SOIL pH AND NUTRIENT LEVELS AT TIKITERE AGROFORESTRY RESEARCH AREA

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ABSTRACT

Soils under various stockings of *Pinus radiata* D.Don at the Tikitere Agroforestry Research Area near Rotorua have shown a significant decline in soil pH with increasing tree age and at higher tree stockings. Soil pH levels in 1975 (year 3) for 0, 100, 200, and 400 stems/ha were 5.6, 5.7, 5.7, and 5.6 respectively, compared with 5.6, 5.4, 5.3, and 5.0 in 1991. Higher phosphorus and sulphate-sulphur levels under trees and an increase in magnesium on open pasture were also evident. A soil profile study at year 19 indicated pH reductions to 150 mm depth, with increasing phosphorus levels to 75 mm depth. Sulphate-sulphur levels increased at all depths in 400 stems/ha plots.

Keywords: agroforestry; needles; pH; soil nutrients; fertiliser; pasture; *Pinus radiata.*

INTRODUCTION

The New Zealand exotic forest crop area totals 1.3 million ha (Sutton 1991) and there are predictions of up to 100 000 ha of new land being planted each year, most of which will be farmland because of the increasing profitability of forestry and the reduced availability of land classes previously used for afforestation. There is also evidence that mean basal area growth of young *Pinus radiata* on farm sites is up to 40% greater than on forest sites (Knowles & West 1986).

There have been reports from overseas (Goldsmith 1979) that planting pines leads to soil acidity. However, there has been no evidence that this has occurred on New Zealand sites (Dyck *et al.* 1985) and an earlier report from Tikitere at tree age 9 years did not show this trend (Percival *et al.* 1984). Cockayne (1914) and Will & Ballard (1976) observed that *P. radiata* crops improved soil fertility. Jurgensen *et al.* (1986) commented that the effect of introduced forest species on soil properties has received relatively little attention in New Zealand, in spite of the large areas of new planting.

The Tikitere Agroforestry Research Area near Rotorua was planted in *P. radiata* at a range of tree stockings in 1973 and soil fertility parameters have been monitored for 19 years. This paper presents the data from this study.

SITE DESCRIPTION AND TRIAL DESIGN

The trial was on a recent volcanic sandy loam (typic Vitrudand) classified as Rotoiti sandy loam. It was on flat to moderately steep land with a mean annual rainfall of 1600 mm, generally evenly distributed. The site had a 50–60 year history of pastoral landuse.

Pinus radiata was planted at stockings of 0, 250, 500, 1000, and 2000 stems/ha. Each stocking treatment covered 8 ha in four 2-ha replicated blocks, surrounded by a 28-m buffer zone. Initial stocking rates were reduced over an 8-year period to final stockings of 0, 50, 100, 200, and 400 stems/ha (McQueen *et al.* 1976).

Fertiliser History

The initial objective was to maintain adequate soil nutrient status across all treatments. However, once pasture production decreased substantially, usually at canopy closure, fertiliser applications ceased.

Tikitere was aerially topdressed annually from 1975 to 1989 at 200–250 kg/ha with either 15% or 30% potassic superphosphate. Potassic serpentine superphosphate was applied in 1977 and 1986. Plots on steep land received an additional 200 kg superphosphate/ha annually from 1977 to 1980. Lime (2 t/ha) was applied to one 50 stems/ha plot with low pH in 1977 and cobalt sulphate (175–350 g/ha) was included in the main topdressing every second year. Topdressing ceased in 1983 (year 10) on the 400 stems/ha plots, in 1986 on the 200 stems/ha, and in 1989 on the 100 stems/ha. In 1991 and 1992, 280 kg cobaltised superphosphate/ha was applied by ground spreading to the 0 and 50 stems/ha plots. When all stocking treatments were receiving fertiliser (1975–83) the nutrients applied annually were phosphorus 13–41 kg/ha, potassium 16–56 kg/ha, sulphur 15–48 kg/ha, and magnesium 8–16 kg/ha.

Grazing Management

At Tikitere, sheep were rotationally grazed from 1975 to 1989. In the 400 stems/ha treatment there was little pasture remaining after year 9 and stock had only periodic access to that treatment after 1982. A similar trend occurred with the 200 stems/ha plots after 1987. Since 1989, the research area has been grazed as one paddock with breeding ewes and beef cows.

Measurements

Soil samples were taken at random within plots using a standard 25-mm-diameter corer. Usually 15–20 samples per plot were collected below the decomposing needle layer. Care was taken to ensure that areas around troughs, gateways, fences, and stock camps were not sampled. Measurements were made of pH, calcium, phosphorus, potassium, and magnesium using the Ministry of Agriculture and Fisheries Quicktest procedures (Cornforth 1982), and phosphate extractable sulphate (Saunders *et al.* 1981).

Samples were taken at 0–75 mm depth at years 0, 3, 5, 6, 7, 8, 9, 11, 15, and 18, usually in May. In 1992, at year 19, samples were taken at depths of 0–35, 35–75, 75–150, and 150–300 mm in all treatments. Analysis for sulphate-sulphur commenced in 1988.

Bulk density samples were taken in March 1992 for one replicate paddock in each tree stocking treatment, and the weight of each nutrient in the 0–75 mm soil layer was calculated.

The data were analysed using standard analysis of variance procedures.

RESULTS

pH

Soil pH levels have remained relatively constant in the open pasture and 50 stems/ha treatments. There has been a trend emerging since year 13 of decreasing pH levels at the 0–75 mm depth with higher tree stockings (Table la). At 400 stems/ha from year 13 and at 200 stems/ha from year 18, reductions in pH were significant ($p<0.05$). Reductions in pH at 50 and 100 stems/ha were statistically non-significant.

The samples taken at a series of depths at year 19 showed statistically significant reductions at 100 stems/ha and higher tree stockings, down to 150 mm. At 400 stems/ha, there was also a reduction at 150–300 mm (Table 1b).

TABLE 1a–Effects of tree stocking and stand age on soil pH levels at 0–75 mm depth

Tree stocking	Year										
(stems/ha)	0	3	5	6	7	8	9	11	13	15	18
0	5.6	5.7	5.7	5.9	5.5	5.4	5.6	5.6	5.5	5.5	5.6
50	5.4	5.6	5.5	5.7	5.6	5.3	5.5	5.5	5.2	5.3	5.4
100	5.6	5.7	5.6	5.7	5.5	5.3	5.4	5.5	5.1	5.4	5.4
200	5.6	5.7	5.6	5.7	5.5	5.4	5.4	5.5	5.2	5.4	5.3
400	5.5	5.6	5.5	5.7	5.5	5.3	5.4	5.5	5.2	5.1	5.0
SED	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

TABLE 1b–Soil pH levels at increasing depth at year 19

Tree stocking	Depth (mm)			
(stems/ha)	0–35	35–75	75–150	150–300
0	5.7	5.6	5.7	5.8
50	5.5	5.5	5.5	5.6
100	5.3	5.4	5.4	5.6
200	5.2	5.4	5.4	5.7
400	4.8	5.1	5.2	5.4
SED	0.1	0.1	0.1	0.1

Calcium

There was a reduction ($p<0.05$) at years 15 and 18 (Table 2a) in the 400 stems/ha plots and at year 18 in the 200 stems/ha for the 0–75 mm depth. Calcium levels declined with increasing depth (Table 2b) and there were reductions ($p<0.05$) down to 75–150 mm at stockings greater than 50 stems/ha.

Phosphorus

A definite trend of increasing phosphorus levels at higher tree stockings has been evident from year 7 onwards (Table 3a), being statistically significant at 100 stems/ha upwards from year 13. The quantity of available phosphorus in the 0–75 mm depth at year 19 increased at stockings up to 100 stems/ha (Table 4) and this trend was noticeable down to 75–150 mm (Table 3b).

Potassium

Potassium status has remained relatively static at all tree stockings since year 6 (Table 5a), although levels at the higher tree stockings were slightly reduced from year 13 onwards. At

TABLE 2a–Effects of tree stocking and stand age on Quicktest soil calcium levels (ppm) at 0–75 mm depth

Tree stocking (stems/ha)	Year 0	3	5	6	7	8	9	11	13	15	18
0	3	3	3	5	5	5	4	4	4	4	5
50	3	4	4	6	6	5	5	5	5	5	4
100	3	3	3	4	4	4	4	4	4	4	4
200	3	4	3	5	4	4	4	4	4	4	3
400	2	3	3	4	4	4	3	4	4	3	2
SED	0.6	0.5	0.5	0.5	0.6	0.4	0.5	0.5	0.6	0.4	0.5

TABLE 2b–Quicktest soil calcium levels (ppm) at increasing depth at year 19

Tree stocking (stems/ha)	Depth (mm) 0–35	35–75	75–150	150–300
0	6	4	3	2
50	5	3	3	2
100	3	2	1	2
200	3	2	2	1
400	2	2	2	2
SED	0.5	0.5	0.4	0.3

TABLE 3a–Effects of tree stocking and stand age on Olsen soil phosphorus levels (ppm) at 0–75 mm depth

Tree stocking (stems/ha)	Year 0	3	5	6	7	8	9	11	13	15	18
0	4*	12*	32	30	28	26	25	25	25	25	23
50	5*	13*	42	32	29	34	29	32	36	30	38
100	4*	16*	36	37	36	34	35	33	41	38	53
200	4*	14*	24	33	35	30	31	33	39	36	48
400	4*	14*	33	28	37	38	34	36	40	31	50
SED	0.9	2.8	8.3	9.4	7.8	9.0	8.5	10.0	9.7	6.2	13.6

*Truog phosphorus

TABLE 3b–Olsen soil phosphorus levels at increasing depth at year 19

Tree stocking (stems/ha)	Depth (mm) 0–35	35–75	75–150	150–300
0	25	24	21	9
50	42	40	29	18
100	57	48	37	21
200	63	38	23	8
400	57	40	25	16
SED	11.7	10.6	12.5	5.1

year 19 there was no consistent trend by depth or tree stocking rate (Table 5b) or in the quantity of potassium in the 0–75 mm depth (Table 4).

TABLE 4–Quantity of nutrients in the 0–75 mm soil layer at year 19

Tree stocking (stems/ha)	Nutrient (kg/ha) Phosphorus*	Potassium†	Magnesium†	Sulphate-sulphur†
0	17	109	75	4
50	28	95	61	6
100	40	82	58	9
200	36	109	44	10
400	38	82	48	14
SED	10	22	10	2

* Olsen phosphorus
† Quick-test

TABLE 5a–Effects of tree stocking and stand age on Quicktest soil potassium levels (ppm) at 0–75 mm depth

Tree stocking	Year										
(stems/ha)	0	3	5	6	7	8	9	11	13	15	18
0	16	7	12	9	8	7	6	6	8	10	8
50	13	8	14	8	8	7	7	7	11	8	7
100	14	9	13	6	6	6	6	5	9	7	6
200	13	10	10	8	7	6	6	7	8	8	8
400	13	8	11	5	9	7	7	6	7	7	6
SED	4.3	1.9	1.7	1.0	1.4	1.4	1.2	0.9	1.6	1.6	1.4

TABLE 5b–Quicktest soil potassium levels (ppm) at increasing depth at year 19

Tree stocking	Depth (mm)			
(stems/ha)	0–35	35–75	75–150	150–300
0	9	5	4	2
50	8	5	5	2
100	6	4	3	3
200	7	5	4	3
400	6	5	4	3
SED	1.2	1.1	1.0	0.5

Magnesium

Levels remained relatively constant up to year 13, but since then have increased on open pasture and at the lower tree stockings, while the levels in the 200 and 400 stems/ha plots have remained constant (Table 6a). At year 19 these differences were evident in the 0–75 mm sample (Table 4) and at 0–35 mm depth, but not in the deeper layers (Table 6b).

Sulphate-sulphur

Sulphate-sulphur levels were measured from 1988 onwards. Although absolute values fluctuated between years, sulphate-sulphur levels tended to increase at higher tree stocking rates and at increasing soil depth down to 300 mm (Tables 7a and b). The increase at higher tree stockings was evident in the quantity of sulphate-sulphur in the 0–75 mm samples (Table 4).

TABLE 6a–Effects of tree stocking and stand age on Quicktest soil magnesium levels (ppm) at 0–75 mm depth

Tree stocking (stems/ha)	Year 0	3	5	6	7	8	9	11	13	15	18
0	12	14	17	16	13	15	14	15	14	16	22
50	13	16	20	15	14	14	14	14	16	18	18
100	10	14	16	12	11	12	11	12	14	15	17
200	12	14	15	12	12	12	13	13	13	15	13
400	11	16	15	12	11	11	11	13	14	13	14
SED	2.0	2.0	2.8	2.0	2.1	2.3	1.8	1.8	2.1	2.4	2.7

TABLE 6b–Quicktest soil magnesium levels (ppm) at increasing depth at year 19

Tree stocking (stems/ha)	Depth (mm) 0–35	35–75	75–150	150–300
0	20	10	7	4
50	19	11	8	6
100	15	7	5	6
200	15	9	8	6
400	15	10	8	6
SED	2.4	2.0	1.3	1.0

TABLE 7a–Effects of tree stocking and stand age on Quicktest soil sulphate-sulphur levels at 0–75 mm depth

Tree stocking (stems/ha)	Year 15	18
0	23	6
50	23	9
100	24	13
200	23	14
400	28	20
SED	4.3	3.5

TABLE 7b–Quicktest soil sulphate-sulphur levels (ppm) at increasing depth at year 19

Tree stocking (stems/ha)	Depth (mm) 0–35	35–75	75–150	150–300
0	19	11	13	29
50	19	13	13	19
100	17	16	16	36
200	18	16	19	61
400	27	27	26	61
SED	5.1	3.2	3.7	21.6

DISCUSSION

pH

The measured changes in soil pH at Tikitere support associated studies on this site. Analyses of regular samples taken to 30 mm depth revealed marked reductions at 400 stems/

ha from year 11 (Hawke, unpubl. data). Yeates (1988) reported significant reductions at 200 and 400 stems/ha at years 13 and 14 at 0–50 mm depth. Sparling *et al.* (1989) reported a significant reduction only at 200 stems/ha in year 13. However, at other agroforestry research sites in New Zealand planted with *P. radiata*, pH reductions were not apparent. The Whatawhata trial near Hamilton is at year 21, and yet pH levels remain at about 5.0–5.2 over the 100–400 stems/ha range (I.L.Power, pers. comm.). At the Otago Coast Forest, the agroforestry trial at year 15 had a level of 5.1–5.2 over the 0–400 stems/ha range (G.G.Cossens & G.S.Crossan unpubl. data). As those levels are lower than the 5.6 starting level at Tikitere, further reductions in pH would be unlikely on those sites. The initial soil pH values at Tikitere, however, are likely to reflect a large proportion of the central North Island pastoral land with potential for tree plantings.

In maturing forest plantations in New Zealand, fertility has rarely been monitored by soil testing (McLaren & Cameron 1990) and so there is no database for comparison. Studies in Western Australia have reported no changes in pH levels under young *P. radiata* agroforestry plantations up to year 7 (Anderson & Moore 1987). However, in Britain, Ovington & Madgwick (1957) reported that soil pH was reduced by afforestation with conifers and that the greatest change occurred within the first 25 years after planting.

Decaying pine needles at Tikitere had a pH of 4.4 and the decomposing organic layer a pH of 4.8 (Hawke unpubl. data). This suggests that pine needles could be affecting soil pH. Ovington (1953) noted that plots of *Pinus* spp. showed an upper zone of increased acidity compared to open pasture, and this zone extended to about 200 mm depth. Needlefall can be quite substantial and annual amounts of 4000 and 6300 kg dry matter/ha have been recorded in 100 and 200 stems/ha plots respectively at year 15 at Tikitere (Hawke, unpubl. data). Needlefall and the production of organic anions are likely to be the main cause of acidification at Tikitere. Other studies at Tikitere (Yeates 1988) have suggested that changes in soil biological activity and declining earthworm numbers are associated with a fall in soil pH.

Soil Nutrient Levels

Calcium

Calcium status showed a similar trend to soil pH levels.

Phosphorus

The high phosphorus levels measured under *P. radiata* are supported by data from the Purukohukohu Catchment (Cooper, unpubl. data) comparing soil chemical parameters under pasture and pine plantations. Higher phosphorus levels under trees were also evident at the Whatawhata and Otago Coast trials (pers. comm.) and have been reported in pine plantations at Lake Coleridge in Canterbury (Davis 1992). Nutrient cycling in a forestry system is very efficient, with only 10–15% of the nutrients taken up by the trees becoming immobilised and the rest being returned via the litter or from canopy leaching (McLaren & Cameron 1990; Will 1968). There are also reduced demands on soil nutrients in the latter part of the tree crop's growth (Will 1968).

Potassium

The relatively static potassium levels under trees confirm that recycling processes are very efficient. On open pasture, nutrient cycling by animals together with addition of potassium fertiliser have maintained levels over time.

Magnesium

The maintenance of reserves of magnesium in the soil under *P. radiata* supports previous studies in New Zealand (Will 1968) and Australia (Hopmans *et al.* 1975). There was no evidence of any treatment effect at Whatawhata (unpubl. data), but in the Otago Coast trial the trend followed the Tikitere pattern (G.G.Cossens & G.S.Crossan unpubl. data). The high magnesium value on open pasture at Tikitere at year 18 is unexplained.

Sulphur

The reduction in sulphate-sulphur levels between 1988 and 1991 suggests that considerable leaching was occurring and that sulphate has not been adequately replaced by sulphur fertilisers (Ledgard *et al.* 1991). Prior to 1988, there was a regular superphosphate fertiliser application. Between 1988 and 1991 fertiliser was applied only to the 0 and 50 stems/ha treatments. In spite of this, the levels in the 100–400 stems/ha treatments were higher.

CONCLUSIONS

At Tikitere there has been significant decline in soil pH levels at tree stockings above 50 stems/ha. These effects became evident from year 13 onwards, i.e., in the second half of the tree production rotation. The decline in soil pH has implications for future land use on agroforestry areas. If the area were to be replanted in forest trees, i.e., a second rotation, there should be little problem but if it were to be returned to pastoral agriculture, a liming programme would be required and possibly legume inoculation and earthworm introduction.

Agroforestry plantations, on the other hand, have generally positive effects on soil nutrient levels. Phosphorus, potassium, sulphur, and magnesium (as measured by Olsen and Quicktest procedures, respectively) have all increased or remained at adequate levels for subsequent pastoral agriculture use (Cornforth & Sinclair 1984).

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