Soil Properties and Processes Under Different Vegetation Types in New Zealand

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Abstract

Soils and the vegetation growing in them are linked through the biogeochemical cycle. Consequently, each affects the dynamic processes occurring in the other. The effect of vegetation on soil properties is seen most directly in forests. Moroid forest soils have very different characteristics from mulloid forest soils. Different mor-forming species affect soil processes in varying ways, depending on such factors as soil parent material and landscape position. Thus some, but not all, mor-forming species in the New Zealand indigenous flora promote podzolisation and those that do may not do so in all soils. Processes associated with individual trees such as stem flow and windthrow significantly affect soil processes and lead to considerable short-range variation in New Zealand forest soils. The conversion of indigenous forests to grassland has led to major changes in soil properties and processes. These changes are attributable not only to the substitution of mulloid grasses for largely moroid forest species, but also to the large fertiliser inputs and grazing management that have allowed the growth of relatively high fertility pasture species. Significant changes in soil properties have also followed the planting of conifers into grassland in the eastern South Island high country but the processes responsible for these changes are not yet understood.

Key words: *forests, forest conversion, soil properties, windthrow, stem flow, podzolisation*

Introduction

Particularly in natural unmanaged ecosystems, the soil pattern may influence vegetation distribution but, equally, the vegetation may influence soil properties. This inter-relationship of soils and vegetation is well established. Jenny's Soil Forming Factor Model (1941) formalised one part of this inter-relationship as:

S = f (parent material, climate, organisms, relief, time)

wherein changes in soil properties (S) are recognised as resulting from the interaction of the soil forming factors, of which the organisms term (including vegetation) is one. The model implies that if we wish to study the effects of different vegetation types on soil properties, it is necessary to choose sites carefully so that the soil forming factors other than vegetation (organisms) are relatively unvarying at the different sites. It also implies that the way in which vegetation affects soil properties is likely to vary between sites where different combinations of the soil forming factors are present.

This paper considers the ways in which vegetation affects soil properties and processes, with particular reference to New Zealand forest examples, where these effects tend to be more easily studied.

Influence of vegetation on soil organic matter forms

The effects of vegetation on the development of mull and mor organic forms are well known (Handley 1954). Classically, mull humus forms are associated with European hardwood forests such as oak and beech and with grasslands on soils relatively high in the base nutrients (calcium, magnesium and potassium). Mor humus forms, on the other hand, have been associated with coniferous forests and with heathlands on soils that are typically acidic and low in base nutrients.

It is now considered that in mor-forming soils, polyphenol production is enhanced, associated with high internal translocation of nutrients (particularly nitrogen) from foliage prior to abscission (Handley 1954, Davies *et al.* 1964). In species such as *Pinus radiata*, translocation of nutrients occurs from very early in needle development (Fife and Nambiar 1984) with up to 50% of the nitrogen withdrawn prior to needle cast (Beets and Pollock 1987). The combination of enhanced polyphenol production and low nitrogen content enhances the development of the mor humus form.

Vegetation and soil processes

Mor-forming species are often associated with podzol formation, but not always. In New Zealand, Atkinson (1980) considered that on a freely drained parent material under a moderate to high rainfall, podzol formation can be induced beneath certain indigenous forest species, particularly kauri (*Agathis australis*), beech (*Nothofagus* sp.), rimu (*Dacrydium cupressinum*), kaikawaka (*Libocedrus bidwillii*), Halls totara (*Podocarpus hallii*) and *Dracophyllum arboreum*. Atkinson also noticed that weaker podzolising effects occur under some shrub species and *Chionochloa* tussock, but that other mor-forming species such as matai (*Prumnopitys taxifolia*), hinau (*Elaeocarpus dentatus*) and miro (*Prumnopitys ferruginea*) are non-podzolising. Kamahi (*Weinmannia racemosa*) appears to podzolise in some situations but not in others.

Perhaps the most widely known New Zealand example of podzol formation caused by a forest species is the 'kauri podzol'. As with all podzols, its classic form is shown best on freely drained (usually sandy) felsic parent materials such as in the Te Koporu podzol in Northland. However, there is limited published information describing the properties or mode of formation of New Zealand kauri podzols. The limited available evidence tends to be fragmentary but it suggests that all of the soil forming factors (Jenny 1941) may interact to determine the extent to which the podzolisation process arising from a particular vegetation finally appears as a podzol profile form.

'Soils of New Zealand' contains descriptions and analyses of two profiles representing kauri podzols. One is the One Tree Point loamy sand, a northern ground-water podzol, described as formed on 'consolidated sands under kauri forests, later becoming a peaty swamp' (NZ Soil Bureau 1968). The chemistry of this soil (table 1) shows some classic podzol features, with eluviation of organic carbon (C) and aluminium (Al) from the upper profile (A11, A12 and A2 horizons) and accumulation in the B1h, B21h and B22hfe horizons. This podzolisation may be regarded as being due to the influence of the previous kauri forest. However, the influence of the current high water table that has presumably occurred since the removal of the

Table 1: Some chemical properties of two soils which either currently (Wharekohe silt) or in the near past (One Tree Point loamy sand) carried kauri forest

		Organic	Oxalate	
		C	Al	Fe
Horizon	pH	%	%	
One Tree Point loamy sand				
A11	5.2	8.3	0.23	0.04
A12	5.8	4.3	0.17	0.03
A2	6.1	3.9	0.32	0.03
B1h	5.3	7.5	nd	nd
B2h	5.5	13.0	5.96	0.04
B22hfe	4.9	5.9	nd	nd
C	4.9	1.4	2.60	0.07
Wharekohe silt				
0	4.7	nd	nd	nd
A21	5.2	14.6	0.07	0.02
A22x	5.5	3.5	0.04	0.01
A23	5.1	2.0	0.30	0.12
B1	4.8	1.8	nd	nd
B21hg	4.9	1.3	0.84	1.07
B22g	4.8	1.0	nd	nd
C1g	4.8	0.7	0.83	0.76

nd – not determined

Source: NZ Soil Bureau 1968

kauri forest is seen in the low oxalate iron (Fe) levels throughout the profile in contrast to the classic podzol feature of Fe eluviation from the upper profile and accumulation in the B22hfe horizon. The influence of the current gleying processes operating in this profile is recognised by its recently revised classification as a humus-pan perch-gley podzol (Hewitt 1992).

The other kauri podzol identified (NZ Soil Bureau 1968) is the Wharekohe silt. However, this soil shows few characteristics of a true podzol. There is no evidence of organic C or Al eluviation, although some accumulation of Fe is present in the B21hg horizon (table 1). The chemistry appears to be more typical of a gley soil or a gley podzol, with any podzolisation imparted by the kauri forest being amended by variations in drainage and aeration within the catenary landscape in which this soil occurs. It is not surprising therefore that the Wharekohe series is classified in the ultic order rather than the podzols in the revised New Zealand soil classification (Hewitt 1992). Thus in both the One Tree Point and Wharekohe soils, any podzolising effect of the kauri has been amended or largely prevented by changes in water-table and landscape position.

Swindale (1957) showed that the extent of podzolisation by kauri was also determined by parent material differences, with podzolisation being more pronounced on rhyolitic (felsic) than basaltic (mafic) parent materials. Although this conclusion was based on very limited chemical analysis, it reinforces the need for co-ordinated studies examining both the mechanisms of podzol formation under kauri, and the manner in which changes in the other soil forming factors (particularly landscape position and parent material) may alter the podzolisation process.

Soil processes other than podzolisation may be induced by vegetation types. Cowie (1965) compared the soils under two different forest types (black beech and podocarp-broadleaf) in the Manawatu. Both soils were on the same parent material and were therefore presumed to have had comparable initial mineralogy and chemistry. Cowie's data (table 2) show that the Aokautere soil under black beech is more strongly leached, more acid, and significantly lower in Truog (available) phosphorus (P) than the Halcombe soil under podocarp-broadleaf forest. Exchangeable calcium (Ca) is particularly low in the lower horizons of the Aokautere soil. Nutrient cycling studies (Miller 1963, Levett *et al.* 1985) have shown that New Zealand beech have a high Ca uptake. This typically leads to low exchangeable soil Ca, particularly below the A or O horizons where litter return maintains relatively high Ca contents. Many soils under beech in Westland also show extremely low exchangeable Ca in the mineral soil (Mew 1980). Cowie's (1965) study provides a clear example of the differential effects of two forest types on soil chemistry and fertility. One would expect that these differences would have been important in the development of these soils for agriculture.

Stem flow

In those soils where podzolisation is enhanced by the vegetation, the effects are often most clearly seen immediately around individual trees as so-called 'egg-cup' podzols. How and to what extent do individual trees contribute to podzol formation?

Stem flow is the localised redistribution of about 5–10% of incident precipitation down the boles of individual trees. This gives rise to a substantially increased leaching potential around larger trees which is enhanced by considerable inputs of soluble organic C arising from canopy and bark leachates (Gersper and Holowaychuk,

Table 2: Some chemical properties of two soils under different forest types in Kairanga County

Depth (cm)	pH	BS %	Ca me %	Mg me %	Truog P mg %
Aokautere hill soil–black beech					
0–8	4.7	27	2.4	2.5	3
13–20	4.9	16	0.1	1.0	1
28–46	5.1	12	0.1	1.2	1
Halcombe hill soil–podocarp-broadleaf					
0–8	6.1	68	6.2	4.6	6
18–30	5.9	45	1.8	2.6	3
41–51	5.8	44	1.2	2.3	3

Source: Cowie 1965

1971). The soluble C input is particularly important in predisposing the zone affected by stem flow to podzolisation both by lowering the soil pH which increases the solubility of Fe and Al and by providing the chelating agent necessary to cause eluviation of both elements with consequent podzol formation. However, in soils of low hydraulic conductivity in areas of high rainfall such as South Westland, stem flow may lead to gleying rather than podzolisation (J A Adams, unpublished data).

Substantial inputs of nutrients also occur in stem flow. Enright (1987) showed the significance of stem flow to the Ca, magnesium (Mg) and potassium (K) nutrition of nikau palm (*Rhopalostylis sapida*).

The detailed changes in soil chemistry and clay mineralogy arising from red beech stem flow on Ahaura soils in Westland (Campbell 1974) are summarised in table 3. Between individual trees, soil pH values were 4.5 or greater and organic matter levels were relatively low. In these conditions, Al and Fe were accumulating in the yellow-brown earth profile, leading to the formation of pedogenic chlorite, kaolinite, gibbsite and allophane in the clay fraction. The presence of red beech stem flow led to the development of localised podzols as pH values fell to below 4.4 and organic matter levels were relatively higher leading to the solubilisation and eluviation of Al and Fe from the upper soil horizons. The clay fraction was now dominated by smectite minerals.

Windthrow

Given a stable landscape with forest cover over long periods of time, we might expect the formation of a continuous podzol form

Table 3: Summarised changes in soil chemistry and clay mineralogy associated with the presence of individual red beech (*Nothofagus fusca*) trees on Ahaura soils, Westland

Parent material
Main clay minerals
mica
primary chlorite
felspars

——→ *Between present trees*
- pH ≥ 4.5
- low OM
- Al and Fe accumulating relatively

Yellow-brown earth profile form
Main clay minerals
pedogenic chlorite
kaolinite
gibbsite
allophane

↓ *Under large beech or old stumps*
- stem flow
- pH ≤ 4.4
- high OM
- Al and Fe lost from upper profile

Podzol profile form
Main clay mineral
smectite

Source: Campbell 1974

(Campbell 1974, Molloy and Cox 1965). Why then don't we see more continuous podzols under New Zealand beech forests? Recent studies (Campbell and Mew 1986, Burns and Tonkin 1987) have shown that windthrow, which is common in these forests, tends to lead to retardation of soil development as the present yellow-brown earth profile form. Although the windthrow pit is a zone of organic matter accumulation and enhanced leaching which leads to the development of a podzol, the windthrow mound covers a much more extensive area. The soil mixing which occurs there, together with the decreased leaching potential on the mound as it sheds rather than accumulates water, leads to the maintenance of yellow-brown earth soils.

Windthrow in rimu forest in South Westland leads to a redirection rather than retardation of soil development, particularly on relatively better drained low ridges within the glacial outwash surfaces (Adams and Norton 1991). In this high rainfall environment, shallow organic soils (peats) develop over the underlying moraine as plant litter accumulates in the typically water-filled old windthrow pits. The windthrow mounds are typically quite stony due to incorporation of moraine and are therefore somewhat better drained than the associated unmodified gleyed yellow-brown earth soils. This leads to increased leaching and eventual development of a podzol on the mounds. The relatively better drainage of the soils of the windthrow mounds affects vegetation re-establishment, with initial colonisation by ferns and tree ferns and subsequent replacement by broadleaved trees, particularly kamahi (Adams and Norton 1991). Thus the vegetation affects soil properties through windthrow, with the changed soil pattern in turn determining the nature and sequence of vegetation re-establishment.

Effects of changing land use on soils

In New Zealand, forest and grassland sites not developed for primary production purposes and which have not received any fertiliser or lime amendment have typically been used for the characterisation of soils (including chemical analysis) as part of soil surveys. The rationale for this appears to be twofold. First, it allows for clearer interpretation of natural soil processes and, secondly, it provides a benchmark against which changes due to human activity can be assessed. However, soil properties and processes under conditions of different vegetation types and management have seldom been compared. The shortage of studies examining the effects of converting indigenous forests, scrubland or grasslands to high-production farmland is particularly surprising, given the extent and significance of these changes.

The development and maintenance of grazed grass-clover pastures typically involves considerable additions of lime and phosphate fertiliser. This leads to an accelerated rate of incorporation of organic matter into the soil as earthworm numbers increase and mulloid humus forms develop. Topsoil organic matter levels typically increase, together with N, sulphur (S) and organic P (Jackman 1965). Although not measured by Jackman, cation exchange capacity would increase with increasing organic matter, and topsoil pH would presumably have risen. Inorganic P contents would be greater too than in the undeveloped soil, although Jackman's data suggest that much of the added P has accumulated as organic P associated with the organic matter. The types of changes described by Jackman (1965), or which can be inferred from his data, are likely to be most pronounced where development of forest land to grazed pasture ecosystems has occurred on relatively strongly weathered and leached soils.

In forests on strongly weathered and leached soils, the biogeochemical cycle typically dominates site fertility with efficient cycling of nutrients between the moroid forest floor and vegetation pools, and very little contribution from the mineral soil. Grazed pasture ecosystems are managed to encourage the growth of high-fertility species through fertiliser and lime applications and enhanced nutrient cycling via the grazing animal. These two ecosystems therefore show considerable differences in both the rate and amount of nutrients cycling within the biogeochemical cycle. However, the extent to which these differences, attributable to land development, have affected soil development processes is unknown, although changes have clearly occurred.

The effects on soil properties that occur following the establishment of *Pinus radiata* plantations are becoming better understood (McIntosh 1980, Turner and Lambert 1988). Again, the effects on soil processes are largely unknown, although, as Will and Ballard (1976) note, claims are periodically made that *Pinus radiata* plantings lead to increased podzolisation. A review of studies investigating the changes in soil properties associated with replacement of indigenous vegetation with radiata pine plantations (Turner and Lambert 1988) found no evidence to support this claim. They found that radiata pine stands generally had lower soil organic matter and N contents, but that the differences in soil N were typically counterbalanced by a greater accumulation of N in the more productive pine biomass. Thus there was effectively a redistribution of N between soil and plant N pools within the biogeochemical cycle, which was most pronounced on lower-fertility sites.

Recently it has been shown that coniferous plantings in the eastern South Island high country are associated with nutrient enrichment in topsoils. In particular, Olsen and Bray 2-extractable P levels were higher under conifers than under adjacent grassland (Ledgard and Belton 1985, Davis and Lang 1991) while topsoil pH declined under the conifers (particularly in drier areas) with an accompanying increase in exchangeable Al (Davis and Lang 1991). Both mineralisation of organic matter by the trees and nutrient transfer from deeper horizons to the soil surface via nutrient uptake and litterfall have been suggested as mechanisms for this effect (Davis and Lang 1991).

Conclusions

Different New Zealand forest types cause differences in the underlying soils, but the effects are not yet clearly identified or understood. Some success has been achieved in identifying the ways in which individual trees affect soil properties. Enhanced podzolisation may occur under certain vegetation types due to the localised effects of increased acidity and soluble organic carbon inputs in stem flow. The extent to which this enhances podzol formation is determined by vegetation type, as well as by differences in parent material and landscape position. Also acting against podzol formation is tree windthrow, which may either retard or redirect pedogenesis.

Changing land use undoubtedly affects soil properties. Grazed pasture ecosystems in New Zealand are of higher soil fertility than forests are, due to management differences. They show accumulation of organic matter and N in topsoils and have greater amounts of most nutrients moving within the biogeochemical cycle. Replacement of indigenous forest by *Pinus radiata* leads to some redistribution of N in particular from soil to plant pools but the extent of podzolisation does not appear to be affected. Plantings of conifers in grasslands or shrublands of the eastern South Island high country has led to decreases in topsoil pH and increases in plant available P. However the extent to which soil processes are altered by changes in land use requires further study.

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