New Zealand Forest Site Management Cooperative

LEGUMES FOR IMPROVING SOIL NITROGEN STATUS IN CANTERBURY DRY LAND FORESTS

By

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Legumes for Improving Soil Nitrogen Status in

Canterbury Dry Land Forests

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Summary

Seventeen legume species were evaluated in a trial at Eyrewell Forest for their potential to improve the nitrogen (N) status and productivity of Canterbury dry land forests.

Legume productivity was evaluated visually at five assessments over a three year period, after which the legumes were removed with herbicide and radiata pine seedlings were planted in the plots to measure the effect of legumes on subsequent tree growth and foliar N concentration. The effect of the legumes on total N levels in soil was also determined.

The best performing legumes were tree lupin, perennial blue lupin, Maku lotus and seredella. Although the lupins performed well over the short trial period, their lack of persistence because of lupin blight limits their potential for improving soil N levels and forest productivity. Maku lotus was a little more productive than seredella, and is considered to have good potential for forest use on drought-prone Canterbury plains soils. However the good performance of Maku lotus relative to other legumes may have been aided by higher than normal growing season rainfall during the first two years of the trial.

Both soil total N and tree foliar N levels were positively correlated with visually estimated legume growth averaged over the trial period, indicating legumes increased N availability in proportion to their productivity. However legumes did not significantly improve tree growth over the two year period of evaluation.

In a separate trial Russell lupin did not respond to superphosphate, but approximately 500 kg/ha of superphosphate was required for optimum productivity of alsike clover. Other pasture legumes, including Maku lotus, are likely to have similar phosphate requirements to alsike clover.

Trials with legumes running the length of a rotation are now required to determine whether incorporation of a legume phase between rotations on Canterbury dry land soils can produce increases in forest productivity sufficient to justify the practice economically.

Introduction

Forests on the free-draining drought-prone soils of the Canterbury plains have marginal foliar N concentrations and have a fairly high probability of N deficiency (Hunter et al 1991). Fertiliser trials at Eyrewell and Balmoral Forests have shown young radiata pine stands respond well to N (Mead 1987). A trial to explore the use of legumes for improving soil N status was established at Eyrewell Forest in 1976 by R. Fitzgerald. Results after 5 years showed soil N levels were increased in the legume plots (from 0.14 to 0.37% in the 0-2.5 cm layer, and from 0.11 to 0.15% in the 2.5-10 cm layer), and tree foliar N levels were also marginally higher in the legume plots. Tree growth was initially lower in the legume plots, but measurements taken at age 15 showed this trend to be reversed. However, as the trial was not replicated and the species used in the trial, namely red and white clovers, and *Lotus pedunculatus*, may not be the best suited to the drought prone soils, a trial was established at Eyrewell Forest in 1992 with a wider range of legumes to find appropriate species for improving soil N levels on dry land forest sites. A second trial was established to determine legume phosphorus (P) requirements. Results of these trials are reported here.

Methods

Site

The trials were located in compartment 23/10 at Eyrewell Forest, approximately 50 km north-west of Christchurch. Annual rainfall averages 850 mm, but is highly variable and summer droughts are common. The soil is a Lismore stony silt loam (pH 5.3) formed from gravels and thin loessial deposits. The selected trial site was logged about 1980, cropped with Christmas trees and then fallowed for six years. Before establishment, the site was sprayed with glyphosate and root-raked to remove existing vegetation, ripped, and then cultivated with agricultural machinery.

Legume species trial

Seventeen legume species (Table 1) were sown in plots measuring 3m x 2m, and given a dressing of 50 kg/ha of P (as superphosphate) and 1 kg/ha of Mo. Seed was inoculated with the appropriate *Rhizobium* bacteria the day before sowing. The plots were harrowed after seeding to cover seed. An unseeded control treatment was included to allow later assessment of soil N accumulation. Lime was applied to half the area of the plots of two species known to prefer less acid soils, (lucerne and Canary clover). The trial was a randomised block design with four replicates. The trial was sown in mid-April 1992, but lack of significant rainfall between mid-January and May resulted in low soil moisture and poor seedling emergence. The trial was re-sown the following August.

Table 1. Species and seeding rates of legumes sown in the species trial.

Species	Common name	Cultivar	Seeding rate (kg/ha)
Perennials			
Trifolium repens	white clover	Huia	4
Trifolium hybridum	alsike clover		4
Trifolium ambiguum	Caucasian clover	Prairie	10
Trifolium ambiguum	Caucasian clover	Treeline	20
Lotus pedunculatus	lotus pedunculatus	Maku	5
Lotus corniculatus	lotus corniculatus	Maitland	5
Coronilla varia	crown vetch	Emerald	40
Hedysarum coronarium	sulla		30
Medicago sativa	lucerne	Wairau	10
Doryicnium hirsutum	hairy Canary clover		10
Perennial Lupins			
Lupinus arboreus	tree lupin		60
Lupinus polyphyllus	perennial blue lupin		200
Lupinus polyphyllus	Russell lupin		60
Annuals			
Vicia dasycarpa	hairy or lana vetch		50
Trifolium subterranean	sub clover	Woogenellup	10
Lupinus angustifolius	annual or bitter blue lupin		200
Ornithopus sativa	serradella	Koha	10

Phosphate requirement trial

Two species, alsike clover and Russell lupin, selected as examples of high and low phosphate (P) demanding legumes respectively, were sown with five rates of P (0, 12.5, 25, 50, and 100 kg/ha) as superphosphate to determine P requirements. Gypsum was applied to balance the varying rates of sulphur applied in the superphosphate. In other respects the trial was similar to the species trial.

Assessment of legume performance

Legume growth was assessed non-destructively by estimating ground cover and measuring sward height, and calculating a growth index (height (cm) x cover (%)). Five assessments were made over a period of 2.5 years in spring (November) and summer (late January or early February).

Effect of legumes on soil N and tree growth
After three years, total N in soil (0-5 cm) was measured in the species trial, and 6 radiata pine seedlings (GF 16) were planted in the plots of the best performing legume species, and in all plots of the P fertiliser trial. All herbaceous vegetation competition was removed from the plots in early October 1995 using herbicide (gardoprim, 15 l/ha; versatill, 2.5 l/ha; gallant, 2.5 l/ha). Further herbicide was applied in October 1996 to maintain the plots free of competing vegetation. Tree height and basal diameter was measured at planting and at the end of the first and second growing seasons. Tree foliar N levels were determined in foliage samples collected in March 1996.

Results

Species trial
Four annual legumes, subterranean clover, seredella, lana vetch, and annual lupin, were included in the trial. The latter two species were the most rapid species to establish (Figure 1). Although seed set appeared satisfactory, re-establishment from seed was poor in both species. Seredella was initially slower to establish but it continually improved to be the second best performing species in the third year of the trial (Figure 5).

Four perennial species (Caucasian clover (two cultivars) crown vetch, and sulla) germinated but failed to grow because of nodulation failure. The performance of these species was therefor not adequately evaluated. The two species to which lime was applied, lucerne and Canary clover, germinated and nodulated but were not productive until the final assessment. Both species responded strongly to lime. The results presented here for lucerne and Canary clover are for the limed half of the plots.

As a group, the three perennial lupins (tree lupin, perennial blue lupin and Russell lupin) established rapidly and grew well initially (Figures 1-4), but then declined. The decline is thought to have been caused by lupin blight (*Colletotrichum gloeosporioides*). Tree lupin was ranked higher than the two herbaceous species, mainly because of greater stem production and height. Of the two species of *Lupinus polyphyllus*, perennial blue lupin was more vigorous than the garden cultivar, Russell lupin.

Of the remaining four perennial species, white and alsike clover initially performed better than the two lotus species, but by the end of the second summer Maku lotus (*Lotus pedunculatus*) had the highest growth index of all the herbaceous species (Figure 4), and its superior performance was maintained in the third year of the trial (Figure 5). Maitland lotus was slow to establish, but improved throughout the trial, though it remained much less productive than Maku.

Figure 1. Legume growth index, spring, year 1.

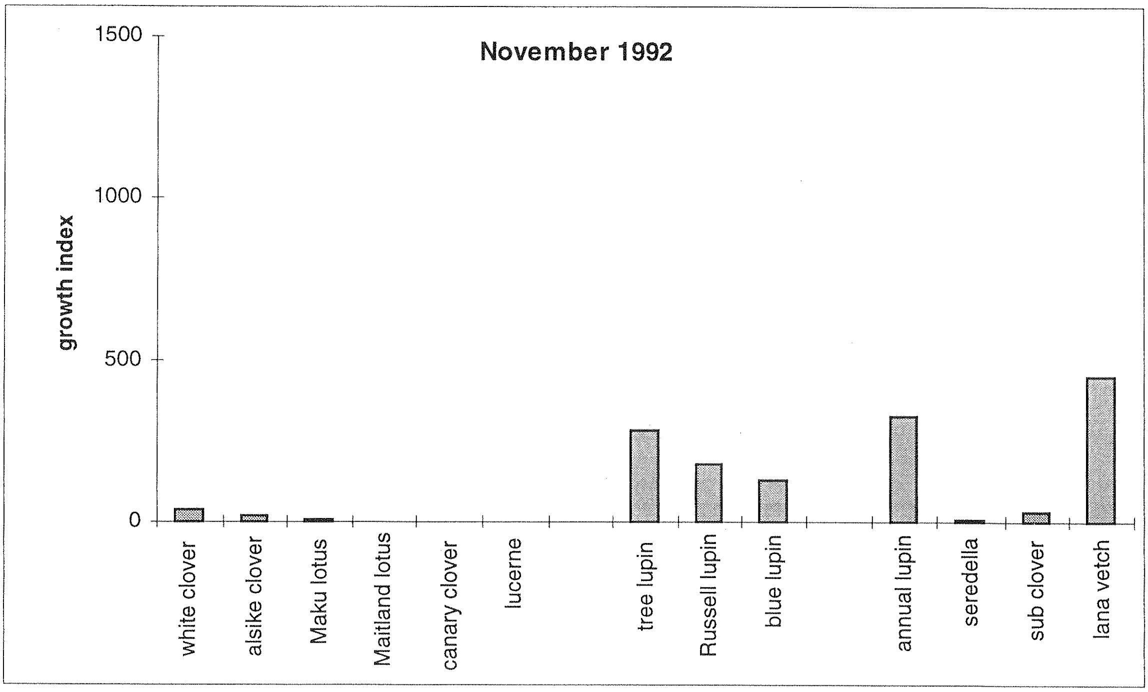


Figure 2. Legume growth index, summer, year 1.

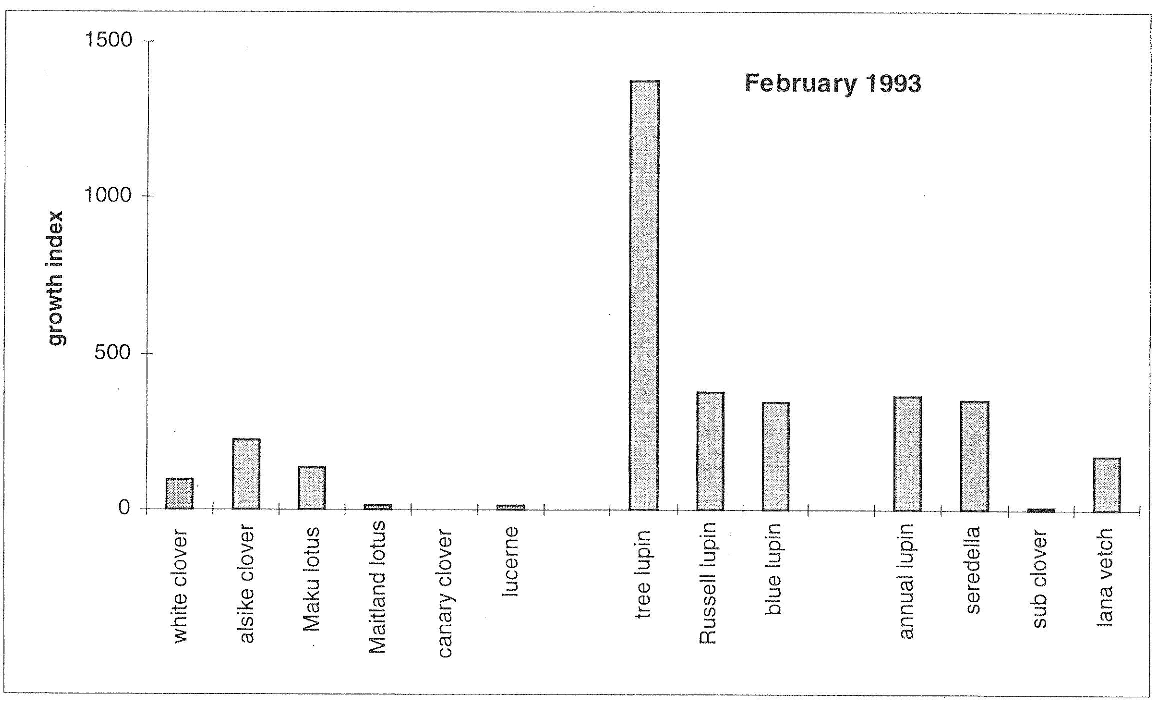


Figure 3. Legume growth index, spring, year 2.

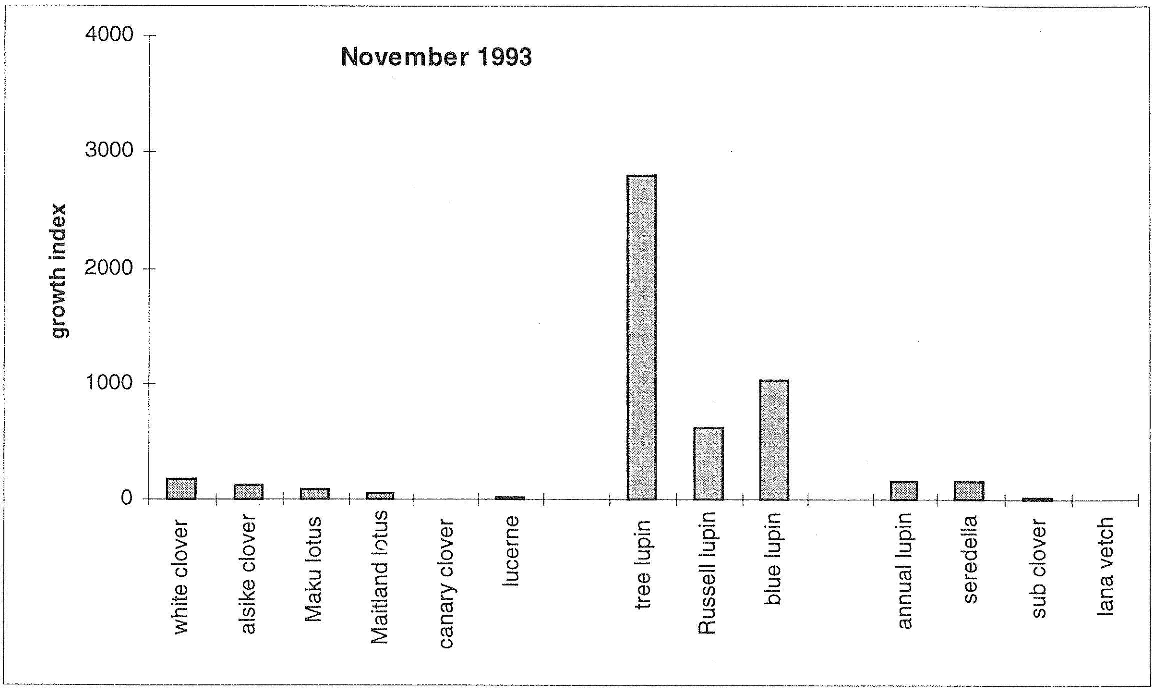


Figure 4. Legume growth index, summer, year 2.

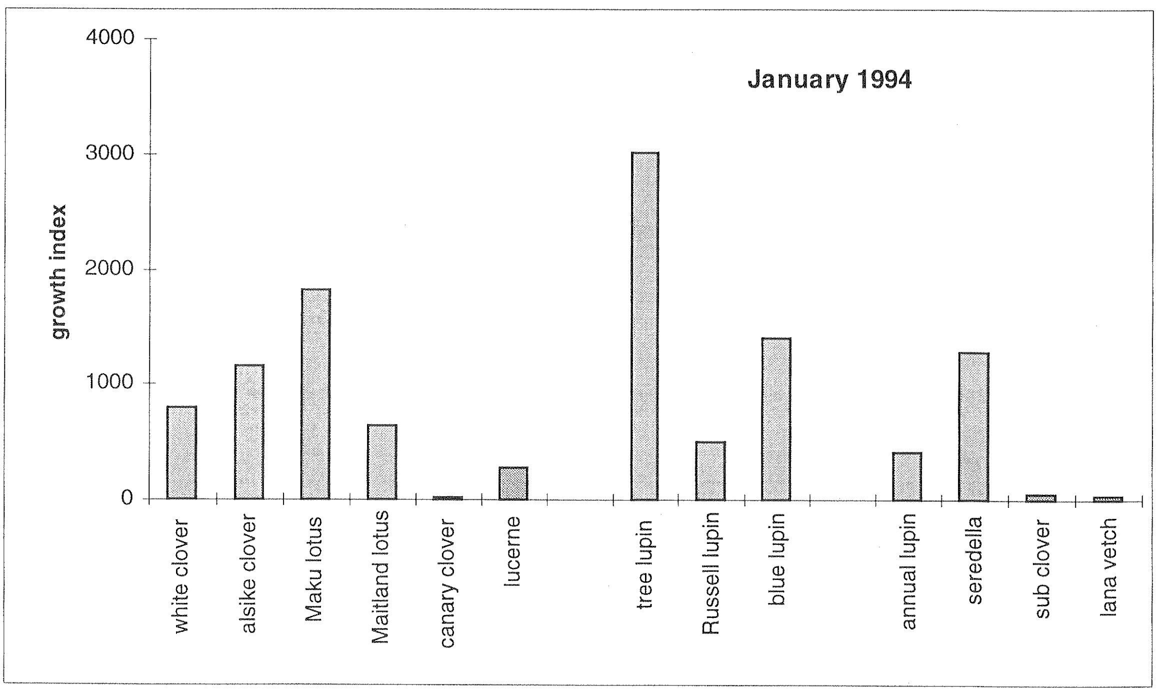


Figure 5. Legume growth index, spring, year 3.

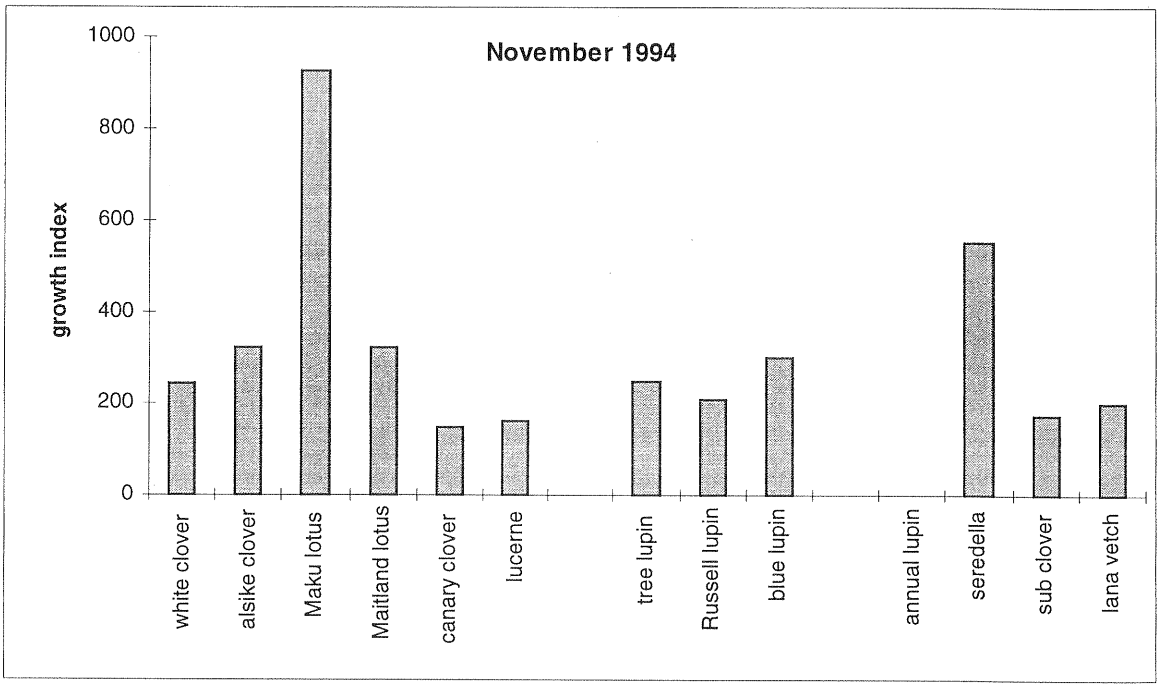
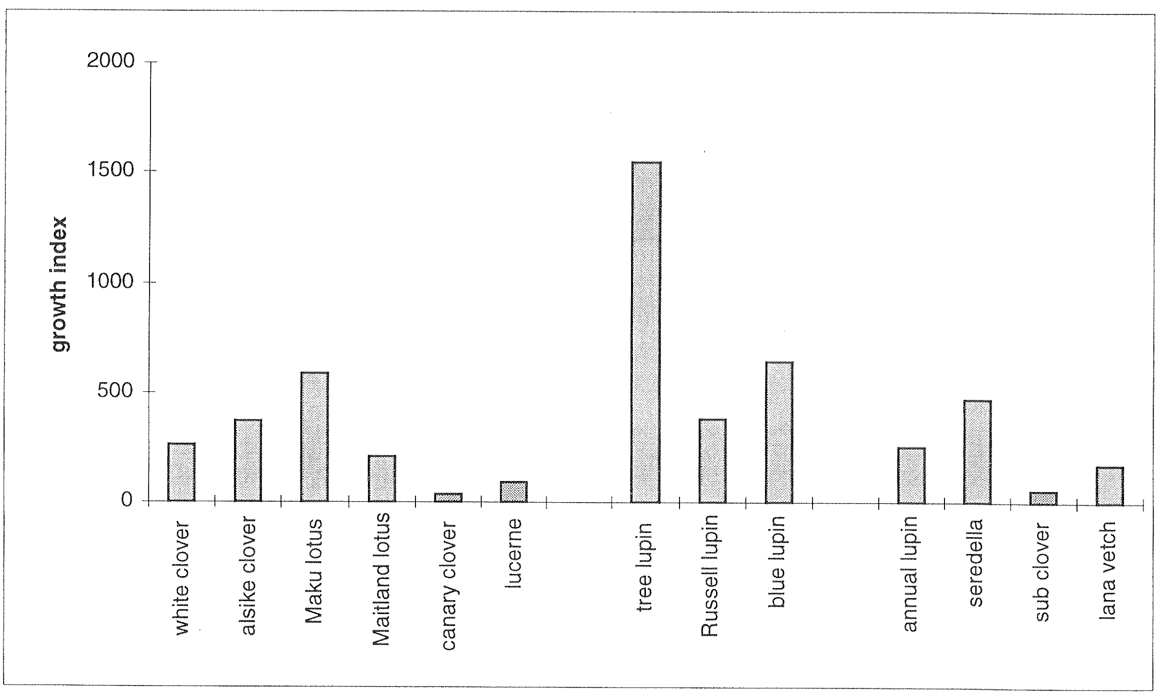


Figure 6. Legume growth index, mean of five assessments.

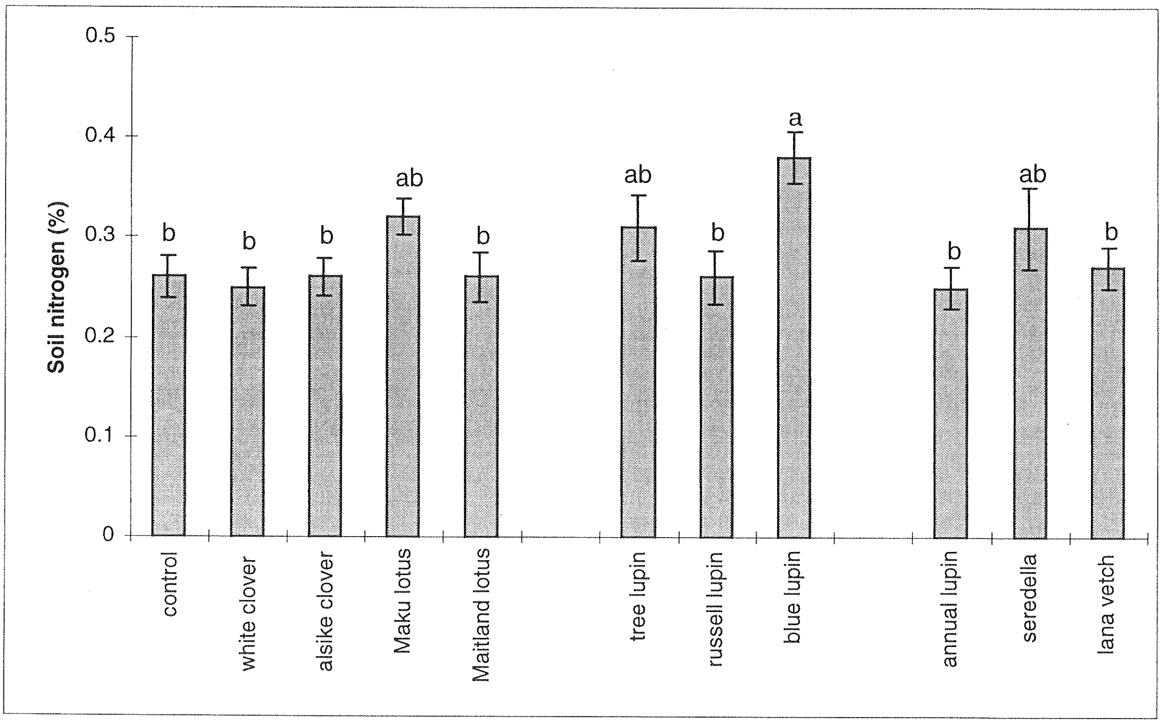


A mean growth index of the five assessments was calculated. The mean growth index declined in the order (omitting species which failed to nodulate):

tree lupin >> perennial blue lupin = maku lotus > seredella > alsike clover = Russell lupin > white clover = annual lupin > Maitland lotus > lana vetch > lucerne = subterranean clover = canary clover (Figure. 6).

Soil total N levels after three years were highest under perennial blue lupin, followed by Maku lotus, tree lupin, and seredella, but only perennial blue lupin had significantly higher soil N levels than the control (Figure. 7). Soil N levels were positively correlated with the mean legume growth index ($r = 0.58$, $p \leq 0.05$).

Figure 7. Total nitrogen levels in soil after three years of legume growth. Treatments without a letter in common are significantly different. Bars show standard errors.



Tree growth after two years did not differ significantly between legume species. Foliar N levels of trees in all treatments exceeded the 'satisfactory' level for radiata pine (1.5%). They were significantly higher in trees growing in perennial blue lupin plots than in control plots (Figure. 8). Although there were no other significant differences from the control, tree foliar N levels were positively correlated with the mean legume growth index ($r = 0.64$, $p \leq 0.05$).

Phosphate requirement trial

Russell lupin showed no response to P fertiliser while Alsike clover responded to a rate of 50 kg/ha, (Figure 9). The growth index of alsike clover at 50 kg/ha of P was about twice that without P.

Tree growth and foliar N levels did not differ significantly between the two legume species, or between P rates, and there were no significant interactions between the two factors. However, there was a trend for tree foliar N levels to be lower in alsike clover plots than in lupin plots at low P rates, with the difference between the two species reducing as the P rate increased (Figure 10). Again, tree foliar N levels in all treatments exceeded the 'satisfactory' value for radiata pine.

Figure 8. Foliar nitrogen concentrations in radiata pine in the legume species trial. Treatments without a letter in common are significantly different. Bars show standard errors.

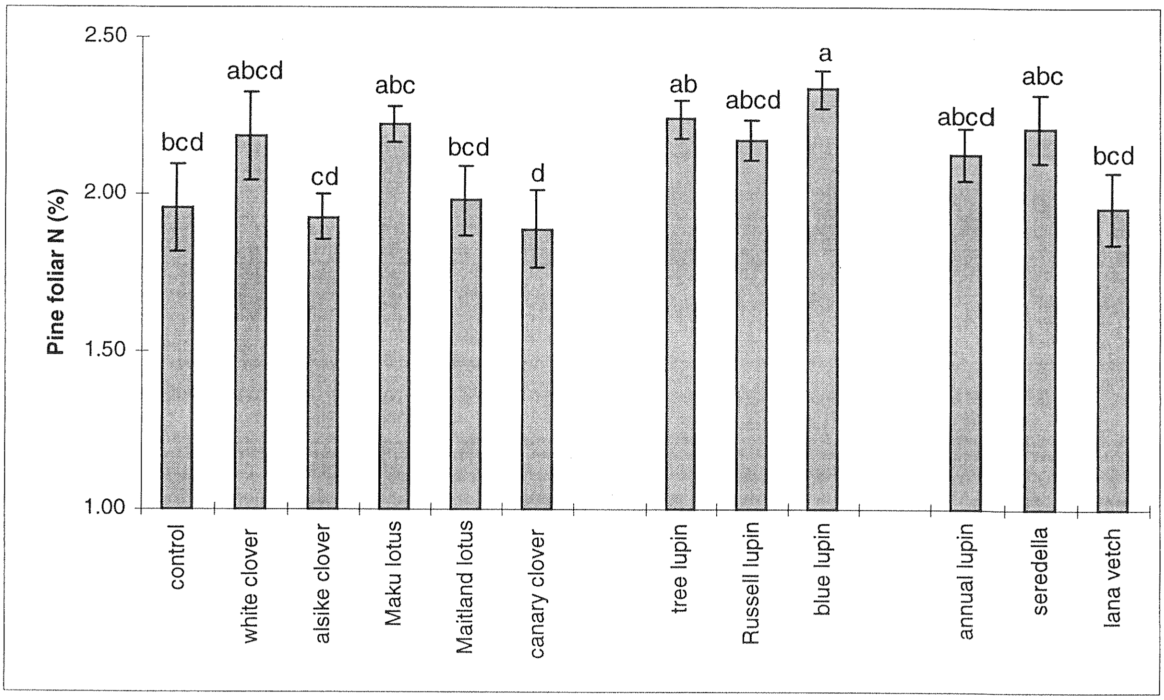


Figure 9. Response of Russell lupin and alsike clover to fertiliser P applied as superphosphate. Values are means of five assessment. Bars show standard errors.

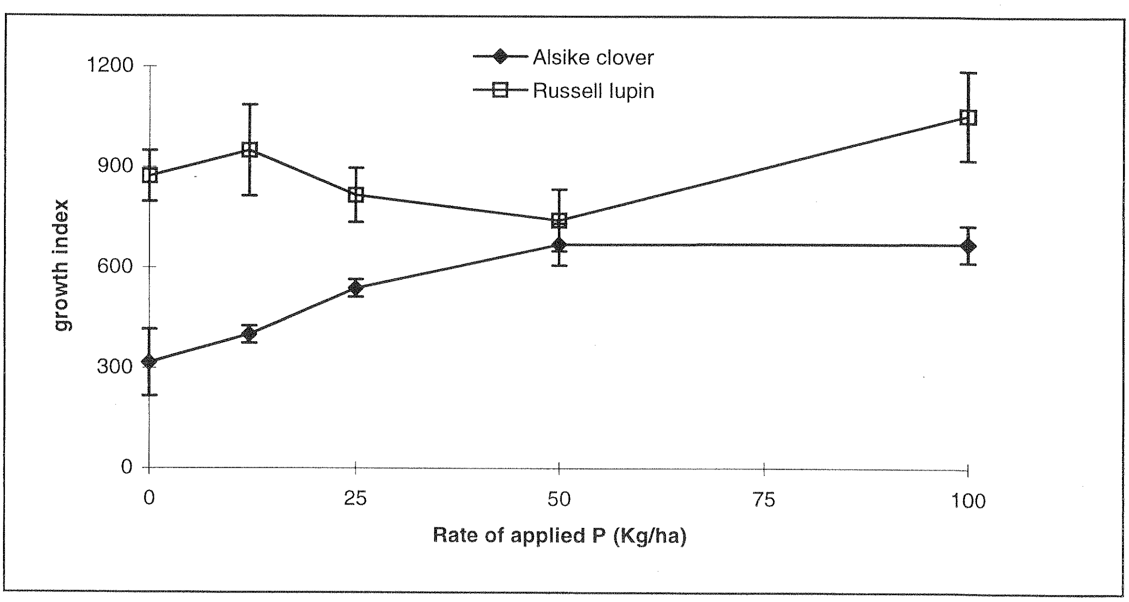
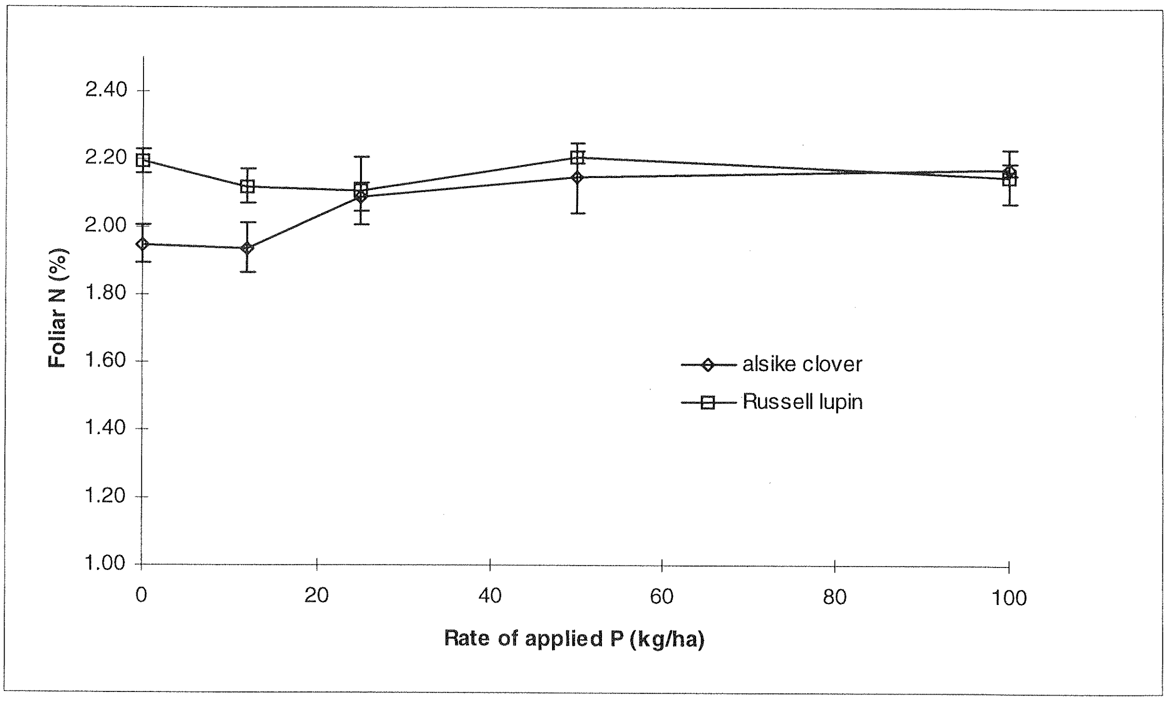


Figure 10. Foliar nitrogen concentrations in radiata pine growing in alsike clover and Russell lupin plots with different rates of superphosphate. Bars show standard errors.



Discussion

Tree lupin was ranked substantially higher than all other species in terms of mean growth index, while perennial blue lupin was ranked highest in terms of soil N and tree foliar N level. Although the high growth index ranking of tree lupin is largely due to its greater stem production, both species initially appeared vigorous and well adapted to the site. However their lack of persistence, presumably because of lupin blight, severely reduces their potential for improving site N levels.

The next highest ranked species in terms of mean growth index was Maku lotus, followed by seredella. Both species performed substantially better than the lupins in the third year of the trial. Both species were ranked highly in terms of soil total N and pine foliar N levels. Maku lotus is normally considered to be suitable for 'infertile, wet and acid soils which are too poor for white clover' (Langer 1990); its good performance on the drought-prone Lismore soil in the present trial was therefor somewhat unexpected. The value of Maku lotus as a legume for improving forest productivity has been demonstrated for a number of North Island forest sites (West and Dean 1998). The good performance of Maku lotus relative to other species at Eyrewell may have been aided by higher than normal rainfall over the growing season during the first two years (Appendix 1). Although it was most productive in the third spring when rainfall was close to normal, its productivity relative to other species may not have been as good under drier than normal conditions. Seredella is adapted to grow on light, sandy soils and was therefor expected to perform relatively well at Eyrewell forest. Langer (1990) comments that Koha seredella lacks persistence and needs to be resown each year, but the cultivar re-established satisfactorily enough from self seeding in the present study.

Although there were few significant differences between legume species and control plots in either soil N or tree foliar N levels, the positive correlations observed between these parameters on one hand, and the mean legume growth index on the other, indicate that the legumes increased N availability roughly in proportion to their productivity. Greater differences between the legume and control plots in soil total N and tree foliar N levels may have developed had the legumes been allowed to grow for a longer period. The correlation between the mean legume growth index and tree foliar N level improved when tree lupin data was removed from the correlation (from $r = 0.64$ $p < 0.05$, to $r = 0.82$ $p < 0.01$). The improvement is likely to have occurred because of the contribution of stem material, which would contribute little energy for N-fixation, to the growth index of tree lupin.

Tree foliar N contents in legume and control plots greatly exceeded the 'satisfactory' level of 1.5% for radiata pine (Will 1985). The high tree foliar N contents would have contributed to the lack of tree growth response to the presence of the prior legumes. The high foliar N levels in the present study reflect the young age of the trees and low demand on the site for nitrogen in the absence of weed competition. Foliar N levels would be expected to decline with increasing tree age; in an adjoining study, where land use history and site preparation were similar, foliar N levels in radiata pine in control (no vegetation) plots fell from 1.8% at year one to 1.3% at year four (Clinton et al 1997, Sun et al 1997).

Differences in tree growth, reflecting differences in foliar N concentration, may have shown up had tree growth been evaluated over a longer period. However the small plot size precluded useful longer term data on tree growth being obtained from the trial.

The fertiliser trial showed that P, equivalent to approximately 500 kg superphosphate/ha, is required for optimum growth of alsike clover at Eyrewell. The P requirements of other pasture legume species (including Maku lotus) are likely to be similar (Davis, 1991).

Conclusions

The best performing legumes at Eyrewell forest were tree lupin, perennial blue lupin, Maku lotus and seredella. Although the lupins performed well over the short trial period, their lack of persistence because of lupin blight limits their potential for improving soil N levels and forest productivity. Maku lotus was a little more productive than seredella, and is considered to have the good potential for forest use on drought-prone Canterbury plains soils, though its performance in drier than normal years was not tested in the present trial. Phosphate fertiliser is required for optimum legume productivity.

Trials running the full length of a rotation are now required to determine whether incorporation of a legume phase between rotations can produce increases in forest productivity sufficient to justify the practice economically. Such trials should incorporate the use of mineral N fertiliser for comparison.

References

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Appendix 1. Mean monthly rainfall for Eyrewell Forest, and monthly rainfall for the trial site from July 1992-June 1994. Data from P. Clinton.