Influence of environmental factors on the abundance of naturalised annual clovers in the South Island hill and high country

T.M.R. MAXWELL[1], J.L. MOIR[2] and G.R. EDWARDS[1]
[1]*Department of Agricultural Sciences,*
[2]*Department of Soil and Physical Sciences*
P.O. Box 84, Lincoln University, Lincoln 7647
tom.maxwell@lincolnuni.ac.nz

Abstract
The abundance of four naturalised annual clovers (striated, cluster, suckling, haresfoot) and two sown clovers (subterranean and white clover) was investigated in relation to topographical, soil fertility and management factors on two contrasting hill/high country stations in the South Island: Glenfalloch in inland Canterbury (1 665 mm annual rainfall), and Mt Grand in Central Otago (703 mm annual rainfall). Site surveys were conducted in three hill blocks per farm, with measurements of grassland species cover, slope, aspect, grazing intensity, soil fertility, soil depth, and altitude made within quadrats along three transects at upper, middle and lower hill slope positions. The only naturalised clover present at Glenfalloch was suckling, whereas all were present at Mt Grand. The % cover of naturalised annual clovers was greater (30.1) than that of white clover (3.8) or subterranean clover (0.1) at Mt Grand. The % cover of white clover decreased with increasing altitude. The % cover of striated and cluster clover was greatest on sunny aspects, while white clover % cover was greatest on shady aspects. White clover cover increased and striated clover cover decreased with increasing available soil phosphorus. Naturalised annual clovers exhibit regeneration and persistence strategies that allow them to regenerate and grow in dry hill/high country pastures.
Keywords: altitude, aspect, Olsen P, soil moisture, *Trifolium striatum*, *T. glomeratum*, *T. dubium*, *T. subterraneum*, *T. repens, T arvense*

Introduction
Sustainability of high country pastoralism, following retirement of high altitude land to improve indigenous grassland conservation and recreation outcomes, has increased the need to improve the productivity of the remaining middle to lower altitude land. An important component of pastoral intensification is to increase legume abundance so as to provide increased feed and nitrogen inputs to nitrogen deficient, summer dry hill country grassland. However, the establishment and persistence of sown legume species such as subterranean clover (*Trifolium subterraneum*) and white clover (*Trifolium repens*) is often limited (Knowles *et al*. 2003; Power *et al*. 2006). This is in contrast to the common presence of other naturalised and unsown legumes, such as cluster clover (*Trifolium glomeratum*), haresfoot trefoil (*T. arvense*), striated clover (*T. striatum*) and suckling clover (*T. dubium*) (Power *et al.* 2006) that may be more suited to the microclimates that exist on these hill slopes (Boswell *et al*. 2003). However, few data exist on the distribution of these naturalised annual species in New Zealand hill country. As part of a wider study of their ecology, the distribution/abundance of these naturalised legumes on two contrasting, climatically different high country farms was surveyed.

The objective of the study was to quantify the abundance of six clover species (cluster, haresfoot, striated, suckling, subterranean and white) in relation to topography, soil fertility and management on extensive grazing blocks on two hill/high country farms in the South Island. The study also identified ecological factors influencing the distribution of these naturalised annual clovers in the variable climatic zone of the South Island hill and high country.

Methods
Location
Six hill country grazing blocks (paddocks ranging in size from 65 to 100 ha plus) were surveyed during late spring/early summer (December 2008 and January 2009) on two climatically different hill/high country farms, namely, Mt Grand Station in Central Otago, and Glenfalloch Station in Canterbury (Table 1).

Site survey procedure
The percentage cover of each legume was visually estimated in three hill paddocks per farm. The cover of clover species, shrubs, grasses (non-tussock), and tussocks was assessed in three 5 x 5 m quadrats laid out at intervals along 200 m transects positioned in the top, middle and bottom of the slope in each hill paddock. A total of 50 quadrats (29 at Mt Grand and 21 at Glenfalloch) were surveyed. For each quadrat, local grazing intensity as indicated by visual assessment

Table 1 Summary of climatic, topographical, and soil characteristics and mean bare ground and vegetative cover (%) on the two high country survey farms from December 2008 to January 2009 (late spring/early summer).

Station	Mt Grand	Glenfalloch
Region	Central Otago	Canterbury
Mean Annual Rainfall (mm)	703	1665
Season		
Autumn	188	345
Winter	172	370
Spring	183	590
Summer	160	360
Altitude Range of survey area (m)	547-876	685-925
Soil properties		
pH	5.6	5.3
Olsen P (ug/mL)	15.5	13
Sulphate S (ug/g)	17.6	11.4
% Cover		
Bare ground	13.7	4.9
Tussock	1.1	9.2
Shrub	3.1	10.4
Forbs/herbs	3.6	14.1
Grass (non-tussock)		
Perennial	26.1	55.6
Annual	30.2	1.3
Perennial Legume (sown)		
White clover	3.8	6.2
Red clover	0	0.04
Lotus pedunculatus	0	1.6
Annual legume		
Cluster clover	4.9	0
Haresfoot clover	0.2	0
Striated clover	19.2	0
Subterranean clover	0.1	0
Suckling clover	5.8	1.5

Table 2 Significance (P) values of predictor variables from multiple regression using generalised linear models for % cover of naturalised annual clovers and white clover % cover at Mt Grand Station, Central Otago. (* P<0.05; ** P<0.01).

Predictor variables	d.f.	Clover species				
		Striated	Suckling	Cluster	Haresfoot	White
Altitude (m)	1	0.15	0.85	0.73	0.065	0.002 **
Aspect	2	0.002 **	0.46	0.037 *	0.78	0.43
Grazing intensity	1	0.14	0.52	0.73	0.14	0.41
Olsen P	1	0.018 *	0.26	0.96	0.92	0.02 *
Perennial grass (%)	1	0.16	0.33	0.7	0.24	0.72
Slope	1	0.46	0.74	0.87	0.33	0.86
Soil depth (cm)	3	0.25	0.67	0.96	0.27	0.27
Sulphate S	1	0.68	0.89	0.79	0.89	0.77
pH	1	0.36	0.54	0.15	0.82	0.97

of pasture height (lax: >3 cm, intense: <3 cm), angle of slope of the quadrat to the nearest 5°, altitude (m) and aspect (full sun: NW to NE; moderate sun: NE to SE combined with SW to NW; and shady: SE to SW) were recorded. In addition, within each quadrat, depth to rock in the top 30 cm of soil was measured using a steel rod, along with soil fertility via the collection of ten soil cores (7.5 cm depth) which were bulked and analysed for pH (water:soil ratio 2.5:1; Blakemore *et al.* 1987), Olsen P (Olsen *et al.* 1954) and sulphate S (Searle 1979). Transects ranged in altitude from 500 to 900 m a.s.l.

Analysis

The percentage cover of each legume in each quadrat was used as the response variable in fitting a multiple logistic regression model using generalised linear models (Crawley 1993) with GenStat Release 12 (VSN International 2009). Due to the low abundance of annual and perennial legumes at Glenfalloch, this analysis was restricted to the Mt Grand data. A normal probability distribution with an identify link function was specified. A maximal model using nine predictor variables was constructed. The predictor variables were altitude, aspect, grazing intensity, Olsen P, perennial grass, slope, soil depth, sulphate S and soil pH. The minimum adequate model was found by deleting variables with no significant effect from the maximal model, leaving those factors whose deletion caused significant effects. Control of the model was manual at all stages.

Results

Table 1 summarises the regional difference between Mt Grand and Glenfalloch in terms of annual rainfall, soil properties, and botanical composition (% cover). Total legume abundance was 34.2% at Mt Grand and 9.4% at Glenfalloch (Table 1). There were more annual legume species present at the lower rainfall site of Mt Grand, with only suckling clover present at Glenfalloch (Table 1). At Mt Grand, striated clover was the most abundant annual legume, followed by cluster and suckling clover, with very little haresfoot and subterranean present ($P<0.05$ from ANOVA of annual legume data; Table 1). More sown perennial legume species were evident at Glenfalloch than Mt Grand, with *T. repens* the dominant perennial legume (Table 1). Total grass cover was similar at both sites, although annual grasses were more abundant at Mt Grand than Glenfalloch (Table 1).

Multiple regression analyses of the % cover of legume species at Mt Grand showed that there was a significant effect of altitude for white clover, aspect for striated and cluster clover and, and plant-available soil phosphorus (Olsen P) for striated and white clover (Table 2). There were no significant effects detected for other species and predictor variables (Table 2). The % cover of white clover showed a general decline with increasing altitude, although the relationship was not strong (Fig. 1). White clover cover decreased from a mean 19% at 550 m to a mean of 5% at around 900 m (Fig. 1). The abundance of striated and cluster clover was highest on full sun aspects, intermediate on moderate sun aspects and lowest on shady aspects (Table 3). The % cover of striated clover decreased and white clover increased with increasing available soil P (Fig. 2a & 2b), although the relationship was not strong.

Discussion

Difference in clover species abundance between sites

There was a distinct difference in the richness and abundance of clover species between the two stations. The drier Mt Grand station in Central Otago had a higher cover of annual clover species, but a lower cover of perennial clover species, such as white clover, than the wetter Glenfalloch station in inland Canterbury. The scarcity of naturalised annual legumes at Glenfalloch is likely due to the higher rainfall at this station leading to greater perennial grass cover and competition for annual legumes (Table 1). Beale *et al*. (1993) showed rainfall had a greater effect on annual clover species distribution than temperature in a Moroccan survey, while Dear & Cocks (1997) found the presence of summer-active perennial grasses suppressed subterranean clover seedling survival due to increased drying of the soil surface. In addition, Hepp *et al*. (2003) demonstrated the positive effect on clover species (white, subterranean, suckling and cluster) abundance from grass suppression with herbicide in late autumn. White clover remained at low abundance at Mt Grand despite regular oversowing. Knowles *et al*. (2003) reported on the limitations of white clover production and persistence in drought prone regions and stated that rainfall was the major factor affecting white clover presence.

Altitude

Within the altitude range 500 to 900 m there was a limited effect of altitude on the abundance of clover species, with only the % cover of the perennial legume white clover reducing with altitude (Table 3). This is surprising given the dominant effect of increasing altitude on lowering thermal time accumulation (Power 2006). However, cluster, haresfoot, striated and suckling clover have lower thermal time requirements for emergence and seedling development than white clover (Lonati *et al*. 2009). Hence, these naturalised annual clovers may germinate rapidly after autumn rains, develop a leaf canopy, and have the ability to reach an advanced stage of seedling development before the onset of metabolic-limiting low winter temperatures.

Figure 1 The influence of altitude (m) on the cover (%) of white clover at Mt Grand Station, Central Otago, December 2008.

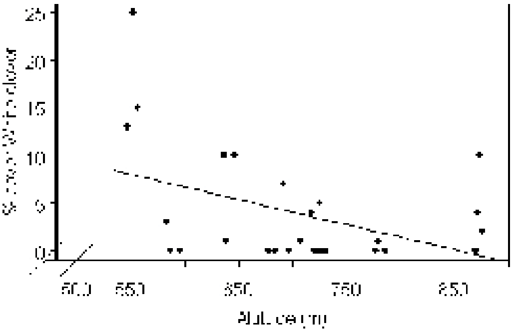
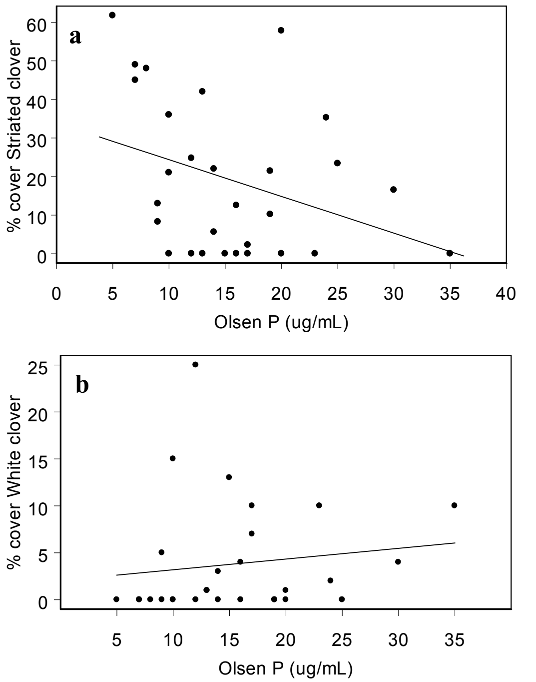


Figure 2 The influence of plant-available soil P (ug/mL) on the cover (%) of (a) striated clover and (b) white clover at Mt Grand Station, Central Otago, December 2008.



Aspect

Striated and cluster clover increased in % cover on sunny aspects while white clover and suckling clover, were more prevalent on shady aspects. Our results support Power *et al*. (2006) contention of the collective dominance of naturalised annual clovers on warm sunny faces (below 910 m a.s.l.) with reduced competition for micro-sites and growth from the perennial grass sward. On these sites, naturalised annual species appear to be able to complete their lifecycle before the onset of dry and warm conditions, typical of sunnier northern aspects (Lambert & Roberts 1976). Suckling clover was not affected by aspect (Table 2 & 3), appearing to have a scrambling growth and regeneration strategy for a wide range of micro-sites.

White clover was also not significantly influenced by aspect in the multiple regression model (Table 2), although there was a trend for more white clover in shady, moister aspects. In part, the lack of an effect on white clover may reflect that the species also persists by seedling recruitment on the sunny faces, behaving in similar fashion to an annual species (Edwards, Clark & Newton 2001). Moreover, Chapman (1987) found seedling survival of *T. repens* in North Island summer-moist hill country (1 280 mm/yr) was highest on steep north-west sites and nil on flat south-west sites, a reflection of competitive stresses from surrounding vegetation.

Available phosphorus

Our finding that striated clover declined with increasing Olsen P has not been reported before in New Zealand. However, a recent glasshouse pot trial (T.M.R. Maxwell unpubl. data) also demonstrated low dry matter response of striated clover to increasing levels of available phosphorus in high country soil, compared with the higher dry matter responses of 'Nomad' white clover, 'Mt Barker' subterranean clover, suckling, cluster and haresfoot clovers. This result with striated clover is possibly due to its adaptation to low soil P environments (Dodd & Orr 1995). Beale *et al*. (1993) reported *T. striatum* (striated clover) to be one of four annual clover species associated with soils of very low P status, among sixteen species identified in an ecogeographic survey of agricultural zones in Morocco. White clover cover increased with increasing Olsen P in this study, as has been previously reported (Caradus & Snaydon 1986; Caradus *et al*. 1995; Singh & Sale 1998).

It was surprising to find no relationship between the clover abundance and grazing intensity, as other studies have shown marked impacts of grazing intensity on clover abundance. For example, Ates *et al*. (2006) found cluster clover dominated ryegrass/subterranean clover pastures by early summer after intensive set stocking in spring, and that populations were also increased when pastures were spelled early in spring to enhance flowering and seed production. Our results suggest naturalised species are more tolerant of grazing, namely they have a lower grazing preference, produce large amounts of seed, and that the differences in grazing intensity were not marked enough to produce a response.

Conclusions and practical implications

- Soil moisture, as determined by annual rainfall, is probably the main factor determining the

presence/absence of naturalised annual clovers in South Island hill and high country.
- Aspect was a dominant factor affecting the abundance of annual legumes with higher abundance in sunny, north facing aspects.
- Naturalised annual clovers grow in combination where the sown species, white and subterranean clover, remain at low abundance, and may contribute significantly to dry hill/high country through pasture production and nitrogen inputs.
- These legumes exhibit regeneration and persistence strategies (avoidance of grazing, high seed production, tolerance of low soil pH, S and P) that allow them to regenerate and grow on dry hill/high country pastures. These strategies could be exploited in breeding programmes for dry hill/ high country pastures.

ACKNOWLEDGEMENTS
The Miss E L Hellaby Indigenous Grasslands Research Trust for generous funding; Evan Gibson, Farm Manager of Mt Grand Station, and Chas and Dietlind Todhunter of Glenfalloch Station willingly provided access to their properties for us to conduct research.

REFERENCES
Ates, S.; Brown, H.E.; Lucas, R.J.; Edwards, G.R. 2006. Effect of ewe stocking rate in spring on subterranean clover persistence and lamb liveweight gain. *Proceedings of the New Zealand Grassland Association 68*: 95-99.

Beale, P.E.; Bounejmate, M.; Lahlou, A.; Marx, D.B.; Christiansen, S. 1993. Distribution of annual *Trifolium* species in Morocco. *Australian Journal of Agricultural Research 44*: 1303-1310.

Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987. Methods for chemical analysis of soil. Scientific report 80, New Zealand Soil Science Bureau, Lower Hutt, New Zealand.

Boswell, C.C.; Lucas R.J.; Lonati, M.; Fletcher, A.; Moot D.J. 2003. The ecology of four annual clovers adventive in New Zealand grasslands. *Legumes for Dryland Pastures. Grassland Research and Practice Series 11*: 175-188.

Caradus, J.R.; Snaydon, R.W. 1986. Response to phosphorus of populations of white clover 2. Glasshouse and growth cabinet studies. *New Zealand Journal of Agricultural Research 29*: 163-168.

Caradus, J.R.; Mackay, A.D.; Dunlop, J.; van den Bosch, J. 1995. Relationships between shoot and root characteristics of white clover cultivars differing in response to phosphorus. *Journal of Plant Nutrition 18*: 2707-2722.

Chapman, D.F. 1987. Natural re-seeding and *Trifolium repens* deomography in grazed hill pastures II. Seedling appearance and survival. *Journal of Applied Ecology 24*: 1037-1043.

Crawley, M.J. 1993. GLIM for Ecologists. Blackwell Science, Oxford, UK. pp. 379.

Dear, B.S.; Cocks, P.S. 1997. Effect of perennial pasture species on surface soil moisture and early growth and survival of subterranean clover (*Trifolium subterranuem* L.) seedlings. *Australian Journal of Agricultural Research 48*: 683-693.

Dodd, M.B.; Orr, S.J. 1995. Seasonal growth, flowering patterns, and phosphate response of 18 annual legume species grown in a hill-country soil. *New Zealand Journal of Agricultural Research 38*: 21-32.

Edwards, G.R.; Clark, H.; Newton, P.C.D. 2001. The effects of elevated CO_2 on seed production and seedling recruitment on a sheep-grazed pasture. *Oecologia 127*: 383-394.

GenStat Release 12, VSN International Ltd. 2009. http://www.genstat.co.uk/

Hepp, C.; Valentine, I.; Hodgson, J.; Gillingham, A.G.; Kemp, P.D. 2003. Effects of grass suppression on legume abundance during two contrasting seasons on a summer-dry hill country site. *Legumes for Dryland Pastures. Grassland Research and Practice Series 11*: 123-129.

Knowles, I.M.; Fraser, T.J.; Daly, M.J. 2003. White clover: loss in drought and subsequent recovery. *Legumes for Dryland Pastures. Grassland Research and Practice Series 11*: 37-41.

Lambert, M.G.; Roberts, E. 1976. Aspect differences in an unimproved hill country pasture. 1. Climatic differences. *New Zealand Journal of Agricultural Research 19*: 459-467.

Lonati, M.; Moot, D.J.; Aceto, P.; Cavallero, A.; Lucas, R.J. 2009. Thermal time requirements for germination, emergence and seedling development of adventive legume and grass species. *New Zealand Journal of Agricultural Research 52*: 17-29.

Olsen, S.R.; Cole, C.V.; Watanabe, F.S.; Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA.

Power, D.R. 2006. Defining the subterranean clover zone on Mt Grand, Central Otago. MApplSc thesis. Lincoln University.

Power, D.R.; Pollock, K.M.; Lucas, R.J.; Moot, D.J. 2006. Clover species cover on summer dry hill country in Central Otago. *Proceedings of the New Zealand Grassland Association 68*: 343-347.

Searle, P.L. 1979. Measurement of adsorbed sulphate in soils-effect of varying soil extract ratios and methods of measurement. *New Zealand Journal of Agricultural Research 22*: 287-290.

Singh, D.K.; Sale, P.W.G. 1998. Phosphorus supply and the growth of frequently defoliated white clover (*Trifolium repens* L.) in dry soil. *Plant and Soil 205*: 155-162.