ESTABLISHMENT OF SELECTED LEGUMES IN A MID-ROTATION *PINUS RADIATA* PLANTATION

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ABSTRACT

Three out of eight legumes tested grew well from seed sown in a 10-year-old, recently thinned and cultivated, 250 stems/ha stand of **Pinus radiata** D. Don. Productivity was lower than would be expected in the open, but **Lotus uliginosus** Schkuhr. "Grasslands Maku", lotus hybrid G4712 (**corniculatus** × **uliginosus**), and **Lupinus arboreus** Sims all produced a sward or an understorey layer which persisted for at least 4 years.

Four legumes failed completely when resown 2 years later (1983) without cultivation in the same stand. Maku lotus and **Trifolium repens** L. (white clover), when resown again (1984) without cultivation, established and persisted for two seasons but plant vigour was very low and there was no sward formation. Poor productivity was not primarily associated with presence of accumulated litter, herbicide treatment before sowing, or animal browsing.

Keywords: legumes; **Pinus radiata**.

INTRODUCTION

The trend in New Zealand plantation forestry towards wider tree spacing and low final-crop stocking of *Pinus radiata* has increased the potential for weed growth in forest stands. As an alternative to herbicide treatment, the concept of replacing weeds with less troublesome or even useful plants is attractive. Many forest soils are deficient in nitrogen, and it is appropriate to consider nitrogen-fixing species for this purpose. Jorgensen (1980) and Turvey & Smethurst (1983) have listed criteria for selecting nitrogen-fixers for use in the forest understorey, but the probability that any species will meet the particular criteria can be judged only from assessments made under the climate/soil/silviculture combination for which it is required. Herbaceous plants that flourish in the open conditions of a young forest stand may not tolerate the reduction of light, nutrient availability, and moisture that may result from increasing site occupancy by maturing trees.

In a previous paper (Gadgil *et al.* 1986) we described the effect of mid-rotation forest conditions on the performance of 35 species and cultivars of legumes. Results were used to compare the response of individually spaced plants grown from seedlings raised in the glasshouse and hardened off before being transplanted into the forest stand. We report here the results of two trials in which the more realistic method of broadcasting seed was used to introduce the legumes. In the first (1981) trial, which ran concurrently with the above assessment, eight of the legumes were monitored over three growing seasons. No fertiliser was used and no other management was imposed. When legumes resown after plots were sprayed with "Roundup" failed to establish, a second (1984) trial was set up to examine some of the factors that could have accounted for the failure.

SITE DESCRIPTION

The trial site was described in detail by Gadgil *et al.* (1986). Briefly, it was a 10-year-old *Pinus radiata* plantation in Whakarewarewa Forest, about 6 km south of Rotorua. The soil was a yellow-brown pumice with low nutrient (phosphorus, potassium, magnesium) status and slight susceptibility to drought (Rijkse 1979). In 1981 the tree stand, grown to a sawlog regime, was reduced to 250 stems/ha. Mean height in April 1981 was 16.5 m and basal area 15.5 m^2/ha.

METHODS

In February 1981 the understorey was removed by windrowing, and soil between the trees was disced and harrowed. The trial area was surrounded with a rabbit-proof fence and 2 days before seed sowing was sprayed with 'Roundup' (3.6 g a.i./*l*). Weed control during the course of the study was confined to handpulling seedlings of bracken, broom, blackberry, and gorse.

Trial 1 (sown 1981)

A randomised block design was used, four 10 × 5-m plots being allocated to each of the eight legumes selected for the trial. Seed inoculated with the appropriate *Rhizobium* culture was sown on 10 April 1981 and raked lightly into the surface soil. Sowing rates are shown in Table 1.

Thirty-six sampling points were designated for each plot so that no point was less than 1 m from the next, or from the plot boundary. Above-ground plant material was harvested from a 70 × 70-cm area centred on each of three randomly-selected points per plot in January, April, and October 1982, January, April, and October 1983, and January 1984. No area was sampled twice and harvesting ceased when undisturbed areas became scarce. Plant tops were sorted into sown legume, wild lotus (in non-lotus plots), and "other" categories. Oven-dry weight and nitrogen content were determined for each category using methods described by Nicholson (1984).

TABLE 1–Legumes used in Trial 1 (sown 1981)

Species	Common name	Inoculum reference No.*	Sowing rate (kg/ha)
Perennial			
Coronilla varia L.	Crown vetch	NZP5462	12 (shelled)
Lotus hybrid G4712 (*corniculatus* × *uliginosus*)	Hybrid lotus	NZP2037 +NZP2257	4
Lotus uliginosus Schkuhr. 'Grasslands Maku'	Maku lotus	NZP2309	2
Lupinus arboreus Sims	Tree lupin	NZP2309	5
Lupinus polyphyllus Lindl.	Russell lupin	NZP2141	5
Trifolium pratense L. 'Grasslands Pawera'	Red clover	NZP560	8
Trifolium repens L. 'Grasslands Huia'	White clover	NZP560	2
Annual			
Ornithopus compressus L. 'Pitman'	Yellow serradella	NZP2309	20

* Inoculum cultures supplied by DSIR Applied Biochemistry Division

Immediately after harvesting, three soil cores each 10 cm diameter × 15 cm deep were removed from each sampled square. Root material of the sown legume was separated and subjected to acetylene reduction assay to estimate nitrogenase activity. Roots from each core were shaken gently and placed in a 600-ml preserving jar. A 50-ml aliquot of air surrounding the roots was immediately replaced with acetylene and the jar incubated for 30 min in a covered soil pit at the trial site. A 10-ml gas sample was then removed for ethylene analysis by gas chromatography.

Trial 2 (sown 1983)

The plots previously allocated to serradella were resown with white clover, and the crown vetch plots with Maku lotus. A split-plot design was used, incorporating factorial combinations of the two species and three treatments, each replicated four times. The treatments were:

(a) Nil

(b) Weeds sprayed with 'Roundup' (3.6 g a.i./*l*) on 19 March 1984

(c) Pine needle litter removed by handraking on 9 April 1984, without disturbing the mineral soil.

Subplot size was 5 × 2.5 m. Animal exclosures (2.5-cm mesh) were used to protect a 1.0 × 1.3-m area in each subplot. Seed inoculated with the appropriate *Rhizobium* culture was sown on 9 April 1984 at a rate of 4 kg/ha (both species).

Seedling counts were made every 2 weeks from 1 May 1984 to 13 July 1984. A visual plot assessment was carried out on 11 March 1985 and dry matter determinations were made for each treatment combination on 22 April 1985, using one 50 × 25-cm quadrat laid over the most vigorous patch of legume growth in each subplot. All material within the quadrat was severed at ground level and separated into "legume" and "weed" components before drying. A final visual assessment was made in November 1985.

RESULTS

Trial 1

Seed of all eight legumes germinated, but establishment of crown vetch and Russell lupins was poor. Crown vetch died out during the first growing season. Serradella grew well during the first year (Table 2) but although seed production was good and seedlings were observed in all plots in April 1982, only a few browsed plants survived the second winter. Productivity of red and white clover was reduced by heavy browsing (possums, deer) and by weed competition, and harvesting was discontinued after January 1983. Only three of the legumes were reasonably productive during the third growing season. For each of these the highest yields had been obtained during the second year, maximum recorded above-ground dry weight being 2307, 2570, and 2016 kg/ha for hybrid lotus, Maku lotus, and tree lupin respectively. These values were all associated with the highest recorded nitrogen content of above-ground material (Tables 3, 4). The two lotus cultivars achieved maximum recorded productivity and nitrogen content earlier (April 1982) than tree lupin (January 1983). Data for lotus in plots where no lotus was sown suggest that the resident population may have contributed to values recorded for sown lotus. In October 1982 the above-ground nitrogen content of the weed component was highest in plots where the sown legume had died or failed to develop: in the crown vetch plots this was not due to nitrogen transfer from the sown legume.

Flowering and seed production were observed in hybrid lotus, Maku lotus, and tree lupin. The contribution made by seedlings to productivity in 1983–84 was not assessed, but is unlikely to have been large.

Differences between the legumes in terms of habit make interpretation of acetylene reduction (nitrogen fixation) data very difficult. To avoid extrapolation errors involved in the calculation of absolute values for nitrogen fixation rates, only relative values are shown in Table 4. These indicate clearly that although Russell lupins performed best at first, tree lupin and Maku lotus maintained the highest relative activity for the longest period.

Although objective dry matter assessment was impossible after January 1984, it was noted that regenerated or disturbed material of the hybrid lotus, Maku lotus, and tree lupin persisted into the fourth growing season.

Trial 2

Seed of both species germinated throughout the trial. During the first 3 months there was little effect of herbicide on seedling density. Litter removal had an obvious depressing effect on density of white clover but not Maku lotus (Fig. 1). There was no consistent positive effect of exclosure. Dry matter production was very poor through-

TABLE 2–Mean dry matter production (kg/ha) (above ground), Trial 1

	Hybrid lotus	Maku lotus	Tree lupin	Russell lupin	Red clover	White clover	Crown vetch	Serradella
19.1.82								
Sown legume }	1702* (143)†	1894 (98)	373 (121)	96 (12)	213 (55)	506 (50)	18 (4)	1527 (180)
Wild lotus			518 (174)	615 (97)	356 (127)	431 (141)	689 (147)	502 (96)
Other weeds	322 (54)	290 (85)	334 (94)	532 (111)	405 (86)	443 (69)	679 (150)	373 (97)
26.4.82								
Sown legume }	2307 (304)	2570 (228)	625 (214)	59 (34)	47 (37)	473 (68)	2 (2)	0
Wild lotus			1285 (215)	913 (171)	694 (247)	616 (187)	1363 (195)	682 (112)
Other weeds	228 (39)	234 (74)	559 (82)	566 (81)	446 (145)	1016 (190)	668 (206)	578 (116)
4.10.82								
Sown legume }	797 (44)	1214 (89)	1110 (332)	60 (17)	44 (24)	105 (17)	0	0
Wild lotus			504 (29)	716 (183)	657 (73)	392 (105)	638 (55)	685 (155)
Other weeds	341 (30)	274 (99)	457 (63)	361 (134)	394 (121)	485 (93)	605 (183)	799 (132)
10.1.83								
Sown legume }	2264 (216)	2137 (139)	2016 (492)	46 (18)	19 (5)			
Wild lotus			1463 (120)	1566 (136)	1539 (121)			
Other weeds	389 (73)	426 (121)	626 (106)	629 (32)	688 (118)			
25.4.83								
Sown legume }	870 (214)	847 (50)	1954 (285)	42 (27)				
Wild lotus			526 (208)	587 (118)				
Other weeds	123 (129)	179 (26)	227 (81)	250 (61)				
10.10.83								
Sown legume }	226 (41)	555 (127)	1313 (326)	63 (40)				
Wild lotus			179 (36)	233 (39)				
Other weeds	319 (82)	504 (271)	381 (95)	436 (108)				
17.1.84								
Sown legume }	363 (88)	923 (116)	1089 (605)	4 (2)				
Wild lotus			229 (47)	445 (82)				
Other weeds	1005 (114)	649 (115)	1064 (353)	849 (119)				

* Treatment mean
† Standard error

TABLE 3–Nitrogen content (kg/ha) of above-ground dry matter, Trial 1

Date and material	Hybrid lotus	Maku lotus	Tree lupin	Russell lupin	Red clover	White clover	Crown vetch	Serradella
26.4.82								
Sown legume	39.2* (5.0)†	56.1 (4.9)	10.1 (3.2)	1.3 (0.8)	1.3 (0.8)	15.1 (2.2)	<0.1 (<0.1)	0
Wild lotus			29.7 (5.3)	23.1 (4.3)	19.8 (6.9)	14.4 (4.5)	32.6 (3.8)	15.9 (3.9)
Other weeds	3.1 (0.3)	4.0 (1.3)	8.5 (1.4)	8.2 (1.2)	7.4 (2.5)	18.5 (3.3)	8.8 (3.2)	10.4 (3.1)
4.10.82								
Sown legume	27.4 (2.4)	42.0 (3.2)	19.7 (5.2)	2.2 (0.6)	1.6 (0.9)	4.0 (0.7)	0	0
Wild lotus			18.1 (1.1)	27.1 (7.0)	24.4 (3.0)	15.2 (3.8)	25.7 (2.1)	24.8 (5.1)
Other weeds	6.6 (0.6)	5.3 (1.9)	8.0 (1.1)	6.4 (2.2)	8.0 (2.6)	9.9 (2.2)	12.2 (3.7)	15.1 (2.1)
10.1.83								
Sown legume	38.8 (3.7)	47.0 (3.0)	25.3 (5.7)	0.8 (0.2)	0.6 (0.2)	5.3 (1.5)		
Wild lotus			35.7 (3.5)	33.2 (3.3)	38.0 (3.2)	35.7 (4.5)		
Other weeds	3.7 (0.9)	4.5 (1.4)	6.7 (0.9)	5.8 (0.7)	7.9 (2.5)	9.0 (4.1)		
25.4.83								
Sown legume	12.6 (2.7)	19.2 (3.2)	22.9 (2.1)	0.4 (0.2)				
Wild lotus			9.3 (3.7)	9.6 (1.7)				
Other weeds	2.0 (0.4)	3.7 (0.6)	3.9 (1.2)	4.3 (1.1)				
10.10.83								
Sown legume	7.0 (1.4)	17.1 (3.8)	13.6 (2.5)	1.4 (0.7)				
Wild lotus			6.7 (1.5)	8.4 (1.3)				
Other weeds	6.3 (1.5)	8.4 (4.5)	8.1 (2.3)	8.9 (2.3)				
17.1.84								
Sown legume	7.8 (1.9)	23.4 (2.2)	11.7 (6.3)	0.1 (<0.1)				
Wild lotus			5.8 (1.3)	11.2 (1.8)				
Other weeds	9.8 (1.4)	7.4 (1.1)	12.5 (4.3)	9.6 (1.6)				

* Treatment mean
† Standard error

out and there was no sward development. Analysis of variance failed to detect any significant treatment effect on dry weight values after 1 year (Table 5). Clover leaflets had been removed by browsing (possums, deer) over considerable areas and, although individual plants benefited from protection by exclosures, growth was too sparse for effects on productivity to be recorded. Plants of both species persisted beyond November 1985 in all treatment combinations, but growth was never vigorous.

TABLE 4–Relative acetylene reduction rates, Trial 1. For each sampling date, acetylene reduction activity (mean rate for 36 soil/root cores) is expressed as a percentage of the highest value recorded

	19.1.82	26.4.82	4.10.82	10.1.83	26.4.83	10.10.83	17.1.84
Hybrid lotus	34	44	35	25	18	25	28
Maku lotus	22	17	63	26	27	66	100
Tree lupin	42	9	100	100	100	100	97
Russell lupin	100	100	66	22	33	23	15
Red clover	17	1					
White clover	26	10	1				
Crown vetch	1						
Serradella	7						

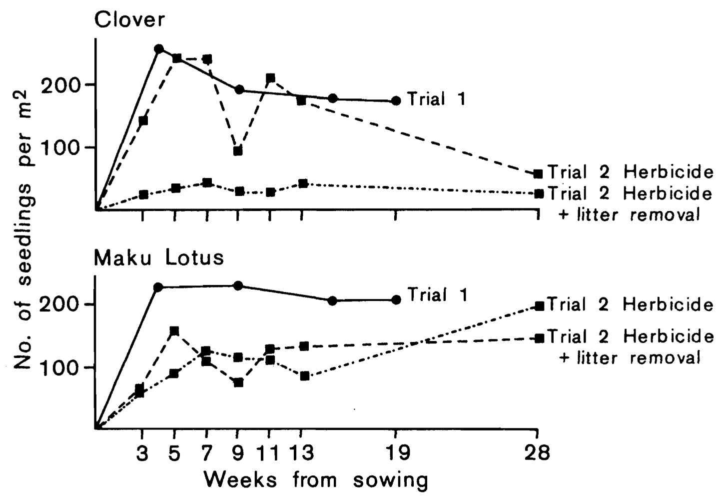

FIG. 1—Seedling density in Trials 1 and 2.
N.B.: Seed sowing rate for both legumes was 2 kg/ha in Trial 1 and 4 kg/ha in Trial 2.

TABLE 5–Above-ground production of dry matter in Trial 2 after 12 months

Treatment	Mean dry wt of plant tops (kg/ha)			
	White clover		Maku lotus	
Herbicide	63	n.s.	274	n.s.
No herbicide	64		256	
Litter removed	59	n.s.	232	n.s.
Litter intact	68		299	
Exclosure	76	n.s.	231	n.s.
No exclosure	51		300	
No treatment	60		422	

n.s. = Not significantly different at p = 0.05

DISCUSSION

In the first trial four of the eight legumes established well from seed and three persisted without further management until the trees were at least 13 years old. After clipping, these three legumes continued to grow as a sward or understorey layer, but their maximum longevity was not determined. Values for maximum recorded productivity were lower than those obtained for legume stands grown in the open (Table 6) and it is probable that nitrogen-fixing activity was similarly affected by stand conditions. Even so, a low level of symbiotic nitrogen fixation can be expected in legumes growing in a 13- to 14-year-old 250 stems/ha tree stand.

TABLE 6–Comparison of legume productivity (Trial 1) with values recorded in other studies

	Plant age (yr)	Above-ground dry matter (t/ha)		Reference and comments
		This study	Legume grown in open	
Hybrid lotus	1.0	2.3	0.8	Morton (1980) — Grass seed also sown. Fertiliser applied.
Maku lotus	1.5	2.6	7.9–8.3	Brock (1973) — Sward clipped three times. Fertiliser applied.
Tree lupin	1.5	1.1–2.0	10.1–25.9	Gadgil (1971) — Marram grass present but not included in dry matter value.
Russell lupin	2.5	Negligible	6.0	FitzGerald (1981) — Study carried out on gold dredge tailings.
Red clover	2.0	0.06	13.2	Anderson (1973) — Plots mown three times. Fertiliser applied.
White clover	1.0	0.5	8.3	Brock (1973) — Sward clipped three times. Fertiliser applied.
Crown vetch	1.0	0.002	7.0	Seim (1968) — Cutting height 5 cm.
Serradella	≥1.0	0	3.7	Williams & de Lautour (1975) — Established as spaced plants; sward clipped twice.

It seems clear from this trial and from parallel results of the spaced plant trial (Gadgil *et al.* 1986) that annual legumes and perennials that are susceptible to either uncontrolled browsing by wild animals or to inundation by weed growth should not be considered for possible enhancement of the forest herb or shrub layer. Maku lotus, the lotus hybrid G4712, and tree lupin were all more successful because of their rapid site occupancy, their spreading perennial growth, and their relative unpalatability (compared with red and white clover).

Volunteer species (resident lotus and other weeds) were responsible for a considerable proportion of the above-ground nitrogen in the herb and shrub layer. Highest overall values for total above-ground nitrogen (volunteers + sown legume) at each of the six assessment dates were observed in Maku lotus plots (three occasions) and tree lupin plots (five occasions) only. Tree lupin plots could be expected to have a higher potential for biological nitrogen accretion if the lupin canopy is sufficiently open to allow a non-competitive nitrogen-fixing herbaceous species to occupy the soil surface between the lupin stems.

Although Trial 2 was not a complete failure, productivity was uneven and unacceptably low. Poor growth could not be directly attributed to the presence of accumulated litter at time of sowing, to herbicide treatment, or to browsing, and it must be assumed that some other overriding factor was responsible.

The results from these trials draw attention to the variability in the growth response of legumes introduced as understorey plants in the mid-rotation forest stand. The variability had two main components: differences were observed between species in Trial 1, and between trials when legumes common to Trials 1 and 2 were studied. Productivity of one of the best performers in Trial 1 was drastically reduced in the subsequent trial.

Sources of variability between trials included the following in addition to those examined:

(a) seasonal climatic factors

(b) increased tree age and growth

(c) absence of soil cultivation in Trial 2.

None of these factors can be ruled out as a major cause of poor legume performance in Trial 2. Local climate records were not kept and objective data are not available. Effects of continuing tree growth could be quite diverse. Although light measurements (Table 7) provided no evidence of progressive shading, litterfall was observed to increase from 1796 $\pm$ 418 kg/ha/yr to 4890 $\pm$ 1260 kg/ha/yr during the experimental period, and could have had an effect different from that of accumulated litter. Occupancy of upper soil layers by living tree roots would almost certainly have been greater in Trial 2 than in Trial 1; conversely, the amounts of decomposing tree root material would have been smaller.

The effects of soil cultivation in preparation for Trial 1 could have been considerable and may have interacted with other factors. Surface tree roots would have been damaged

TABLE 7–Light measurements 1 m above the forest floor (integrated over 1 week)*

Date	Light received 1 m above ground-level expressed as percentage of value obtained outside the tree stand	
	Mean (n = 54)	Range
Oct 1981	36.7	13.8–53.8
June 1982	56.2	30.8–84.6
June 1983	28.2	18.5–61.5
Dec 1983	32.0	12.7–72.0
Oct 1984	33.3	22.5–56.1
Dec 1985	36.7	17.6–71.8

* Determined by a technique modified from that of Friend (1961)

and changes in microbial populations probably occurred as a result of the physical loosening of the soil. Von Bredow-Stechow (1963) and Rehfuess (1979) have reported from separate series of trials that soil cultivation is necessary for the establishment of perennial lupins from seed in pole-stage and older conifer stands in Germany. Rehfuess was concerned about the effect of root damage on tree growth and did not consider reasons for the effect of cultivation on the lupins. Both workers commented on the unexpected degree of shade tolerance shown by the introduced understorey. Consideration of the German work and of the present study suggests that it might be advisable, in mid-rotation stands, to confine the introduction of legume seed to sites where the soil surface has been disturbed, at least until properly controlled cultivation trials have been carried out.

The relative effect of individual legumes on tree growth has yet to be evaluated. If their successful introduction to the tree stand depends on soil disturbance, the timing of this disturbance in relation to the dynamics of tree nitrogen demand would be a critical factor in the management of nitrogen transfer from the legume to the tree crop.

The low productivity of forage legumes, compared to potential growth in open pasture, suggests that their introduction to enhance forest grazing in a mid-rotation *P. radiata* stand would require careful stock management. The effect of uncontrolled browsing on the more palatable species (red and white clover, serradella) demonstrated that overgrazing is possible. On the other hand, it might be expected that regular, infrequent grazing would stimulate legume regeneration and control weed growth. More work is required to determine the optimum grazing regime for legumes in a tree stand of this age and to assess the value of legume introduction in terms of tree growth, animal productivity, and understorey control.

CONCLUSIONS

(1) A persistent sward or understorey layer of legumes can be established in a 10-year-old recently thinned stand of *P. radiata* growing at 250 stems/ha, providing that the existing understorey is removed and the soil cultivated.

(2) Maku lotus, the lotus hybrid G4712, and perennial tree lupin are suitable species for pumice soil.

(3) Legume productivity is lower than it would be in the open.

(4) A low level of biological nitrogen fixation can be expected from these legumes after 3 years of unmanaged growth.

(5) If legumes are introduced to enhance forest grazing, careful stock management will be required.

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