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# Soil impacts of afforestation in the high country

Murray Davis[1]

## Abstract

*Afforestation of South Island high-country grassland soils with exotic conifer species influences the amounts of plant nutrients in topsoils, nutrient availability and soil acidity. The effects are dependent on soil type and tree stand age. Under young stands levels of total nitrogen (N) and phosphorus (P) and Bray-2 extractable potassium (K) and magnesium (Mg) are generally lower than under adjoining grasslands – an effect attributed to greater nutrient uptake by trees. Under older stands total N and P and extractable cation levels are sometimes lower, but may be similar or higher than under grassland. Afforestation stimulates mineralisation of organic matter in topsoils, leading to increased levels of mineralisable (potentially available) N and of sulphate sulphur (S) in hygrous high-country yellow-brown earth soils, and to increased availability of P in all soil groups examined. Under mature pine stands on drier Mackenzie Basin soils mineralisable N is commonly lower than under grassland. Vegetation growing under young pine stands prior to canopy closure contains markedly higher concentrations of N, P, and S in foliage than similar vegetation in adjoining unplanted grassland. Such vegetation may also contain higher concentrations of K and Mg, which is not consistent with results of soil analyses. Soil pH is reduced by afforestation. Productivity of pasture established after harvest of plantations at three sites was found to be 1.5 to 14 times greater than that in adjoining grassland.*

*Access to organically bound nutrients means that growth of conifers is less likely than pasture growth to be limited by N, P or S supply. Improved availability of nutrients to understorey species may increase the potential for grazing in high-country forests.*

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[2] *Soil chemical analyses were as follows:*
*Total P: P extracted in sulphuric acid after ignition of the soil at 550°C*
*Inorganic P: P extracted in sulphuric acid without ignition of the soil*
*Organic P: The difference between total and inorganic P*
*Olsen P (=plant available P): P extracted in alkaline sodium bicarbonate*
*Total N: N extracted by Kjeldahl digestion (boiling sulphuric acid)*
*Mineralisable N (=potentially available N): N extracted in potassium chloride after aerobic incubation of samples in the laboratory*
*Sulphate S (=available S): S extracted in potassium phosphate*
*Bray-2 K, Ca, and Mg: Cations extracted by the Bray-2 reagent (hydrochloric acid and ammonium fluoride)*

## Introduction

Annual productivity of unimproved South Island high-country pastoral grasslands is low, often around 0.1 – 2 t dry matter/ha (O'Connor, 1966; Sinclair and McIntosh, 1983; Scott *et al.* 1985). Productivity of grasslands can be greatly increased with the use of fertilisers. On the other hand, pines (*Pinus* spp.) and other conifers, notably larch (*Larix* spp.) and Douglas-fir (*Pseudotsuga menziesii*), are capable of rapid early growth and high productivity in the absence of fertiliser once they have achieved canopy closure. For example, Nordmeyer and Ledgard (1993) found that total above-ground annual production levels in 15-year-old stands of larch, *Pinus ponderosa*, *P. nigra*, and Douglas-fir at a montane site in Canterbury ranged between 15 and 24 t dry matter/ha. Coupled with this high productivity, vegetation in the immediate vicinity of young conifers often appears more vigorous than similar vegetation in nearby unplanted grassland. This paper reviews studies on the impact of afforestation on chemical properties of high-country topsoils, and presents new information on productivity of grassland after a rotation of pines. Possible mechanisms for increased nutrient availability in soils under conifers are discussed.

## Soil chemistry under conifers and grassland
### Influence of afforestation on soil nutrients

The first indication that conifers may influence nutrient availability in high-country soils came from a survey by Ledgard and Belton (1985) of productivity of conifers (mainly pines) growing in woodlots on farms in the Canterbury high country. Analyses[2] of topsoil samples collected under the stands showed levels of inorganic P to be higher than those normally found under unimproved grassland in soils of the same groups in the region. The samples were subsequently re-analysed using the Olsen extractant, commonly used in agriculture as a measure of plant-available P, to allow comparison with a wider range of existing grassland data (O'Connor 1986; Belton *et al.* 1995). Over a range of terrace, fan, and downland terrain, Olsen P levels were found to be consistently two to four times higher in soils under the conifers than in those under grasslands in the region (Table 1).

Further analysis of topsoil samples collected in the Canterbury and Otago high country from pine stands paired with

## Table 1

| Soil set | Unimproved grassland | Exotic conifer |
|---|---|---|
| **Brown-grey earths** | | |
| Grampians | 22 | 54 |
| **Yellow-grey earths** | | |
| Meyer | 15 | 55 |
| **Dry hygrous high-country yellow-brown earths** | | |
| Mackenzie | 16 | 49 |
| Dalgety | 15 | 50 |
| Pukaki | 11 | 33 |
| Tekapo | 5 | 50 |
| Ohau | 5 | 23 |
| **Hygrous high-country yellow-brown earths** | | |
| Craigieburn | 11 | 18 |
| Cass | 14 | 31 |
| **Youthful yellow-brown earths on loess** | | |
| Mesopotamia | 28 | 55 |
| **Recent soils on alluvium** | | |
| Tasman | 15 | 34 |

Table 1: Olsen P values (ppm) for soil sets under unimproved pasture and exotic conifer plantations in the South Island high country. Mean conifer stand age was 46 years (range 20-67 years). Values are means of 1-16 samples. Data are from Belton *et al.* (1995).
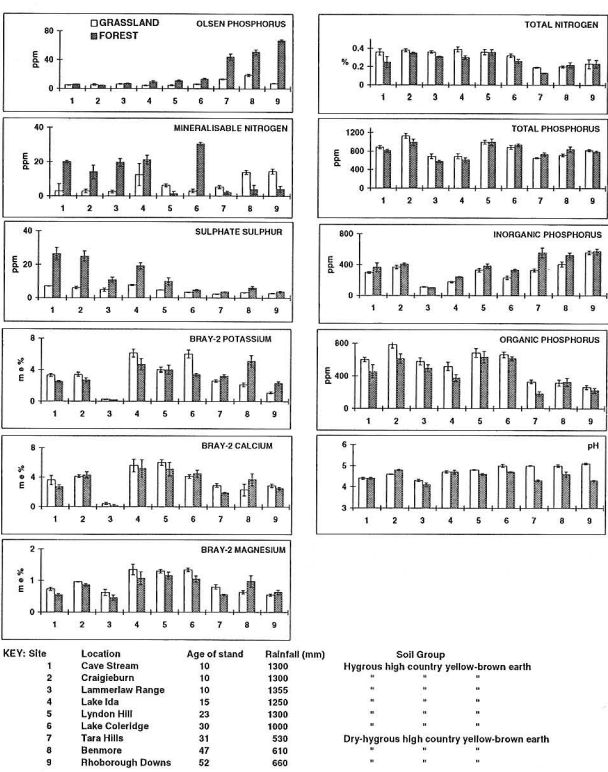


Figure 1. Chemical properties of topsoils (0-10 cm) under forest and adjoining unplanted grassland. Sites are arranged in order of increasing age of the conifer stand. Bars show standard errors. Data are from Davis and Lang (1991) and Davis (1994).

adjoining unimproved grassland generally confirmed the survey results (Davis and Lang 1991, Davis 1994). In these studies it was found that while inorganic P levels were mostly higher, organic P levels were generally lower under pines (Fig. 1). The opposite trends for inorganic and organic P levels indicate that pines may obtain most of their P from organic sources in these high-country soils. Plant available P was found to be higher under pines than under adjoining grassland at all sites except those with young (10-year-old) stands. The increase was greater under older stands on dry Mackenzie Basin soils (sites 7-9 in Fig. 1) than under stands on hygrous high-country yellow-brown earths from the central Canterbury high country, indicating an influence of soil type and/or stand age on the magnitude of increase in available P. Belton *et al.* (1995) found no interaction between vegetation type (grassland or plantation) and soil group for Olsen P in their survey, which included soils from six major high-country soil groups, indicating that enhancement of P was similar for all groups. Hawke and O'Connor (1993) reported increases in Olsen P under pines in an agroforestry trial at Tikitere, near Rotorua, after age 13, with the difference between grassland and forest increasing with stand age. Stand age rather than soil type may therefore be the major factor involved in the different magnitude of increase in available P between the high-country sites evident in Fig. 1.

In addition to P, the availability of N and S may also be greater under pines (Davis and Lang 1991; Davis 1994). Higher levels of mineralisable (potentially available) N and/or sulphate S were found in soil under stands of pines than under adjoining grassland on hygrous high country yellow-brown earths (Fig. 1, sites 1-6). Hawke and O'Connor (1993) also reported an increase in sulphate S under pines in the Tikitere agroforestry trial. Earlier Steele and Percival (1984) had reported a reduction in available N under young pines at the same site, which they attributed to reduced N-fixation by clover under the pines. In contrast to the more hygrous soils, mineralisable N was lower under older stands

on the dry Mackenzie Basin soils (sites 7-9 in Fig. 1), and sulphate S was only marginally higher under these stands than under the adjoining grasslands. From Fig. 1 it can be seen that substantial increases in mineralisable N and sulphate S occurred under stands 10 years of age on hygrous high-country yellow-brown earths. No comparisons have been made with younger stands from drier regions.

In contrast to plant available forms, there was a marked tendency for total N and P levels to be lower under younger stands of pines (aged up to 15 years) on hygrous high-country yellow-brown earths than under adjoining grassland (Fig. 1). Similarly, levels of Bray-2 extractable K and Mg were often lower under these stands. These lower values may be due to greater uptake of nutrients from the soil and sequestration into biomass by forest than by grassland. For older stands values were often similar or higher under trees, suggesting, given the amounts of nutrients removed from the soil and sequestered in tree biomass, some redistribution of nutrients into the topsoil horizon by cycling from lower horizons. Belton *et al.* (1995) reported higher levels of total N in soils under mature conifers on drier soil groups (brown-grey and yellow-grey earths) and on youthful soils on loess, than under grassland on the same soil groups. Little or no increase was observed under mature conifers on soils with higher native N levels (high-country yellow-brown earths and recent soils on alluvium).

### Influence of afforestation on soil acidity

Belton *et al.* (1995) found soil pH to be lower under mature conifer stands than under grassland, the mean decline being much greater (0.7-1.0 pH units) for the drier soil groups and youthful soils on loess (those soil groups with lower native N levels) than for high-country yellow-brown earths and recent soils on alluvium (0.1-0.3 pH units). Although confounded by differences in stand age, a similar pattern is evident from the comparisons in Fig. 1, which show the greatest differences in pH on drier Mackenzie Basin soils with lower native N and organic P levels.

These patterns indicate that pH decline with afforestation may be greater on poorly buffered soils with low organic matter contents than on soils with higher organic matter contents.

The decline may be partly reversed after harvest, when cations contained in tree crowns are returned to the soil. The decline in pH under forest would be of little consequence if the land was replanted with trees after harvest. Liming may be necessary to achieve optimum production if pasture was to be re-established.

## Nutrients in associated shrubs and herbaceous vegetation

Analyses of foliage collected from vegetation persisting under young (approximately 10-year-old) pine plantations, and from the same species growing in adjoining unplanted land, have provided further evidence of increased nutrient availability under conifers. Three examples are given (see Fig. 2).

King devil hawkweed (*Hieracium praealtum*) growing under nine-year-old Scots pine (*P. sylvestris*) at Balmoral Station, Mackenzie Basin, contained substantially higher concentrations of N, P and K, and marginally higher concentrations of S, than plants growing between tree rows. The hawkweed growing under the pine was much more vigorous than that between tree rows (Fig. 3). Ca and Mg concentrations were not significantly different between the two locations.

Snow tussocks (*Chionochloa rigida*) growing amongst young radiata pine (Site 3 in Fig. 1) were larger and had higher concentrations of N, P, S, and also Mg than tussocks in an adjoining unplanted catchment (Davis, 1994). Potassium and Ca concentrations were not affected.

Two young stands of pines were included in the study of Davis and Lang (1991) described above (Sites 1 and 2 in Fig. 1). Native shrubs (species of *Cassinia, Leptospermum, Dracophyllum, and Hebe*) were present in the understorey. Nitrogen, P, and K concentrations were found to be higher in all species except manuka (*Leptospermum*) under both stands of pines, while Ca and Mg were not affected. Sulphur levels were not determined originally, but recent analysis of one species (*Hebe venustula*) has also shown foliar S levels to be higher under pines. Data for this species are shown as an example in Figure 2.
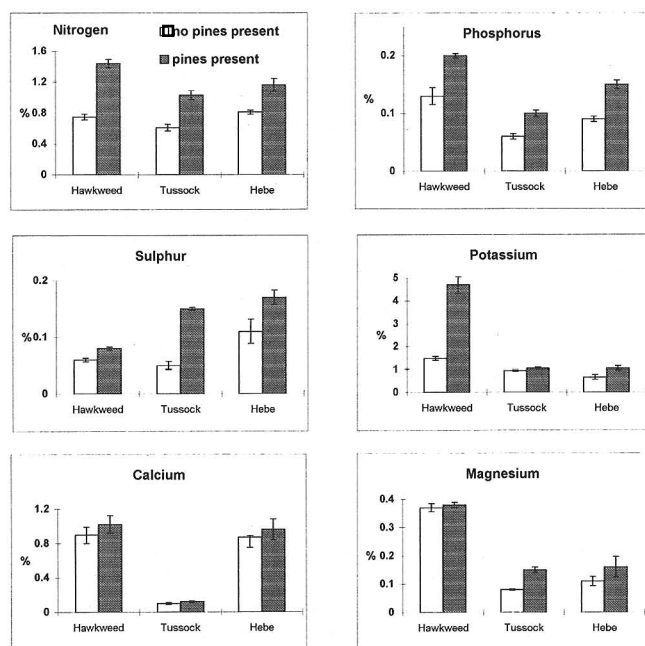
**Figure 2. Foliar nutrient concentrations in vegetation growing beneath young conifer stands and in adjoining unplanted grassland. The three species are from different sites (see text). Bars show standard errors.**

### Table 2

| Site | Plantation age at felling (years) | Time since clearfelling (years) | Grassland area | Ex-forest area | Significance level |
|---|---|---|---|---|---|
| Craigieburn 1 | 10 | 3 | 177 | 1104 | <0.01 |
| | | 4 | 250 | 1078 | <0.01 |
| Craigieburn 2 | 14 | 14 | 530 | 830 | <0.05 |
| Lake Coleridge | 30 | 9 | 225 | 788 | <0.01 |
| | | 10 | 319 | 4678 | <0.01 |

**Table 2: Spring-summer productivity (kg/ha) of pasture or volunteer species after exotic pine forest compared to adjoining unplanted grassland at three locations in the Canterbury high country.**

For available N and S, but not for available (Olsen-extractable) P, these foliage analysis data are consistent with the results of analyses of topsoils under young tree stands. Although not consistent with Olsen P small increases in available P determined by the Bray-2 method have been observed in soil under some young high-country pine stands (Davis and Lang, 1991). The data show that foliar concentrations of K and Mg are sometimes increased by association with young trees, despite observed reductions in levels of extractable amounts of these nutrients in the soils. For the first two of the above examples there is evidence that plant biomass per unit area was not decreased by association with the trees. Increases in foliar nutrient concentrations may therefore be regarded as a direct indication of enhanced nutrient availability under young pine stands.

**Figure 3. Vegetation growing under Scots pine at Balmoral Station, Mackenzie Basin, is much more vigorous than that growing between tree rows. This may be partly due to modified microclimate. Hawkweed growing under the trees had significantly higher foliar N, P, S and K levels than plants growing between tree rows (See Fig. 2).**

## Pasture production after harvest of pine plantations

Measurements of pasture production at three sites in the Canterbury high country that had previously supported a pine crop allow a further assessment of the impact of afforestation on soil fertility. The plantations at two of the sites (Craigieburn 1 and Craigieburn 2, Table 2) consisted of small experimental plantings of pines which were felled at a young age, while the plantation at the third site (Lake Coleridge) had been felled at maturity (30 years old). Spring-summer pasture growth only was measured. At Craigieburn 1 site, production was measured within the felled area and on adjoining grassland in plots which had been established and sown with pasture species after removal of all vegetation and litter. At the other two sites productivity of swards

that had established naturally after felling was compared with that of the adjoining grassland. Production at Craigieburn sites 1 and 2 exceeded that in adjoining grassland by factors of 1.5 to 6.2, while production at the older plantation site exceeded that from adjoining grassland (see Figs 4 and 5) by a factor of 3.5 in the first year of measurement, and 14.6 in the following year (Table 2). Soil data (sites 2 and 6 in Fig. 1) suggest that the pasture may have responded to increased N, P or S availability in the pine soils.



Figure 4. Measuring pasture production in low-productivity grassland, Lake Coleridge. Compare with Fig. 5.

The tree plantations at the above sites were not established for the purpose of determining the influence of afforestation on subsequent pasture production. Because of lack of internal replication it cannot be inferred for individual sites that the increased pasture prouction was due to an influence of the previous pine crop. Taken together, however, the results are consistent with increased nutrient availability demonstrated by soil and foliar analyses, and indicate that increased nutrient availability could benefit pasture production for a number of years after the removal of tree plantations.

## Mechanisms for increased nutrient availability under conifers

There are several possible mechanisms whereby nutrient availability in topsoils may be increased under conifers. These include:

1. *Enhanced mineralisation:* Conifer exudates may have specific chemical properties that facilitate release of nutrient elements from soil organic materials.

2. *Nutrient pumping:* Deep rooting conifers may take up



Figure 5. Pasture production after a rotation of pines near Lake Coleridge greatly exceeds that from adjoining grassland (see Fig. 4).

nutrients from subsoils or lower horizons, and subsequently return them to the soil surface in litterfall.

3. *Aeolian deposition:* The canopies of some high-country stands are dusty, indicating that entrapment of windblown material (loess) by the forest canopy may contribute to nutrient enrichment.

4. *Animal transfer:* Livestock, feral animals, and birds using plantations for shelter may transfer nutrients, ingested from surrounding vegetation, as excreta.

5. *Suppression of ground vegetation:* At canopy closure ground vegetation is suppressed by competition from the trees, and nutrients would be released from this material.

6. *Microclimatic effects:* Shade and shelter provided by the tree canopy may influence nutrient concentrations of understorey plants indirectly through growth effects resulting from modification of moisture, insolation, wind-stress, or temperature.

While all of the above mechanisms could account to some degree for increased nutrient availability in older stands, it is unlikely that observed increases under the younger (10-year-old) stands are due to nutrient pumping and/or aeolian deposition, because of the length of time it would take for nutrients to accumulate in the topsoil.

Chemical changes similar to those observed in the field can be induced by growing pine seedlings in grassland soils in a glasshouse environment. Radiata pine (*Pinus radiata*) and the common pasture species cocksfoot grass (*Dactylis glomerata*), as a control, were grown in small pots containing grassland soils collected from several sites in the South Island montane zone. Full details of the experiment are given in Davis (1995). Analysis of soils after one year showed that the availability of N, P, and S in the soil was higher after pine growth than after grass, a result which is consistent with results from the field studies. Lower levels of total N, and total and organic P after pine growth than after grass, were also consistent with results of the field analyses. Organic carbon (C) was also lower after pine growth. Cation concentrations were not determined.

Elevated levels of plant available nutrients observed in the glasshouse were not associated with nutrient pumping, aeolian deposition, animal transfer, vegetation suppression or microclimatic effects. The absence of these factors, combined with the lower levels of total N and organic P and C in the pine soils, indicates that the elevated levels of available N and P, and presumably S, in the pine soils resulted from a greater degree of mineralisation of organically-bound nutrient elements under pine than under grass. This conclusion does not imply that the other mechanisms do not operate under field conditions.

The suggestion that pines can enhance mineralisation is not new. The theory was advanced by Stone and Will (1965) to account for observations of improved growth and N nutrition of species of *Araucaria* (Australia), *Fraximus* (North America), and *Cupressus* and *Chamaecyparis* (New Zealand) when planted adjacent to pines. Similarly, Fisher and Stone (1969) suggested that mineralisation of soil organic compounds by conifer roots was the most likely reason for elevated levels of available N and P in soils and understorey herbaceous vegetation under several young *Pinus* and *Larix* stands in New York State, USA. Will (1968) showed that 'bleaching' of the $A_1$ horizon of pumice soils under *P. radiata* is associated with reduced C and N concentrations. The stimulation of soil organic matter mineralisation in the topsoil (A horizon) contrasts with the inhibitory influence of mycorrhizal roots on decomposition of litter beneath *P. radiata* observed by Gadgil and Gadgil (1971, 1975).

The stimulation of mineralisation of soil organic matter by pines is somewhat similar to the effect achieved by soil cultivation, though different processes may be involved. $^{31}P$ nuclear magnetic resonance studies have shown that when mineralisation of organic P is enhanced as a result of cultivation of grassland or forest soils, orthophosphate diester forms of organic P are mineralised more readily than monoester forms (Condron *et al.* 1990). In contrast, analysis of soils from Cave Stream, Lyndon Hill, and Tara Hills has shown that orthophosphate monoesters and diesters are mineralised in proportionately similar amounts under conifers (Condron *et al.* 1996). The ability of pines and other conifers to access nutrients from soil organic matter is due to their association with ectomycorrhizal fungi. Mycorrhizas produce extracellular enzymes which allow the trees to access nutrients that are normally unavailable to non-ectomycorrhizal plants (Marschner and Dell, 1994). Situations can be envisaged in young or open stands where nutrients made available, but not taken up by the trees, can be used by other plants.

## Conclusions

The results of the various studies summarised here show that pines commonly increase the availability of plant nutrients in high-country soils. The ability of pines (or other species which form associations with ectomycorrhizal fungi) to access organically bound nutrients means that they may not be greatly limited by N, P or S supply, which is inadequate for pasture species in the region. Fertiliser trials are required to confirm this suggestion. Since pines increase the availability of nutrients to understorey species, and since trees in the high country grow at slower rates than at lower elevations, there may be some scope for increased grazing amongst pines on afforested land in the extended period prior to canopy closure. Revenue from grazing in young stands could help to offset the costs of afforestation, which, due to greater rotation length, have to be borne over a longer time period than elsewhere.

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