EFFECTS OF PLANTATION FOREST SPECIES ON SOIL PHOSPHORUS

Ivan Chirino[A], Leo Condron[A], Roger McLenaghen[A] and Murray Davis[B]

[A]*Faculty of Agriculture and Life Sciences, PO Box 84, Lincoln University, Lincoln, 7647, New Zealand, Email Ivan.ChirinoValle@lincoln.ac.nz*
[B]*SCION, PO Box 29237, Fendalton, Christchurch, New Zealand*

Research rationale and study sites

Rationale

Recent large-scale afforestation of pastoral farmlands represents a major land-use change in New Zealand (Chen *et al.*, 2003). The area under short-rotation plantation forestry (mainly radiata pine (*Pinus radiata*)) doubled from 0.9 to 1.8 million ha (c. 7% total land area) between 1985 and 2005 (Davis, 1998). Most of the established forests were planted on hill country areas developed under pastoral farming, where significant accumulation of organic matter and associated nutrients (nitrogen [N], phosphorus [P], sulphur [S]) occurred in these soils as a consequence of fertiliser inputs (Binkley and Högberg, 1997). This change in land-use was attributed to a combination of declining returns from pastoral farming and the expectation of increased future returns from forestry (Davis, 1998). In addition to the potential economic benefits associated with the establishment of conifer plantations, development of forestry in grassland areas may help to restore degraded lands and control soil erosion, especially in hill and high country areas (Davis, 1998). There is evidence from studies conducted in New Zealand that there are short and medium term effects associated with the change in land use from grassland to forest such as increased phosphorus availability (Chen *et al.*, 2008). It is commonly believed that conifers degrade soil fertility in various ways, although there has been little consistent scientific evidence for this (Binkley, 1995). However, there is evidence from studies conducted in New Zealand that there may be some short term beneficial effects associated with the change in land use from grassland to forest such as increased phosphorus availability (Davis and Lang, 1991; Belton *et al.*, 1995; Chen *et al.*, 2008). Most afforestation studies carried out to date in New Zealand have focused on the influence of radiata pine on soil properties and processes, and have involved paired site comparisons at one point in time, commonly 15-20 years after forest establishment (Chen *et al.*, 2000; Chen *et al.*, 2008).

Closer examination of changes in soil properties over time following establishment of different tree species will improve our understanding of the mechanisms responsible for changes in nutrient availability. The objective of this project is to investigate the effect of three tree species on soil P dynamics and bioavailability over 10 years following forest establishment.

Study Site

A replicated field experiment was established in 1999 at Orton Bradley Park on Banks Peninsula, New Zealand (S 43º 39´ 53´´; E 172º 42´ 17´´) to investigate and quantify temporal changes in soil properties and processes following afforestation of established grazed pasture with three contrasting commercial tree species. The reference for the impact of the different tree species was comparison with the soil at tree planting, and it was neither feasible nor necessary to include a grazed pasture treatment in the trial design. The field trial was established on lower north-east facing slopes (70-150 m elevation) on Takahe silt loam soil (Mottled Fragic Pallic, NZ classification) formed in greywacke loess (Mean annual rainfall over the trial period at Living Springs (5 km distant, 38 m a.s.l.) was 900 mm. The trial included four replicates of the three species (*Pinus radiata*, *Eucalyptus nitens* and *Cupressus macrocarpa*) arranged in a randomized block design of twelve plots each measuring 30 by 30 m. The plots have been developed under grazed pasture with some fertiliser inputs, but were fenced off at trial establishment. The trees were planted at 1250 stems/ha, and while no fertiliser was applied following establishment, the different species were pruned and thinned in accordance with commercial plantation management practices.

Methods

Soil Sampling and Analysis

Samples of mineral topsoil (0-5cm) were taken by soil corer (6 cm diameter) at 4 depths (0-5, 5-10, 10-20, 20-30 cm) from five sites randomly located in the middle of each replicate plot in September 1999 (at trial establishment), September 2004 (5 years after planting) and November 2009 (10 years after planting). Soil samples were air-dried and sieved <2 mm prior to determination of total, organic and inorganic P. Various forms of inorganic, organic and total P were determined using sequential extraction of soil with 1M NaCl, 0.5M $NaHCO_3$, 0.1M NaOH (NaOH I), 1M HCl and 0.1M NaOH (NaOH II) according to the method described by Chen *et al.* (2000), Total extracted Pi and Po were determined by summing the Pi and Po in each fractions.

Results

Mean concentrations of total extracted Pi and Po determined for 0-5 cm, 5-10 cm and 10-20 cm soils taken from the *Pinus radiata*, *Eucalyptus nitens* and *Cupressus macrocarpa* plots in 1999, 2004 and 2009 are shown in Table 1, while the corresponding data for the various sequential fractions are expressed in Table 2. The analysis by fractionation showed that for all three species, concentrations of P were similar for 0-5cm, 5-10cm and 10-20cm. It also reveals that most of the P was present in the NaOH (I) fraction, as it was expected. Some specific major changes with respect to time were observed between species. For example, *P. radiata* and *E. nitens* showed an increase in the concentration of Pi after five years and a decline after ten, while *C. macrocarpa* did not showed any particular trend. On the other hand, the concentration of Po decreased after five years and posteriorly stabilized under *P. radiata* and *E. nitens*, while it continue dropping under *C. macrocarpa*. It also indicates that the concentration of P increased in the most recalcitrant fraction NaOH (2) for all the three species. In general, the concentration was significantly higher in the top 0-5 cm compared to the other depths.

Table 1. Mean concentrations (mg/kg) of total extracted inorganic P (Pi) and organic P (Po) determined for 0-20cm soils taken from the *Pinus radiata*, *Eucalyptus nitens* and *Cupressus macrocarpa* plots in 1999, 2004 and 2009.

	Pinus radiata		*Eucalyptus nitens*		*Cupressus macrocarpa*	
0-5	**Pi**	**Po**	**Pi**	**Po**	**Pi**	**Po**
1999	209.6	443.4	224.7	398.4	219.5	419.0
2004	221.4	358.3	211.5	365.0	222.3	372.0
2009	191.8	371.6	183.9	343.4	213.5	327.8
5-10						
1999	235.6	409.7	187.7	414.6	204.4	394.9
2004	240.4	350.1	225.7	362.6	202.3	393.0
2009	212.0	353.1	183.3	341.6	219.0	340.1
10-20						
1999	214.9	386.8	200.0	380.8	215.1	415.2
2004	229.1	331.9	251.9	313.8	213.9	348.3
2009	225.4	318.6	187.7	317.0	213.0	332.1

Table 2. Mean concentrations (mg/kg) of inorganic P (Pi) and organic P (Po) determined for various sequential fractions (NaCl, $NaHCO_3$, NaOH (1), HCl and NaOH (2)) for 0-20cm soils taken from the *Pinus radiata*, *Eucalyptus nitens* and *Cuppresus macrocarpa* plots in 1999, 2004 and 2009.

	NaCl		NaHCO3		NaOH (1)		HCl		NaOH (2)	
	Pi	Po	Pi	Po	Pi	Po	Pi	Po	Pi	Po
Pinus radiata										
0-5										
1999	3.8	12.9	23.0	81.9	114.2	252.1	43.5	7.8	25.1	88.7
2004	3.8	14.2	30.8	82.9	125.8	177.3	38.5	4.1	22.6	79.8
2009	2.5	6.9	19.3	51.9	98.3	194.9	31.8	3.2	40.0	114.7
5-10										
1999	3.1	9.6	15.0	72.4	152.1	227.8	39.9	8.1	25.6	91.7
2004	3.4	10.5	26.8	66.2	151.3	185.7	36.5	7.2	22.5	80.5
2009	2.1	6.0	15.6	42.1	114.7	204.1	35.3	4.0	44.3	96.9
10-20										
1999	2.8	8.3	7.2	49.4	140.6	231.7	39.9	6.0	24.4	91.5
2004	3.0	10.5	17.6	48.3	147.5	185.3	38.7	4.3	22.4	83.6
2009	1.8	5.2	8.3	30.6	145.3	185.1	28.2	4.1	41.8	93.5
Eucalyptus nitens										
0-5										
1999	3.8	12.4	21.2	76.3	135.2	217.3	41.3	10.3	23.2	82.1
2004	3.7	16.1	35.8	83.9	110.4	178.2	38.3	4.3	23.3	82.4
2009	2.9	7.1	22.0	57.2	96.7	177.6	29.3	3.5	33.0	98.0
5-10										
1999	3.0	11.3	13.6	68.2	111.1	236.0	35.4	10.7	24.7	88.4
2004	3.1	13.6	29.1	73.6	133.9	181.7	35.9	8.8	23.7	84.8
2009	2.6	6.0	15.8	48.5	99.9	179.5	29.9	4.7	35.2	103.1
10-20										
1999	2.6	8.6	7.8	47.9	129.2	222.7	36.1	10.7	24.3	91.0
2004	2.9	10.5	21.7	58.5	165.4	150.9	38.4	6.5	23.4	87.3
2009	2.1	5.3	10.4	33.2	109.7	185.0	27.4	2.7	38.1	90.7
Cupressus macrocarpa										
0-5										
1999	4.1	14.7	25.4	81.3	120.4	220.0	43.2	9.5	26.4	93.4
2004	4.0	15.9	35.3	84.4	122.2	186.0	38.1	5.2	22.8	80.5
2009	2.9	6.1	26.8	49.7	120.3	168.6	32.6	3.5	30.9	99.9
5-10										
1999	3.2	12.6	15.9	75.4	121.1	204.7	38.3	9.2	25.9	92.9
2004	3.5	13.0	23.6	80.3	117.1	215.8	35.7	3.5	22.5	80.5
2009	2.4	5.9	16.3	44.9	128.1	193.3	32.0	3.1	40.2	92.9
10-20										
1999	2.7	10.3	8.8	54.6	140.2	243.7	38.0	11.7	25.4	95.0
2004	3.7	11.0	15.8	48.6	139.8	202.4	33.1	6.1	21.5	80.3
2009	2.1	5.3	8.3	32.0	133.8	182.6	28.4	4.8	40.4	107.5

Highlights

The findings of this study revealed that depletion of top soil Po under all of the three tree species over 10 years following afforestation of grassland had a rapid and major impact on soil properties and processes mainly attributed to enhanced mineralisation of readily extractable organic P. The apparent net reduction in topsoil total P can be attributed to a combination of factors including cessation of grazing, decomposition of pasture residues, tree uptake, changes in organic matter and nutrient returns to soil under trees compared with grassland, and direct impacts of changes in the nature, distribution and activities of tree root systems compared with grassland. These findings confirm that afforestation of grassland has a major long-term impact on soil properties and processes.

References

Belton MC, O´Connor KF, Robson AB (1995) Phosphorus levels in topsoil under conifer plantations in Canterbury high country grasslands. *New Zealand Journal of Forest Research* **25**, 262-282.

Binkley D (1995) The influence of tree species on forest soils - processes and paterns. In 'Proceedings of the Trees and Soils Workshop'. (Eds DJ Mead, IS Cornforth) pp. 1-34 (Lincoln University Press Publishing: New Zealand).

Binkley D, Högberg P (1997) Does atmospheric deposition of nitrogen threaten Swedish forests?. *Forest Ecology and Management* **92**, 119-152.

Chen CR, Condron LM, Davis MR, Sherlock RR (2000) Effects of afforestation on phosphorus dynamics and biological properties in a New Zealand grassland soil. *Plant and Soil* **220**, 151-163.

Chen CR, Condron LM, Davis MR, Sherlock RR (2003) Seasonal changes in soil phosphorus and associated microbial properties under adjacent grassland and forest in New Zealand. *Forest Ecology and Management* **177**, 539-557.

Chen, C.R., Condron, L.M. and Xu, Z.H., 2008. Impacts of grassland afforestation with coniferous trees on soil phosphorus dynamics and associated microbial processes: A review. Forest Ecology and Management, 255(3-4): 396-409.

Davis MR (1998) Soil impacts of afforestation in the high country. *New Zealand Forestry* **42**, 34-38.

Davis MR, Lang LH (1991) Increased nutrient availability in topsoils under conifers in the South Island high country. *New Zealand Journal of Forest Science* **21**, 165-179.

Glass BP (1997) A survey of afforestation intentions in New Zealand between 1996 and 2010. *New Zealand Forestry* **42**: 34-37.