

Are there benefits of pasture species diversity in hill country?

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Abstract

We conducted an experiment at two hill country sites in the North Island to determine whether more diverse pasture swards were beneficial in terms of pasture herbage yield and resistance to weed invasion. In this study diversity was characterised by variation in the number (between 0 and 8) of functional groupings of pasture plant species. Seed mixtures were oversown into sprayed resident pastures in low and high fertility paddocks and steep and easy slopes within those paddocks. We measured pasture yield in terms of net herbage accumulation in spring and autumn of 1999-2000 and the botanical composition of the harvested material, identifying unsown species in the plots. The dominant influences on pasture yield were site, fertility and slope, rather than species diversity. The presence of particular functional groups was also weakly associated with differences in pasture yield. Increasing the number of functional groups sown had a negative effect on the invasion of unsown species, and their contribution to yield, and this may be the main benefit of pasture diversity.

Keywords: functional groups, hill country, pasture yield, species diversity, weed invasion

Introduction

Improvements in the production and persistence characteristics of New Zealand hill country pastures can be achieved through changes in botanical composition, by oversowing desirable pasture cultivars (Williams *et al.* 1982; Lambert *et al.* 1985), by grazing effects through subdivision and grazing management (Bircham 1977), and by the addition of fertiliser (Lambert *et al.* 1982). These attempts to alter botanical composition effectively represent decreases in species diversity, since the aim has traditionally been to manipulate the sward toward the dominance of a few species having highly desirable animal feed characteristics. In hill country, gains in pasture production and shifts in species composition have been demonstrated following the introduction of new species (Barker *et al.* 1993). However, attempts to increase the proportions of desirable species already present (by introducing new cultivars) have met with little long-term success (Dodd *et al.* 2001). Botanical

composition usually reverts to the pre-sown state, demonstrating the strong resilience of these pasture communities.

Much of New Zealand's pasture cultivar development has historically been dominated by a few species, mainly perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) but also to a lesser extent species such as cocksfoot (*Dactylis glomerata*) and subterranean clover (*Trifolium subterraneum*) (Charlton & Stewart 1999). More recently there has been greater interest in the development and use of a wider range of pasture species, recognising the limits of adaptability of the commonly used species (Charlton & Belgrave 1992). This could be interpreted as recognition of the importance of species diversity for the desired functions of hill country pasture ecosystems (e.g. forage production, seasonality of growth and feed quality).

The relationship between species diversity and ecosystem function has received a great deal of international research attention in recent years. Two major issues have emerged: the impact of diversity on the magnitude of ecosystem processes (e.g. productivity), and on the stability of ecosystem processes (e.g. resistance to invasion). Experiments with randomly assembled communities in grasslands have generally shown positive relationships between these characteristics. However, analyses of diversity-productivity patterns in natural grasslands typically show a negative relationship, whereby the most productive ecosystems have low diversity (Loreau *et al.* 2001). An important aspect of the discussions has been whether these types of relationships are driven by species diversity *per se*, by the characteristics of individual species or by clusters of species with similar characteristics (functional groups). Typical functional groupings reported in many New Zealand grassland studies are limited to grasses, legumes and weeds. Nicholas *et al.* (1998) developed a set of six functional groups for New Zealand hill country pasture species based on responses to management and environmental factors, but found no clear relationship between species diversity and pasture production.

The objectives of the experiment described in this paper were to use constructed pasture communities

to test whether pasture species diversity affects two important functional characteristics of hill country pasture swards: pasture yield (i.e. herbage dry matter accumulation) and stability (i.e. invasion by unsown species). If such relationships were found to exist, it was of interest to determine whether there was any influence of spatial variation (in site, slope and fertility) on those relationships. Similar overseas studies have involved transplant approaches and intensive weeding to maintain botanical composition. However, those types of study have limited practical value for pastures that are usually established by oversowing or drilling and maintained by lower levels of selective weed control.

Methods

Study site locations

The experiment was conducted at two locations in the North Island, the Whatawhata Research Centre and the Ballantrae Hill Country Research Station. There were a number of environmental and management differences between these two locations, but primarily Whatawhata was warmer, with a pronounced summer dry period from January-March, and pastures were more subject to rotational grazing. The main soil type at the Whatawhata trial site is the Kaawa hill soil, a sedimentary soil with volcanic ash cover on the ridges (Bruce 1978). The main soil types at the Ballantrae trial site are the Ngamoko silt loam and the Mangamahu steeppland soil, both sedimentary soils with some loessal influence (J.D. Cowie & R.H. Wilde pers. comm.). Experimental sites at both locations were on sunny NW aspects.

Plant material

Plant species diversity was represented by eight functional groups, in an extension of the groups identified by Nicholas *et al.* (1998). A C₄ species group was added that was not present in their analysis

(Table 1). The groups were developed on the basis of a number of distinguishing features: 1) broad taxonomic groups (i.e. grasses, leguminous forbs and non-leguminous forbs); 2) phenology (i.e. annuals and perennials); 3) physiology (i.e. C₃ and C₄ grasses); and 4) dominance of the ecosystem biomass at the two locations (i.e. ryegrass and browntop were regarded as functional groups in this sense, for Whatawhata and Ballantrae respectively).

Each functional group included a mixture of species and/or seed sources so that it comprised a diversity of well-adapted plant material, to ensure establishment success at both sites. Seed mixes included registered cultivars, hill country seed lines held at the Margot Forde Forage Germplasm Centre, and seed collected from ecotypes at both Ballantrae and Whatawhata during the summer and autumn of 1997/98. For each functional group, the composition of the seed mix at both locations was identical.

Experimental design

The experiment used a balanced partially confounded factorial design (Federer 1955). There were 256 (2⁸) plots, representing every possible number and combination of 8 functional groups. While this design means that most of the plots are in the middle of the range of functional group combinations (i.e. 3-5), it allows for the effects of number of functional groups and identity of functional groups to be estimated independently. Superimposed within this treatment structure was a 2×2×2 factorial combination of location (Whatawhata and Ballantrae), slope (gentle [0-10°] and steep [20-30°]) and fertility (high [Olsen P >30] and low [Olsen P <12]). Each combination of slope and fertility had 2 replicate blocks at each location, and within each of the total of 16 sites, 16 1m² plots were marked for allocation of the functional group treatment combinations.

To achieve as much uniformity of initial conditions for the plots (within a block) as possible, visual assessments of plot topography and botanical composition were made. This was supported by cluster analysis of composition data to identify and remove outliers. Botanical composition was measured in December 1997 by harvesting herbage from 0.25m² quadrats in the plots to a height of 10 mm, separating herbage sub-samples by species and measuring dry weights.

Sward establishment

The plots were sprayed twice with Roundup®, three months and one

Table 1 Eight functional groups sown in the plots.

Functional Group	Species	Common name
Dominant species (Whatawhata)	<i>Lolium perenne</i>	ryegrass
Dominant species (Ballantrae)	<i>Agrostis capillaris</i>	browntop
Perennial legumes	<i>Trifolium repens</i>	white clover
Annual legumes	<i>T. dubium</i>	suckling clover
	<i>T. subterraneum</i>	subterranean clover
Perennial grasses	<i>Cynosurus cristatus</i>	crested dogstail
	<i>Holcus lanatus</i>	Yorkshire fog
Perennial C ₄ grasses	<i>Paspalum dilatatum</i>	paspalum
Annual grasses	<i>Bromus hordeaceus</i>	goose grass
Perennial forbs	<i>Plantago lanceolata</i>	plantain
	<i>Hypochaeris radicata</i>	catsear

month prior to oversowing in June of 1998. Seed weight and germination data were used to construct the seed mixtures, with the aim of applying a total of 1000 viable seeds/m².

Measurements

Herbage accumulation was measured in spring 1999 and summer/autumn 2000. Plots were pre-trimmed to 20 mm height in September and caged for a period of approximately 40 days, then harvested to the same height from a 0.25 m² quadrat (Whatawhata) or a 0.48 m² quadrat (Ballantrae). The plots were pre-trimmed again in February and caged for a period of approximately 70 days, then harvested to the same height. Harvested pasture was sub-sampled for separation into the individual species components of herbage mass. Bulk and sub-sample material was oven dried and weighed. Results are expressed on a kg DM/ha equivalent basis. Total numbers of species present in the sub-samples were recorded and numbers of unsown species counted. Unsown species included species other than those listed in Table 1, and those in Table 1 but not sown on specific plots. We were unable to distinguish the contribution of volunteer plants where the same species was sown in a specific plot.

Some supplementary measurements were made at Whatawhata only. Pre-trial assessments of species richness and diversity on resident pastures were made by calculating a Shannon-Weaver (1949) index for each plot using the species dry-weight data noted above. Cover assessments were made using point estimates (80 per plot) on the plots in August 1999 prior to herbage harvests.

Statistical analyses

The relationship between the main treatment factors (location, slope, fertility and number of functional

groups sown) and the response variables of interest (relative yield in spring and autumn, number of invaders, proportion of yield as unsown species) was explored using analysis of variance, performed with the PROC GLM function of the SAS[®] statistical software package. In addition, to examine the importance of the identity of functional groups (as opposed to number) sown, the stepwise selection option of PROC REG was used to construct regression models for the same response variables, but including dummy variables for the presence/absence of particular functional groups as well as the site factors noted above in the list of independent variables available to the procedure. Significance levels for entry and exit of terms in the statistical model were set at 0.05.

Results and discussion

Location, slope and fertility treatments all influenced pasture yield, as measured by net herbage accumulation (Table 2). Higher yields in spring were measured at Ballantrae, on easy slopes and on high fertility paddocks (though the latter effect was only statistically significant at $P < 0.10$). The pastures at Ballantrae were dominated by browntop (*Agrostis tenuis*), which typically has high growth rates around the late spring period over which harvests were made in this experiment (Rumball & Claydon 1990). In autumn, yield differences between location, slope and fertility treatment followed the same patterns, but were more marked. It is likely that summer moisture stress was a key factor affecting this observation, being more marked at Whatawhata and on steep slopes.

The invasion of unsown species into the plots was greatest on steep slopes and low fertility paddocks, though these differences did not translate into a significantly greater proportion of yield from unsown species at these sites (Table 2). Steep slopes and low fertility sites had lower pasture cover (Table 3) and thus more sites available for colonisation by invaders, and this effect is consistent with observations of greater species richness and diversity on such sites, as measured on resident pastures prior to this experiment (Table 3).

The number of functional groups sown into the plots had no significant effect on total yield in spring (Figure 1). Results for autumn were similar (data not presented). However, when the yield calculation and subsequent

Table 2 Main effects of location, slope and fertility on plot yield (kgDM/ha equivalent) and invasion by unsown species (significant differences for $P < 0.05$ indicated by different letters).

Treatment	Total plot yield (spring)	Total plot yield (autumn)	No. of species invading	% of yield as unsown species
Location				
Ballantrae	1286 a	1129 a	*	46 a
Whatawhata	937 b	181 b		41 a
Slope				
Easy slope	1195 a	813 a	6.0 a	46 a
Steep slope	1028 b	497 b	6.2 a	41 a
Fertility				
Low fertility	1053 a	488 a	6.5 a	45 a
High fertility	1171 a	822 b	5.8 b	42 a

*between-location comparison not valid due to differing plot sizes.

analysis was repeated using only the data from sown species, there was evidence of a functional group diversity effect on yield. Increasing the number of functional groups sown did increase sown species yield with the addition of the first 1-3 species, but not significantly thereafter. This effect was significant ($P < 0.05$) in the analysis of variance model. This 'diminishing returns' effect of adding species is consistent with results from constructed grassland experiments (Tilman 1999). What was demonstrated by the comparison between total and sown yield is the dampening of this effect when re-invasion of the plots was allowed from the local species pool. Under normal farm conditions this would be the case, and hence any beneficial effect of species diversity in sown mixtures would soon be lost.

There was a significant beneficial effect of functional group diversity on the resistance of the plots to the re-invasion process. Plots with greater numbers of functional groups sown were invaded by fewer species, and those species contributed less to total herbage accumulation (Figure 2). This indicates that more diverse sown mixtures will lead to less "weedy" pastures and slow down the process of reversion to resident swards. It has been suggested that more diverse communities use a greater proportion of total available resources, and are therefore more resistant to invasion by new species (Tilman 1999).

The regression models confirmed the importance of 'environmental' factors (location, slope and fertility) in contributing to yield. Location and slope variables were selected for the spring yield model and location, fertility and slope variables were selected for the autumn yield model (Table 4). However, the latter model also included the presence of perennial grasses (Yorkshire fog, *Holcus lanatus*; crested dogstail, *Cynosurus cristatus*) as having a positive influence on autumn yield. This suggests that the identity of the seed mix components has a

Table 3 Percentage of cover as bare ground on the trial plots in August 1999; and species numbers and diversity as measured in resident pastures at Whatawhata.

Site	Bare ground cover (%)	Mean number of species recorded	Shannon-Weaver diversity index
Slope			
Easy slopes	4.3	10.4	1.47
Steep slopes	8.1	12.1	1.67
Fertility			
Low fertility	7.1	13.2	1.90
High fertility	5.3	9.3	1.25
SEM	0.7	0.3	0.04

Figure 1 Plot yield in spring 1999 with varying number of functional groups sown (bars represent SEM).

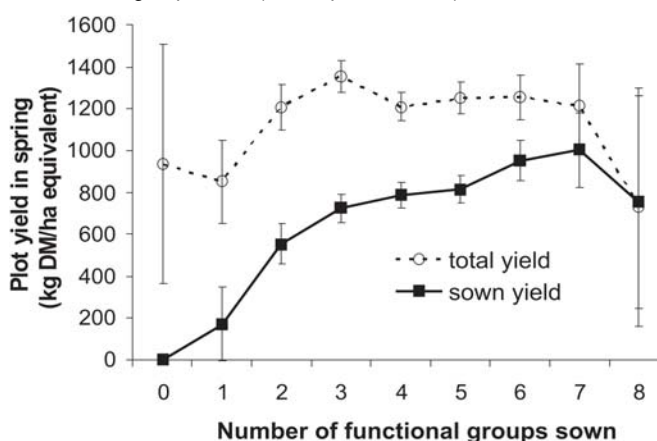
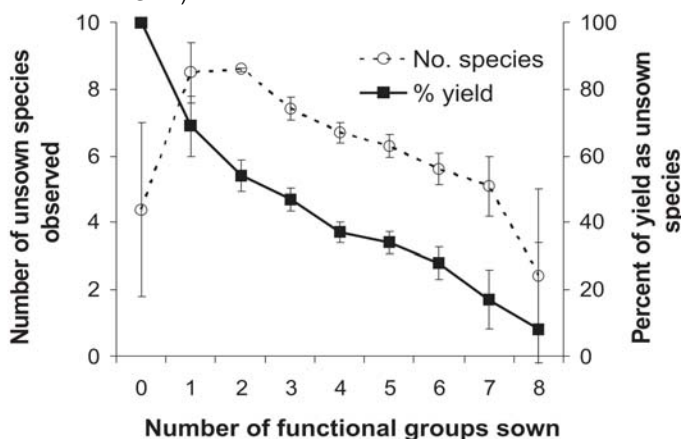


Figure 2 Resistance of plots to invasion by unsown species with varying number of functional groups sown (bars represent SEM).



role in determining total yield, apparently more so than species diversity *per se*.

The regression model for the percentage of yield attributable to unsown species also identified the

presence of a number of functional groups as having a negative effect on this parameter (Table 4). The list included browntop, perennial grasses, perennial forbs (plantain, *Plantago lanceolata*; catsear, *Hypochaeris radicata*) and ryegrass. Thus the identity of the seed mix components also has an impact on improving the ability of the sown sward to resist invasion by unsown species.

Overall, there were no significant first order interactions between the number of functional groups sown and the location/slope/fertility factors, for any of the response variables of interest. This indicates that the main effects (or lack of) outlined above were consistent under the variation in environmental factors examined.

In summary, from a pasture management point of view, these short-term results indicate no pasture yield advantage of greater species diversity in sowing mixtures, but do suggest that sowing diverse mixtures can 'fill' sites with desirable species and exclude undesirable invaders (i.e. weeds, by definition). The medium-long term implications of increased pasture plant diversity remain to be further researched, and other relationships addressed, e.g. effects of plant diversity on pest populations.

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REFERENCES

- Barker, D.J.; Lancashire, J.A.; Moloney, S.C.; Dymock, N.; Stevens, D.R.; Turner, J.D.; Scott, D.; Archie, W.J. 1993. Introduction, production and persistence of five grass species in dry hill country 8. Summary and conclusions. *New Zealand Journal of Agricultural Research* 36:61-66.
- Bircham, J.S. 1977. Grazing management for the improvement of browntop pastures in hill country: a programme. *Proceedings of the New Zealand Grassland Association* 38:87-93.
- Bruce, J.G. 1978. Soils of part Raglan County, South Auckland. *New Zealand Soil Bureau Bulletin* 41.

Table 4 Regression models for three response variables developed by stepwise selection (+/- sign indicates direction of effect).

Response variable	Selected terms	Partial r ²	P-value
Spring total yield	location (-)	0.08	<0.01
	slope (-)	0.02	0.03
Autumn total yield	location (-)	0.43	<0.01
	fertility (-)	0.06	<0.01
	slope (+)	0.05	<0.01
	perennial grasses (+)	0.01	<0.01
Spring % yield as unsown species	browntop (-)	0.22	<0.01
	perennial grasses (-)	0.08	<0.01
	perennial forbs (-)	0.06	<0.01
	ryegrass (-)	0.01	0.04

Soil Bureau, DSIR, Wellington.

- Charlton, J.F.L.; Belgrave, B.R. 1992. The range of pasture species in New Zealand and their use in different environments. *Proceedings of the New Zealand Grassland Association* 54:99-104.
- Charlton, J.F.L.; Stewart, A.V. 1999. Pasture species and cultivars used in New Zealand – a list. *Proceedings of the New Zealand Grassland Association* 61:147-166.
- Dodd, M.B.; Sheath, G.W.; Wedderburn, M.E.; Tarbotton, I.S. 2001. Long-term performance of white clover in summer-dry hill country. *Proceedings of the New Zealand Grassland Association* 63:85-89.
- Lambert, M.G.; Luscombe, P.C.; Clark D.A. 1982. Soil fertility and hill country production. *Proceedings of the New Zealand Grassland Association* 43:153-160.
- Lambert, M.G.; Rhodes, A.P.; Barker, D.J.; Bircham, J.S. 1985. Establishing and managing improved plants in hill country. pp. 31-34. *In: Using Herbage Cultivars. Grassland Research and Practice Series No. 3.* Eds. Burgess R.E.; Brock J.L. New Zealand Grassland Association, Palmerston North.
- Loreau, M.; Naeem, S.; Inchausti, P.; Bengtsson, J.; Grime, J.P.; Hector, A.; Hooper, D.U.; Huston, M.; Raffaelli, D.; Schmid, B.; Tilman, D.; Wardle, D.A. 2001. Biodiversity and ecosystem functioning: Current knowledge and future challenges. *Science* 294:804-808.
- Nicholas, P.K.; Kemp, P.D.; Barker, D.J. 1998. Biodiversity, stability and pasture management – the role of functional groups. *Proceedings of the 9th Australian Agronomy Conference*: 294-297.
- Rumball, W.; Claydon, R.B. 1990. The breeding of 'Grasslands Muster' browntop and other low-fertility grasses for moist hill country. *Proceedings of the New Zealand Grassland Association* 51: 143-146.

- Shannon, C.E.; Weaver, W. 1949. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, Illinois.
- Tilman, D. 1999. The ecological consequences of changes in biodiversity: a search for general principles. *Ecology* 80:1455-1474.
- Williams, W.M.; Lambert, M.G.; Caradus, J.R. 1982. Performance of a hill country white clover selection. *Proceedings of the New Zealand Grassland Association* 43:188-195.