available for high country farming. Dairy cattle expansion into lowland areas has reduced the area of pasture available for intensive finishing of sheep and beef cattle reared on hill and high country (Moot *et al.* 2009). Nitrogen (N) inputs sourced primarily from sward legumes and associated biological N fixation (Haynes & Williams 1993) drives productivity of remaining hill and high country pasture in summer dry (500–800 mm rainfall per annum) areas.

Increasing the abundance of legumes within grazing lands has been the keystone of pastoral improvement in New Zealand hill and high country, as low available N of most hill and high country soils (White 1990) is the primary limitation to pasture productivity. Traditional pasture improvement in upland New Zealand areas involved broadcast oversowing with legume species such as white clover (*Trifolium repens* L.) and subterranean (sub) clover (*Trifolium subterraneum* L.) in combination with aerial topdressing of phosphorus (P) and sulphur (S) fertiliser (Bowatte *et al*. 2006). However, long term abundance of white and sub clover is limited. Poor establishment on summer dry slopes with annual soil moisture deficits limit production, survival, and thus persistence of white clover (Knowles *et al*. 2003; Power *et al*. 2006) which phenologically exhibits optimum growth and stolon propagation during summer when soil moisture stress is greatest. Additionally, white clover is as a highly productive legume species adapted to high soil fertility conditions (high P, S and pH levels) for optimum growth (Haynes & Williams 1993; Moir *et al*. 1997). Low available P and S and low pH (4.5–5.5) levels are the main soil fertility limitations to pasture legume productivity in hill and high country areas (Edmeades *et al*. 1984; Moir & Moot 2010). Achieving greater legume abundance necessitates P, S and lime ($CaCO_3$) application to alleviate soil fertility constraints.

New Zealand's herbaceous flora contains a suite of naturalised annual legumes. Haresfoot clover (*Trifolium arvense* L.), suckling clover (*T. dubium* Sibth), cluster clover (*T. glomeratum* L.) and striated clover (*T. striatum* L.) are widely distributed across South Island hill and high country (Boswell *et al*. 2003; Rose & Frampton 2007; Maxwell *et al*. 2010). Originating from Asia Minor, the Mediterranean, North Africa and Western Europe (Webb *et al*. 1988) they are commonly present to locally abundant in summer dry zones, especially on hillsides of northerly-facing (sunny) aspects (Boswell *et al*. 2003; Power *et al*. 2006; Maxwell *et al*. 2010). Increasing the abundance of these naturalised annual clover (NAC) species may elevate overall legume abundance of hill and high country grazed pasture. However, little is known about their biomass accumulation, especially in comparison to white and sub clover in hill and high country environments. The relationship between NAC seedling regeneration and superphosphate fertiliser application has yet to be studied in a New Zealand hill or high country context. Recent climate-controlled studies by Maxwell *et al*. (2012, 2013) showed little dry matter (DM) response by NAC species to phosphate (P), sulphate (S), and lime addition. More field-based agronomic information about NAC species will benefit sustainable livestock production practice in low-input, hill and high country dryland areas.

At a summer-dry hill country site on an extensive sheep and beef high country station in Central Otago, a field trial was conducted with the objective of quantifying annual DM production of NAC species compared to white and sub clover, and measuring autumn seedling recruitment in relation to low and high superphosphate (P and S) application.

Methods

Study Site

The field trial was conducted at Lincoln University's Mt Grand Station, 2131 ha of hill and high country farmland located near Lake Hawea, Central Otago (lat 44°38′01.93″ S; long 169°19′42.89″ E) with altitude ranging from 380 to 1400 m a.s.l. The mid-altitude trial site (700 m a.s.l.) was situated on a north-facing (sunny aspect) hillside of moderate to steep slope (20–30°) within a 65 ha hill block of Arrow steepland soil (Pallic/Yellow Grey Earth; USDA classification Fragiudalf) with schist and loess parent material (Duncan *et al*. 1997; Power *et al*. 2006). Soil pH was

Table 1 Pasture biomass and botanical components of the mid-altitude (700 m a.s.l.) summer dry high country field site at Broadspur hill block, Mt Grand, Central Otago, New Zealand, from October 2008 to May 2010. ***, ** and * indicate significant differences at P ≤ 0.001, P ≤ 0.01 and P ≤ 0.05 respectively. Different letters denote means that are significantly different at the 5% level.

	Biomass (%)		Biomass (kg DM · ha⁻¹)	
Botanical components	**Year 1**	**Year 2**	**Year 1**	**Year 2**
Naturalised annual clovers				
Haresfoot *T. arvense*	0.4 a	0.01 a	12.6 a	0.3 a
Suckling *T. dubium*	5.7 b	0.1 a	125.7 b	1.8 a
Cluster *T. glomeratum*	7.2 b	0.1 a	186.7 c	1.9 a
Striated *T. striatum*	14.4 c	1.7 b	343 d	46.6 b
Historically oversown clovers				
White *T. repens*	0.4 a	0.2 a	12.2 a	6.8 a
Sub *T. subterraneum*	0.4 a	0.04 a	8.9 a	0.7 a
Total clover	28.4	2.2	689.1	58.1
Significance	***	***	***	***
Grasses [1]	35.5 b	27.3 b	888 b	730 b
Weeds [2]	2.6 a	3.2 a	62 a	65 a
Herbs [2]	0.1 a	0.8 a	2 a	11 a
Dead	33.4 b	66.6 c	859 b	1570 c
Significance	***	***	***	***
Naturalised annual clovers	27.6 a	1.9 a	668 a	51 a
Grasses	35.5 b	27.3 b	888 b	730 b
Dead	33.4 ab	66.6 c	859 b	1570 c
Significance	**	***	**	***
Mean Annual Pasture biomass			2500	2433

1 Grass species present: Browntop *Agrostis capillaris L.,* Kentucky bluegrass *Poa pratensis L.,* Annual poa *Poa annua L.,* Sweet vernal *Anoxanthum odoratum L.,* Tall oat grass *Arrhenatherum elatius L.,* Blue wheat grass *Elymus spp.,* Danthonia grasses *Rytidosperma spp.,* Perennial ryegrass *Lolium perenne L.,* Cocksfoot *Dactylis glomerata,* Downy brome *Bromus tectorum L.,* Ripgut brome *Bromus diandrus* Roth, Needle grass *Austrostipa nodosa*

2 Weed and herb species present: Mouse-ear hawkweed *Hieraceum pilosella,* Hawksbeard *Crepis capillaris L.,* Storksbill *Erodium cicutarium,* Sheep's sorrel *Rumex acetosella L.*

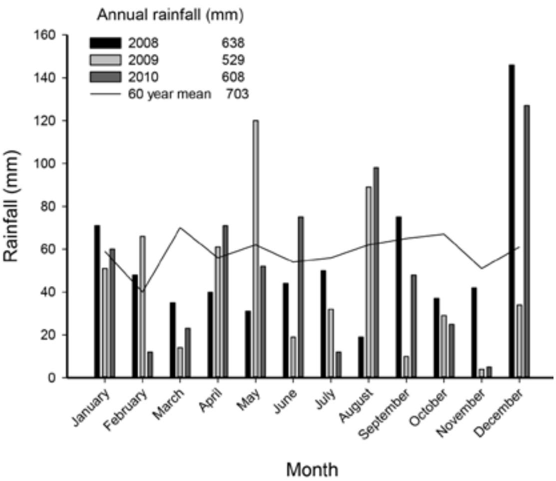

Figure 1 Annual and monthly rainfall during the study period of 2008 to 2010 at the mid-altitude (700 m a.s.l.) high country field site on Mt Grand Station, Lake Hawea, Central Otago, New Zealand. NB: autumn (March–May), winter (June–August), spring (September–November), and summer (December–February).

5.5, Olsen P was 18 mg/litre, and sulphate-S was 9 mg/kg. The site chosen was representative of the hill block's vegetation cover. Established populations of NAC species and white and sub clover were present among an array of annual and perennial grass species (Table 1) and patches of sweet briar (*Rosa rubiginosa* L.), matagouri (*Discaria toumatou* Raoul) and kanuka (*Kunzea ericoides* J. Thompson) shrubs. During the study period from October 2008 to May 2010, average winter temperatures were 4.2ºC (day) and 2.7ºC (night) with a minimum average of 1.5ºC in June. Average summer temperatures were 15.1ºC (day) and 11.7ºC (night) with a maximum average of 15.5ºC in February. Average annual rainfall (60 years) is 703 mm, with high annual and monthly variability. Annual rainfall collected for 2008 was 638 mm and for 2009 was 529 mm (Figure 1).

The hill block was continuously grazed with 300 pregnant Merino ewes (lambing in late September) from the start of spring growth until late summer (February). Grazing resumed again from mid-autumn (April) with 300 ewes and 4 rams and some rising two-year-old cattle to assist with control of pasture quality by grazing down areas of accumulated standing dead matter. Grazing ceased in mid-winter (July), resuming again in spring. The annual grazing management regime was typical of very low intensity grazing land use.

Experimental Design and Treatments

This experiment was part of a larger field trial investigating the effect of grazing deferment and superphosphate application on NAC species (Maxwell *et al.* unpublished). It was established as a factorial split plot randomised complete block design, with two superphosphate (SP) treatment split plots (2.5×5 m) within grazing management treatment main plots (5×5 m) in four blocks. Split plots had either low (75 kg/ha) or high (200 kg/ha) rates of 30% sulphur SP; the low SP treatment being 5 kg P/ha and 23 kg S/ha equivalent and the high SP treatment being 9 kg P/ha and 38 kg S/ha equivalent. Fertiliser was applied on 6 September 2008.

Measurements

Two 0.2 m^2 quadrat cuts of standing pasture biomass were harvested within split plots in spring, summer, and autumn over a 19-month period from October 2008 to May 2010. Botanical composition was determined by sorting cut herbage to obtain DM values (percentage and kg DM/ha) of each clover species, grass, weed, herb, and dead matter components at each harvest time. Sorted samples were oven-dried at 70ºC for 48 hours and weighed.

Seedling recruitment was measured in autumn 2009 and 2010 by counting clover seedling numbers present in 20 soil cores 6.1 cm diameter by 4.5 cm deep from each split plot. All clover seedlings present were counted as an estimate of autumn regeneration of clover species per m^2.

Statistical analysis

Data for standing biomass of clover species, grass, weed, herb, and dead matter were analysed using one-way analysis of variance (ANOVA) to determine any statistically significant differences between these botanical components in the first and second year. Superphosphate effect on clover seedling recruitment was analysed by a split plot ANOVA for one date in each year (i.e. autumn 2009 and autumn 2010). All analyses were conducted using GenStat 13 (Lawes Agricultural Trust, Rothamsted, UK).

Results

Naturalised annual clover species collectively contributed more to pasture biomass than white and sub clovers in both years (Table 1, Figure 2). First year pasture biomass ranged between 1673 and 3582 kg DM/ha from October 2008 to May 2009, averaging 2500 kg DM/ha. The DM of naturalised annual clover species accounted for 28%, while white and sub clover accounted for only 0.8% (Table 1). The legume content of the pasture varied immensely between years. In the second year, pasture biomass ranged between 1474 and 3523 kg DM/ha from November 2009 to May 2010, averaging 2400 kg DM/ha, with NAC species accounting for 2% and white and sub clover

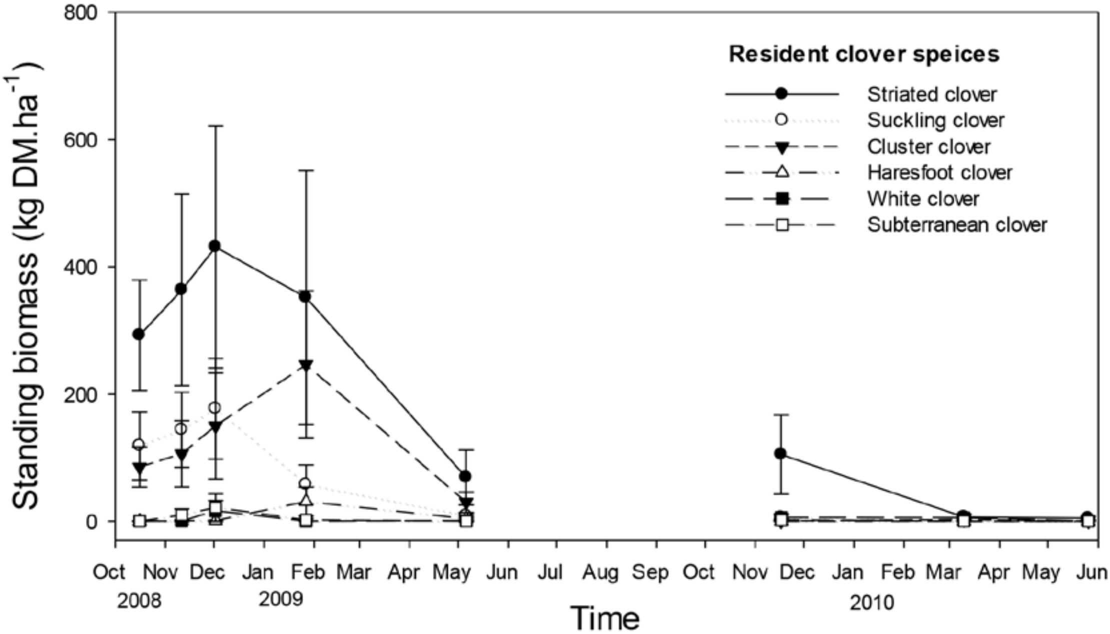

Figure 2 Standing biomass (kg DM/ha) of all naturalised annual clover species (striated clover *Trifolium striatum,* suckling clover *T. dubium,* cluster clover *T. glomeratum,* haresfoot clover *T. arvense)* and white clover *T. repens* and subterranean clover *T. subterraneum* from October 2008 to May 2010 in a summer dry, mid-altitude (680–700 m a.s.l.), north-facing (sunny) upland pasture community on Mt Grand Station, Central Otago, New Zealand. Error bars are ± SEM.

accounted for 0.2% (Table 1). Clover standing biomass (naturalised species and white and sub clover) averaged 689 kg DM/ha in the first year, falling considerably to 58 kg DM/ha in the second year (Table 1), strongly reflecting the general scarcity of clover during mid-spring of the second year (Figure 2).

Striated clover was the dominant species with more standing biomass (P<0.001) than all other clover species in both years (Table 1). Striated clover contributed 343 kg DM/ha (14%) in the first year, while cluster clover contributed 187 kg DM/ha (7.2%), and suckling clover 126 kg DM/ha (5.7%) to first year total pasture biomass (Table 1). Haresfoot, white, and sub clovers were least dominant with less standing biomass (P<0.001) than striated, cluster, and suckling clovers (Table 1 and Figure 2). In the second year, striated clover standing biomass dropped to 47 kg DM/ha (1.7%) with the standing biomass of cluster, suckling, haresfoot, white and subterranean clovers not significantly different from each other (P<0.001, Table 1 and Figure 2).

Superphosphate

Superphosphate application influenced clover regeneration, with more seedlings observed under low SP application. In May 2010, average clover seedling recruitment was significantly greater (P<0.001) in low SP split plots (563 seedlings/m^2) than high SP split plots (271 seedlings/m^2). A significant interaction (P<0.001) between clover species and SP was observed in May 2010 (Figure 3). Striated, suckling and cluster clovers showed greater seedling recruitment under low SP fertiliser application with 1406, 1559 and 365 seedlings/m^2 respectively, compared to 756, 637 and 176 seedlings/m^2 respectively within the high SP treatment (Figure 3).

Discussion

Naturalised clover dominance

Three NAC species (striated, cluster and suckling clover) produced more DM over two growing seasons and regenerated with larger seedling populations in consecutive autumns than white and sub clover at this site. These NAC species have the ability to grow to maturity and produce viable seed in most years before the onset of late spring–summer soil moisture deficits, followed by autumn regeneration every year from the large soil seed reserve. White and sub clover were not dominant at any time over the 19-month period, adding further support to the contention that white clover (Knowles *et al*. 2003) and sub clover (Power *et al*. 2006) struggle to persist and make a valuable contribution to summer dry hill pastures of north-facing aspect.

This observed NAC species abundance is attributed to their ability to germinate and establish seedlings at lower temperatures than white clover in autumn. They have lower base temperatures for germination and lower thermal time requirements for seedling emergence and

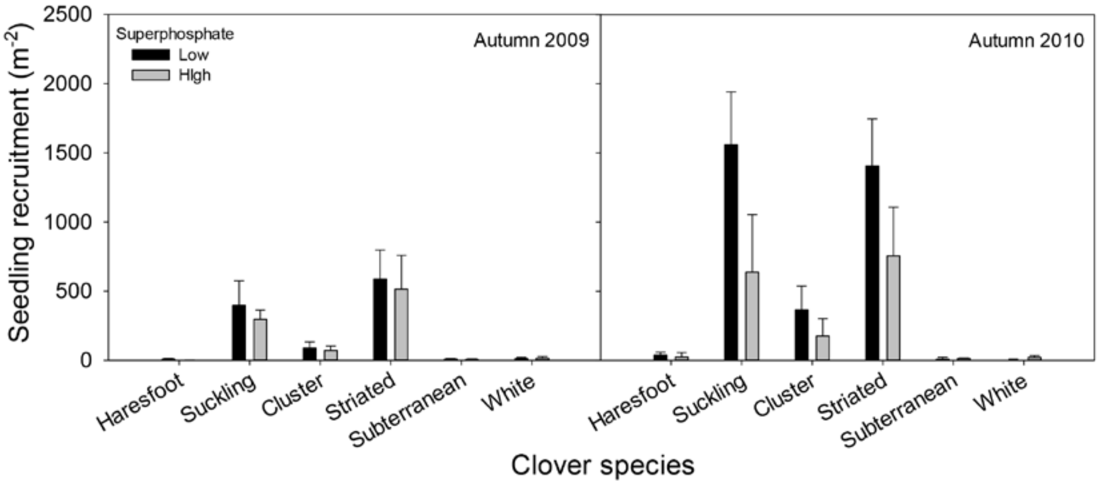

Figure 3 Influence of low (75 kg/ha) and high (200 kg/ha) superphosphate fertiliser application (30% sulphur super) on seedling recruitment (m^2) of the six resident clover species over two consecutive autumns in a summer dry, mid-altitude (680–700 m a.s.l.), north-facing (sunny) upland pasture community on Mt Grand Station, Central Otago, New Zealand. Error bars are ± SEM

seedling growth than white clover (Lonati *et al*. 2009). Striated, cluster and suckling clovers are well adapted to regenerating and producing biomass under the climatic conditions of north-facing slopes on Mt Grand Station. As annual plants, they can complete their lifecycle (germinate, establish, flower, and produce seed) before the onset of soil moisture deficits typical of sunnier northern aspects in late spring–summer (Lambert & Roberts 1976) that are detrimental to white clover growth and stolon propagation in most years.

Seasonal rainfall influence

Large variation in annual clover abundance was strongly driven by contrasting rainfall received during the spring and early summer periods in 2008 and 2009. Naturalised annual clover species average biomass was approximately 14 times greater in the first year (2008/2009 season) than the second year (2009/2010 season). Rainfall during the growing season in September, October, November and December 2008 was much greater at 75, 37, 42 and 146 mm respectively than that of the following year (2009) at 10, 29, 4 and 34 mm, respectively. This was particularly evident in September and November of 2009 when rainfall was considerably lower than the 60 year average for those months in spring.

Hepp *et al.* (2003) attributed a 2.5-fold difference in clover abundance (white, subterranean, suckling and cluster clovers) to higher soil moisture availability and more even rainfall distribution in the second season in comparison to the first season of sampling in summer dry North Island east coast hill country. Though soil moisture levels were not measured at our site, we can assume spring and early summer soil moisture availability for dominant NAC species was greater during the first year growing season.

Despite the large variation in clover content, average pasture biomass was similar (2433 and 2500 kg DM/ha) between the two years owing to the large mass of dead material accumulation during the first year that remained for much of the second year. These values are comparable to other South Island hill country (200–600 m a.s.l.) annual pasture biomass values recorded in low rainfall areas (350–760 mm), (White *et al.* 1972; Radcliffe & Cossens 1974; Vartha *et al.* 1982) as well as summer dry (800 mm) North Island hill country annual pasture biomass (Gillingham *et al.* 1998).

Superphosphate response

Prior to fertiliser application at this field site, available P was moderate while available S was low. Significantly more striated, suckling and cluster clover seedlings were evident in low SP spilt plots. These clover species appear to have a low S requirement for optimum DM production (Maxwell *et al*. 2012) with adaptation to low soil P levels (Dodd & Orr 1995).

Within the lower–middle altitude zone of Mt Grand, no association was observed between soil S fertility level and botanical cover (percent) of striated, cluster, and suckling clover (Maxwell *et al*. 2010). Maxwell *et al*. (2012) concluded that all four NAC species require low S availability for optimum DM production, under conditions of optimum soil pH, P fertility, and micro-nutrient status. Beale *et al*. (1993) reported striated clover being associated with soils of very low P status in Morocco. Similarly, Maxwell *et al*. (2010) found greater striated clover percent cover was associated with lower soil P levels in the lower–middle altitude range at Mt Grand. Maxwell *et al*. (2013) reported all four NAC species showed optimum DM accumulation under low to medium soil P fertility, with striated clover showing a relative lower DM response to increasing P fertility in a South Island high country soil compared to suckling, cluster and haresfoot clovers.

Conclusion

Three NAC species (striated, cluster, and suckling clover) contributed more to pasture biomass than traditionally sown species of white and sub clover at a sunny-aspect, summer dry hill environment during a moist year. In a very dry year, NAC species abundance dropped, though striated clover still out-performed white and sub clover, with the other NAC species having similar biomass to white and sub clover. The contributions of NAC species appear extremely significant for annual biomass provision to grazing livestock and N inputs in the climatically-variable hill and high country zone.

Spreading NAC species within grazed hill and high country areas should be strongly encouraged to increase pasture legume content for livestock feed in spring and associated annual N-fixation inputs. Spreading NAC species could be achieved through concentrated grazing pressure in areas where NAC species are abundant and subsequent seed dispersal via dung to exploit soil moisture in favourable rainfall years for annual legume production. Aerial broadcasting of NAC seed will further their spread to areas in hill and high country of limited legume cover and introduce these species to areas where they have yet to arrive and colonise.

Phosphorus and sulphur requirements of NAC species appear to be low. If increasing NAC species abundance is the focus, adjustment to traditional applications of superphosphate could be considered. This is important as heavy superphosphate application has traditionally been the pathway of intensification in South Island hill and high country.

ACKNOWLEDGEMENTS

Research funding provided by the Miss E.L. Hellaby Indigenous Grasslands Research Trust. Thanks to Evan Gibson, Keith Pollock, Daniel Dash, Elina Stang, Steele Taylor, Marianna Gallo, Vonny Fasi, Rob Kidd and Kimberley Pulley for valuable field assistance at Mt Grand.

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