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19. EFFECTS OF TREES ON SOILS

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Despite a considerable literature on the subject, there is very little substantive evidence about effects of different tree species on soils and soil processes. This lack of evidence is surprising, because the reputations of certain conifers for acidifying and creating podzols (Noirfalise, 1968), and of some hardwoods, notably birch, for ameliorating podzols (Gardiner, 1968) suggest, if true, profound implications for forestry practice and land use in the uplands.

Accordingly, a study was begun in late 1973 to identify the trends, rates, limits and causes of soil changes associated with birch development on poor moorland soils. This paper summarises the main findings to date, and then discusses three topics whose general importance has become increasingly apparent as the study proceeded: the consequences of soil changes, the role of roots in soil changes, and the effects of forestry management practices on nutrient availability.

1. Effects of birch

Thirteen sites situated from Sutherland to north Yorkshire are being studied. At each site, soils under first generation birch stands of different ages are being compared with soils in immediately adjacent areas without birch. Two of the sites are old quarry floors in moorland, 3 are felled Scots pine stands planted on former heather moorland, while the other 8 are on heather moorland. *Betula pubescens* predominates at 3 of the sites, and *B. pendula* at the others. The degree of uniformity of soil and vegetation over each site before birch colonization began was assessed by examination of soil mineralogy and particle size distribution, soil profiles, and buried stem fragments, viable seed and pollen. This examination provided the background against which present differences could be interpreted.

Since birch colonization, substantially the same trends seem to be evolving at all sites although the extent and rate of change vary considerably between sites. (Table 29 shows some of these trends at one site.).

TABLE 29 Soil analyses from heather moorland and nearby stands of *Betula pendula,* aged from 18 to 90 years old, Advie, Morayshire, Scotland.

		Age of *B. pendula* stands				
	Heather moorland	18 years	26 years	38 years	90 years	LSD at 5% level
* pH	3.8	3.9	4.0	4.7	4.9	0.1
**Exchangeable H (mg dm^{-3})	117	108	109	101	89	25
**Exchangeable Ca (mg dm^{-3})	196	201	207	489	319	83
**Total P (mg dm^{-3})	151	210	196	240	232	82
**N mineralization after 14 days incubation (mg dm^{-3} week^{-1})	−1.3	25	41	45	40	10
**C/N ratio	30	26	19	22	15	11
**C/P ratio	500	320	280	270	170	200
**C/K ratio	440	430	410	460	310	210
**Bioassay: mean shoot dry weight (mg) of 8 weeks old radishes.	8.7	18	43	59	66	18
Mean number of earthworms per 1 m^2 (by formalin extraction)	1	5	27	127	78	26
***Extractable Fe (mg 100 g^{-1})	173	125	670	590	640	530
***Extractable Al (mg 100 g^{-1})	128	150	375	520	480	632

* Soil from 0-5 cm, after removing L + F layer.

** Soil from 0-15 cm, after removing L + F layer.

*** Soil from the bottom 10 cm of the A horizon.

1.1 Vegetation changes:

a) Gradual death of the *Calluna* ground cover as birch canopies develop, and it is replaced by *Deschampsia flexuosa* and *Vaccinium myrtillus* in particular, the former especially on more mineral soils, the latter where an organic surface horizon is better developed.

b) Gradual appearance of species characteristic of woodlands and grasslands, eg *Agrostis* spp, *Anthoxanthum odoratum, Hypericum pulchrum, Oxalis acetosella, Viola riviniana,* as soil conditions change.

1.2 Soil changes:

a) An early decrease in suitability of the ground as a seed bed follows changes in the field layer, but there are indications of a later improvement, possibly associated with increased concentrations of large herbivores attracted to the changed swards.

b) A gradual change takes place in the composition of the buried seed flora to one characteristic of woodland; soil pollen accumulations change similarly.

c) There is a considerable increase in numbers of surface living earthworms, especially *Lumbricus rubellus,* with *Lumbricus terrestris* and *Allolobophora* spp appearing later as soil conditions change.

d) There is a gradual breakdown of the old *Calluna* mor humus layer and its conversion to a mull-like form, probably due largely to earthworm feeding.

e) Increased rates of organic matter decomposition and of nitrogen mineralization are recorded.

f) There is a decrease in exchangeable hydrogen, but increases in pH, exchangeable calcium and total phosphorus.

g) There is a decrease in carbon/nitrogen, carbon/phosphorus and carbon/potassium ratios from the critical levels present on the moorlands (*c*20-30, 350-500 and 400-500 respectively) at which nutrient immobilization and deficiencies would be expected (Evers, 1967; Gosz *et al.,* 1973; Dowding, 1974).

h) Growth of test plants (radish, *Luzula sylvatica* and *Rumex acetosa*) increases in bioassay trials.

i) A suggestion that the bleached Ea horizon in podzols was being gradually obliterated by the incorporation of organic matter and ferric iron, thus tending to form brown podzolic profiles.

The work has raised many questions; 2 in particular are being investigated:

(i) What is the origin of the increased amounts of calcium found in the topsoil of relatively old stands of birch? Through its effect on pH, this calcium seems to be critically involved in the change from mor to mull. Initially, it was suggested that birch may be absorbing calcium at greater depths than heather, but, while this is being investigated, current evidence suggests that birch is also accelerating the weathering of soil minerals throughout the profile as compared with heather.

(ii) If depodzolization does occur under birch, how is the Ea horizon obliterated? Soil mixing is probably the major cause. If so, to what extent can this be attributed to earthworms, other soil living animals and to the growth of roots?

To verify the soil changes inferred from this survey, and to elucidate further the mechanisms involved, a series of long term experiments is being established. Birch is being planted at 3 heather moorland sites on podzols, and heather is being established after felling birch at 3 sites with brown podzolic soils. With the information gained it is hoped that a more complete and meaningful model of the soil processes involved can be made.

2. Consequences of soil changes

Unlike birch and many other broadleaved species, many conifers are typically associated with mor humus systems (eg pines and spruces) with (i) relatively slow rates of organic matter decomposition and nutrient release, (ii) considerable immobilization of nutrients in the soil organic matter, and (iii) soil acidification and, in susceptible soils, accelerated podzolization (Miles, 1978). What are the consequences of these changes under conifers compared with those under mull-forming broadleaved species?

Because podzols and mor humus systems are generally associated with poorer volume growth of trees, even of species adapted to such conditions, than are brown podzolic soils and mull humus systems (Lag, 1962; Pyatt, 1970; Page, 1971), it might be expected that soil changes under conifers would eventually cause declining yields. But the evidence is equivocal. Whereas some studies have indicated slower growth rates of second generation stands of conifers at some sites (Siren, 1955; Keeves, 1966; Whyte, 1973), others have been unable to detect changes (Genssler, 1959; Holmsgaard *et al.,* 1961; Hausser, 1964; Bublinec, 1973).

However, because the faster rates of decomposition and nutrient release associated with broadleaved trees in mull-forming systems would be expected to accelerate plant growth, would an admixture of broadleaved trees benefit the growth of conifers? There have been claims to this effect (Shumakov, 1958; Kovalev, 1969; Blintsov, 1971; Prudic, 1972), but the supporting data are unconvincing. The value of pure versus mixed stands clearly needs critical examination. In much of Britain and the rest of western Europe, soils developed under natural broadleaved woodland have now been replanted with conifers. Remembering that in natural conditions soils are commonly subject to a succession of tree species, while indeed in boreal regions like much of the Scottish highlands, conifers and broadleaved species tended to alternate, should we be considering rotations of species in these plantations? Or has their need been obviated by the ubiquitous use of ploughing and the increasing use of fertilizers? The answers are as yet unknown.

3. The role of roots in soil change

Because of the technical difficulties involved, many important questions about the influence of roots on soil processes remain unanswered, eg:

3.1 What is the relative importance for different tree species of different parts of the profile, including the litter layers, as zones of nutrient uptake?

3.2 How do roots and mycorrhizas affect the weathering of mineral particles and the availability of particular nutrients?

3.3 To what extent do roots, mycorrhizas and rhizosphere microbes influence nitrogen availability by inhibiting nitrification (Moore & Waid, 1971; Rice & Pancholy, 1972, 1973), stimulating nitrogen fixation (Richards, 1964, 1973; Richards & Voigt, 1964), and utilizing organic, and possibly also organically bound, forms of nitrogen (Fisher & Stone, 1969; Lundeberg, 1970; Stribley & Read, 1974)?

3.4 To what extent do mycorrhizas stimulate (Bjorkman, 1970) or inhibit (Gadgil & Gadgil, 1971) organic matter decomposition?

3.5 To what extent do roots alter the balance of soil resources and transfer materials over distances by contributing exudates and moribund tissues, whether whole roots or plates of cells, by causing mechanical disturbance, and through the influence of root grafts? What are the effects of these processes on nutrient cycling and availability?

4. Effects of management practices on nutrient availability

Of these, ploughing and harvesting are of outstanding importance. In nature, soils are 'ploughed' through the effects of growing root systems and of soil-living animals, and as a result of disturbances when trees are uprooted by wind. These processes cause *inter alia* the downward movement and fragmentation of surface accumulations of organic matter, and the upward movement of deeper lying, relatively unweathered, nutrient rich mineral particles. However, these are rarely the reasons for ploughing as a preparative site treatment. Nonetheless its effects on nutrient cycling should be known and related to those of natural soil mixing. The latter is a gradual process, with the associated mobilization of nutrients probably being more or less balanced by their uptake by plants. In contrast, ploughing as a management technique is abrupt and grossly disruptive. It is likely to cause a surge in nutrient mobilization, with the products being in excess of the requirements and absorbtive capacity of the surviving vegetation, resulting in possibly substantial losses of essential nutrients from the system. On infertile soils these losses may have long lasting effects on tree growth (Van Goor, 1954).

Removal of trees has 2 contrasting effects. On the one hand it accelerates the decomposition of soil organic matter and the mineralization of nutrients (Wright, 1957; Wells & Jorgensen, 1975), and this may be reflected in increased tree growth (Haberland & Wilde, 1961). On the other hand, loss of trees deprives the system of a considerable accumulation of nutrients. Rennie (1955) thought that their repeated loss from nutrient poor soils would eventually reduce tree growth, but he overlooked the accession of nutrients to the system from the atmosphere and from mineral weathering, and his fears were ignored at a time when the addition of fertilizers to make good soil nutrient deficiencies was becoming more general. However, nutrient losses may assume greater importance if whole tree harvesting, with the removal of branches and major roots, were to become accepted practice (Malkonen, 1974; Nilsson & Wernius, 1976), and even more so if needles and leaves were also used (Alestalo, 1974; levins *et al.,* 1974). There could be serious repercussions on the cycling of nutrients, also queries about the wisdom of spending larger sums on the replacement of nutrients whose manufacture is energy-demanding. The subject warrants re-examination. How much tree growth can be sustained on particular site types with natural or achievable rates of nutrient cycling, nitrogen fixation and mineral weathering, with the additional help of beneficial mycorrhizas?

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