Long-term experiments in the South Island high country: an example from Mt. Possession, Canterbury

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Abstract

This paper discusses the successional changes that have occurred during 13 years of a designed experiment in short tussock grassland. The experiment site is at Mt. Possession Station, Canterbury and was established in 1979. Nine species of legume were overdrilled and 9 phosphate rates (0-800 kg P/ha) broadcast at sowing. A vegetation survey of all plots was carried out in November 1991 and soil sampled in the following year. Legumes were dominant during the early years of the experiment but the responses to P rates differed. Some of the differences in the present vegetation could be explained by earlier treatment effects. Exotic grasses invaded the plots which received higher levels of fertiliser with the exception of plots sown with *Lupinus* species where grass growth was independent of the applied P rate. The initial treatments have strongly affected present vegetation. Had an attempt been made at the beginning to predict the current composition, or even half way through the experiment, the conclusions are unlikely to have been realistic. It is suggested that the dynamics and composition of the responses are inter-related and complex, and as such, they require long-term monitoring before any predictions can be made.

Keywords: long-term experiment, phosphate gradient, sown legumes, species composition, tussock grasslands

Introduction

The increasing abundance of *Hieracium* spp. in the native tussock grasslands of the South Island (Hunter 1991; Treskonova 1991a; Hunter *et al.* 1992) has been ascribed to the degradation of these ecosystems (Treskonova 1991a, 1991b). One aspect of a degraded ecosystem is depletion in soil fertility. This has been modelled in tussock grasslands (O'Connor & Harris 1991) but little attempt has been made to investigate the effect of soil fertility on species composition in a community. A better understanding of this relationship could assist in assessing the stage of vegetation decline.

The objective of this paper is to give an example of long-term effects of fertiliser application on species composition in a high country experiment and demonstrate how such results might be useful for management.

Methods

Site description

The study site was an existing experiment at Mt. Possession Station, Canterbury, established in short tussock grassland by the Forest Research Institute in 1979. It is located in the lake district of the upper Ashburton at an altitude of 680 m with a mean annual rainfall of 870 mm (Thompson 1985). The soil belongs to the Pukaki series of the yellow-brown earths. The experimental area was fenced from livestock and had not been cultivated or fertilised before the experiment was set up (Davis 1991). The initial aim of the experiment was to compare the performance of a range of legumes that were known to vary in edaphic adaptation along a phosphate gradient (Davis 1991). Nine species of legume were overdrilled, together with a non-legume control, and 9 phosphate (P) rates broadcast at sowing as superphosphate (Table 1). Altogether there were 90 treatments, each replicated 4 times. All plots were 2.3x4 m in size and they received a basal application of magnesium, potassium, sulphur and molybdenum. Since 1979 no further fertiliser applications have been made. Four new plots were established in the summer of 1991/92 within the exclosure but in an untreated area to act as indicators of natural succession which had occurred since the area was excluded from stock.

Table 1 Initial treatments at Mt. Possession.

Sown legumes:	Phosphorus rate (kg P/ha)
Trifolium repens (Grasslands Huia)	0
Trifolium pratense (Grasslands Pawera)	6.25
Trifolium hybridum (Terra)	12.5
Trifolium ambiguum (Prairie)	25
Medicago sativa (Wairau)	50
Lotus corniculatus (Maitland)	100
Lotus pedunculatus (Grasslands Maku)	200
Lupinus arboreus	400
Lupinus polyphyllus	800
Fertiliser only	

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Data gathering

The species present were recorded, together with their abundance using the Braun-Blanquet scale (r=rare, one or few individuals; +=occasional plants. cover<1 %; l=cover 1-5%; 2=6-25%; 3=26-50%; 4=51-75%; 5=76-100%; Westhoff & van der Maarel 1978). The vegetation cover was estimated in November 1991. There was the concern that planted trees could have affected the species composition in some plots and consequently these were deleted from the data set. Ten soil cores to 15 cm depth were taken from each plot. The 10 cores were bulked, air dried at 25°C and sieved through a 2 mm sieve. Soil total P, inorganic P, organic P, pH (Blakemore et al. 1987) total nitrogen (N) and total carbon (C) (Goh pers. comm.) were analysed.

Data analysis

Because of the number of variables in the data set, multivariate analyses were chosen. The species data were first studied by applying correspondence analysis (CA) to investigate the distributional pattern of the data set (based on the midpoints of the cover values of the Braun-Blanquet scores). Results and patterns observed from the CA tables implied that the species response curves to their environment were bell-shaped and therefore it was acceptable to use unimodular methods. The next step was the use of canonical correspondence analysis (CCA) which was applied on the data set using treatments and measured soil components as environ-mental variables. Replicates were used as covariables for excluding the variance, if any, between them. The analyses were carried out using the program CANOCO version 3.1 (ter Braak 1988 and 1990). The soil data were also analysed by analysis of variance (ANOVA) using SAS, version 6.07 (Sas Institute Inc. 1990).

Results

Results of the two ordination techniques show a differentiation in species composition along a fertility gradient. Eigenvalues in ordination indicate the variance in the analysed data set which the relevant axis explains and in general the higher the eigenvalue, the more important is the axis (ter Braak 1988). An eigenvalue is also a measure of dispersion of the variables (e.g. species) along the ordination axis (Jongman et *al.* 1987). In this study the first two axes explained most of the variance in the species composition for both types of analyses (First axis: 0.56, 0.39; second axis: 0.49, 0.34; third axis: 0.30, 0.17; fourth axis: 0.24, 0.10; for CA and CAA respectively). Having ranked the plot and species scores obtained for the first ordination axis in CA, a pattern was observed. Plots that received low or nil superphosphate received lowest CA scores and plots with high P rate received the highest scores. Since the spread of the plots along the first two axes indicated some kind of fertility gradient a Spear-man correlation coefficient was calculated for the plot scores of the first axis and applied P rate giving overall r_s=0.67 ($P<0.001$). This was consistent with the results from CCA in which the first ordination axis was determined mainly by the applied fertiliser and soil P with additional contribution from *Lupinus* spp. and untreated plots (Figure 1). The second axis was strongly linked to sown *Trifolium ambiguum.* Plots with *T. ambiguum* differed from those containing other legumes in the way that *T. ambiguum* was still dominant in the highest P rate, excluding most other species. The only other legume that was found dominant in any plot was *Lupinus polyphyllus* that had also invaded many plots of other legume treatments over time. The general pattern was that the number of species decreased with increasing fertility and native species mostly disappeared at the highest fertility. The largest differences were between plots that received 12.5 kg P/ha and those that received 200 kg P/ha or more ($P<0.05$). Species richness also differed between sown legumes. While all the clovers showed similar results the plots that contrasted were those that had *L. polyphyllus.* The lupin plots had fewer species along the whole P gradient than any other legume and only few native species grew there.

Of the measured soil components inorganic P had the most influence on species composition (r^2=0.75 in correlation with the first environmental axis, $P<0.001$) and also positively correlated with applied P rate (rk0.89, $P<0.001$; meaning that the more P applied in 1979 the higher the soil inorganic P in 1992). Inorganic soil P was the soil component that varied most between applied P levels ($P<0.001$ in ANOVA, Table 2). Soil pH averaged 5.84, %N 0.52, %C 7.31 and C/N ratio 13.95. They explained very little of the species variation even though their trends were informative.

Discussion

The superphosphate applied in 1979 has had the most effect in determining the species composition in 1991 although some legumes also contributed to the picture. During the first few years of the experiment the vegetation went through a legume-dominant stage (Davis 1991). All legumes responded to superphosphate except the *Lupinus* spp. which had high production throughout the P gradient because of its known ability to grow on soils low in available P (Davis 1981).

Figure 1 Treatments and soil components for first and second axes of canonical correspondence analysis (CCA) ordination for the Mt. Possession experiment in 1991192. Legume treatments and the untreated **area** are considered as nominal variables and shown as filled squares while the quantitative variables are displayed with vectors. Three species are displayed with dots: *A odo* = *Anthoxanthum odoratum, A cup* = *Agrostis capillaris, Ppra* = *Poa pratensis.*

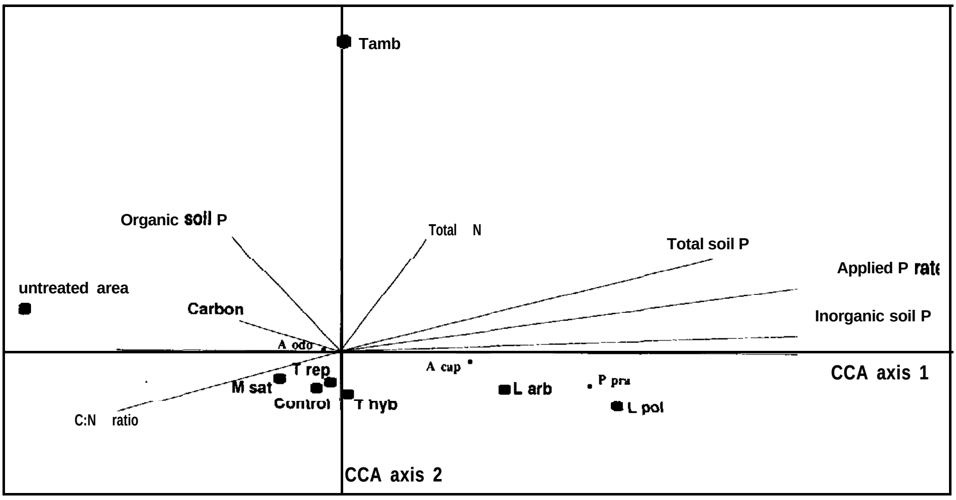

Table 2 The effect of P applied in 1979 on total, inorganic and organic soil P levels at Mt. Possession in 1992.

P rate	Sample #	P_{total} ppm	$P_{inorganic}$ ppm	$P_{organic}$ ppm
6.25	21	796	77	719
12.5	29	672	65	767
25	30	796	99	697
50	33	869	111 111	756
100	21	906	123	763
200	36	946	161	766
400	30	1070	305	765
600	39	1350	646	702
SE_{mean}[1]		35.3 ***	26.3 ***	34.6 *
CV		13	41	16

Significant levels are indicated with stars. * = $P < 0.05$, *** = $P < 0.001$.[1] SE varies between treatments because of the unbalanced design caused by the trees affect. A conservative approach is followed here showing the largest SE for each treatment.

However, there were differences in the response between legumes, with *Trifolium* spp. (except *T. ambiguum)* being much more productive than any of the other pasture legumes after one growing season. This changed slightly in the second season with relatively greater increases in productivity of *Lotus corniculatus* and *T. ambiguum* than any of the other species (Davis 1991). Grass invasion into plots was recorded as early as 1981 after a dry summer (Davis 1991). The introduced grasses most commonly found in 1991 when ranked along the applied P gradient (the ranking is also valid for inorganic soil P) were *Poa pratensis* at the highest rates, followed by *Agrostis capillaris* and *Anthoxanthum odoratum* (Figure 1). Little grass (mainly *A. odoratum)* occurred in the lowest P rate where *Hieracium pilosella* was a dominant species.

All of the legumes were still in the experiment 13 years-after the-establishment-but-their-frequency-varied-greatly and only *L. polyphyllus* and *T. ambiguum* were found in any abundance. Species composition differed between these two legume treatments and they were also distinct from any other species treatment (Figure 1). The distinctive position of *T. ambiguum* treatment in Figure 1 is suggested to be due to its dominance in the highest P rates whereas other species are mostly excluded. This is probably caused by the enormous below-ground biomass (15-20 t/ha) that has been observed under these conditions (Strachan *et al.* 1994). Vigorous grass growth occurred in all plots with sown *L. polyphyllus,* and its location in Figure 1 suggests that the legume simulates high P rate plots. Only a few native plants grew under these conditions of tall legume and grass growth.

This research demonstrates that we are able to change the soil fertility with sown legumes and superphosphate and hence affect vegetation composition. These effects on vegetation composition do not occur all at the one time, but occur as a series of changes initiated by the combination of treatments at the outset, and expressed as diverging outcomes while potentially complicating influences were excluded. Management treatments applied at the beginning, whether in an experiment or in farm practice, may influence the present condition of vegetation far more than current management treatments (O'Connor & Harris 1991). This stresses the need to set clear objectives for each occasion since management options differ depending on them. There would for instance be different approaches to achieve native species conservation than for productivity.

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