Podzols and Associated Soils in Semi-Natural Oak Woodlands A Preliminary Report

D. J. Little[1], E. P. Farrell[1], J. F. Collins[2], K. Kreutzer[3] and R. Schierl[3]

[1]Department of Environmental Resource Management, University College Dublin.
[2]Department of Crop Science, Horticulture and Forestry, University College Dublin.
[3]Lehrstuhl für Bodenkunde, University of Munich, Germany.

Summary

In a survey of semi-natural Irish oak woodlands on podzolised soils fourteen sites were chosen for intensive site investigation, morphological observation and analytical assessment. Historical data yield two important facts relevant to soil formation processes. Firstly, all sites have been disturbed to a greater or lesser degree and secondly, most sites appear to have supported *Pinus sylvestris* before it became extinct. Both these factors would almost certainly have led to the export of bases, curtailed recycling and alteration of the chemical content of the woodland floor. When these factors are considered along with climate, parent material etc. it is difficult to determine if podzolisation was initiated under a dominant oak stand.

These woodlands are located on siliceous parent materials and annual precipitation values exceed 1000 mm. Soil analyses confirm that the soils are highly acidic, very infertile and are very low in clay content. They tend to be free draining coarse sandy or fine silty soils with low cation exchange capacity values.

Introduction

In 1989 a joint study involving University College Dublin and the University of Munich was initiated to determine the occurrence of podzol soils under semi-natural oak woodland sites in Ireland. The objects of the study were to obtain a better understanding of podzolisation in these ecosystems and to ascertain whether podzol forming processes are ongoing, or if the soils are merely relict podzols formed under a different vegetation phase hundreds, or even some thousands of years ago. Studies on the first two of these objectives are described below while work is continuing in an attempt to realize the third.

Podzols under oak woodland are uncommon in Europe as a whole. Their occurrence in Irish oakwoods is therefore of interest, although it has to be said that their apparent prevalence here is partly as a result of the virtual extinction of the better quality stands on more fertile soils. What we see today are remnants, surviving on the poorest and often least accessible sites (McCracken, 1971). In Ireland, podzols are a common occurrence in upland regions on siliceous parent materials, where precipitation is relatively high (Gardiner & Radford, 1980). Morphologically they are characterized by a peaty surface layer (O horizon) which tends to become darker towards its base due to increased humification. Beneath it is a leached, ash-grey mineral layer (E horizon), which in turn is underlain by B horizons which are yellowish-red in colour. The C horizon is usually extremely stony, originating as till or weathered bedrock.

Conventionally, podzolisation is the formation of an eluvial/illuvial horizon sequence due to the translocation of iron and aluminium with or without humus. A prerequisite seems to be the presence of base-poor parent materials or the acidification of base-rich materials including carbonate removal, if present. Podzolised soils have been associated traditionally with an acid-generating flora such as pine or heather. Their association with oak-dominated deciduous woods in Ireland has therefore focussed attention on the nature of their pedogenic history on these sites. Current interest in accelerated soil acidification as a consequence of atmospheric pollution has made the understanding of natural podzol forming processes more relevant.

Vegetation/soil dynamics

In a review of published data dealing with vegetation/soil dynamics, Stone (1975) has commented that site history, especially in relation to past exploitation, has often gone unrecognized or ignored when foresters and ecologists have sought to explain local differences in vegetation or productivity. Modification of the forests by human influence over the last four thousand years approximately has altered these ecosystems so much that there are probably no pristine native broadleaved woodlands remaining in Ireland. At best the few remaining patches can be described as semi-natural. In Ireland today there are 84,000 ha of semi-natural broadleaved woodland (Cross, 1987).

Numerous accounts outlining the role of vegetation on soil forming processes have been published including those of Dimbleby & Gill (1962) Wilde (1964) Page (1968) and Miles (1985). Overall, it appears that broadleaved species, with the exception of beech, tend to maintain a high base status and to retard podzolisation compared with most conifer species (Miles, 1985). However a number of authors, especially in England, have indicated that podzolisation may occur under oak stands as in the New Forest, Hampshire (Dimbleby & Gill, 1955) and in Sutton Park in the west Midlands (Mackney, 1961). Kubiena (1953) states that iron podzols develop under acid-tolerant oakwood in northern Europe. While deciduous forest, excepting beech (Dimbleby & Gill, 1955), is not generally associated with podzolisation, oak is found, in the poorest edaphic environments, in association with mor/moder humus forms and podzols. It is difficult, however, to establish conclusively that oak is directly responsible for the initiation of this process as the effects of oak are usually confounded by other factors such as climate, parent material, other tree species, ground vegetation, soil fauna and previous land-use history.

Materials and Methods

General woodland survey

In a reconnaissance survey of soils which support semi-natural woodland, thirty-five sites on a wide range of parent materials were visited. They were all extensively augered to ascertain the dominant soil type. Where podzols predominated, a detailed site investigation was carried out. In all, fourteen sites were selected for further investigation (Fig. 1). At each, a plot 20 x 20 m was demarcated and all trees were measured for diameter at breast height, top height and timber height. Site characteristics such as slope, aspect, altitude, drainage and topography were also recorded. The main ground vegetation species were noted as was any evidence of disturbance.

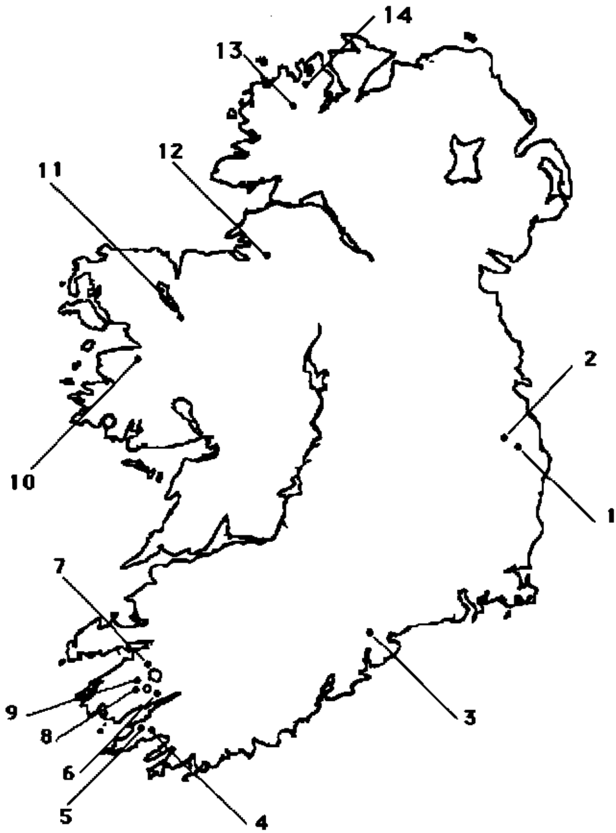
Soil analysis

A pit was dug to expose a soil profile and a soil description made at each site. Soil samples were collected for laboratory analysis which included pH (in H_2O), particle size analysis, organic matter content (loss on ignition), and cation exchange capacity (CEC) using an unbuffered NH_4Cl solution.

Iron oxides were extracted in all horizons from three sites (Clara Vale, Uragh and Brackloon) using sodium tetraborate (Bruckert & Souchier, 1975), ammonium oxalte (McKeague & Day, 1966) and sodium dithionite-citrate-bicarbonate (Mehra & Jackson, 1960). Sodium tetraborate extracts humic iron complexes i.e. organically bound iron (Fe_b), while ammonium oxalate does likewise but also partially extracts poorly crystalline iron oxides belonging to the group of ferrihydrite minerals (Fe_o) (Schwertmann & Murad, 1990). All iron, bound in secondary oxides i.e. the total iron oxides present, is extracted by the dithionite procedure (Fe_d). Thus by using these methods one can differentiate between poorly crystalline organically bound iron, which appears to be most of the iron involved in podzolisation (Farmer et al, 1983), and the total iron oxide content.

Results

Nineteen of the thirty-five sites visited were found to have varying degrees of podzol development. As mentioned previously, fourteen were selected for detailed study. Twelve of these were classified as podzols *sensu*



Site no.	Site Name	Grid Ref.	Parent Material	Dominant soil type
1	Clara Vale	T1892	Shale	Brown podzolic
2	Glendalough	T1196	Schist	Podzol/brown podzolic
3	Lismore	S0502	Devonian sandstone	Podzol
4	Glengarriff	V9256	Devonian sandstone	Podzol
5	Uragh	V8362	Devonian sandstone	Podzol
6	Derrycunihy	V9081	Devonian sandstone	Podzol
7	Tomies	V9188	Devonian sandstone	Podzol (iron-pan)
8	Eamons	V9284	Devonian sandstone	Unclassified
9	Glaisin	V9284	Devonian sandstone	Podzol
10	Brackloon	A9879	Schist/Gneiss	Podzol
11	Laughil	G2005	Granite	Podzol
12	Cullentra	B3478	Gneiss/Quartzite	Podzol
13	Glenveagh	C0220	Granite	Podzol
14	Glen Valley	C0928	Granite	Podzol/brown podzolic

Figure 1: Study sites carrying semi-natural oakwood on podzolised soils.

stricto. Of the other two, one was a brown podzolic and the other was not classified. The latter possessed a leached ash-grey horizon but lacked a B horizon and hence, does not fit neatly into any great soil grouping such as podzols or lithosols. Five sites with soils showing podzolisation were omitted from the detailed study. All occurred in Wicklow, from which two sites were selected. As brown podzolics are the most frequently occurring soils in the Wicklow oakwoods, one site, Clara Vale, was chosen to represent this soil type. Glendalough represents the more podzolised associated soil type. All fourteen soils are derived from siliceous parent materials of either granite, sandstone, gneiss, schist or shale origin.

The geographical spread of the locations of the study sites is shown on the accompanying map (Fig. 1). The principal tree species on these sites are *Quercus petraea, Betula pubescens, Ilex aquifolium* and *Sorbus aucuparia* while the ground vegetation consists mainly of *Vaccinium myrtillus, Luzula sylvatica* and *Calluna vulgaris*.

At sixteen of the original oak-dominated sites, the soils did not show evidence of podzolisation either because of wetness (low humic gleys and peaty gleys), high clay (grey brown podzolics) or unusual biology. At many of these sites the following species were found in addition to oak: *Fraxinus excelsior, Corylus avellana* and, to a lesser extent, *Ulmus glabra* as well as a diverse ground vegetation.

As site history is important in elucidating soil forming processes, information on land use history for each site was researched using a combination of documented accounts, old maps and pollen diagrams. Although it was not possible to obtain a complete historical record for each site – maps are often inaccurate, records invariably incomplete and pollen diagrams more often than not, reflect the vegetation history over large areas – the ornamentation on the maps of the first Ordnance Survey suggests that all sites carried deciduous woodland in or about 1840.

Two important facts relevant to soil formation processes were established. Firstly, all sites have been disturbed to a greater or lesser degree through felling, grazing, burning, the planting of exotics and woodland management. Secondly, all sites (with the possible exception of Lismore) appear to have supported *Pinus sylvestris,* before it became extinct about 2,000 years ago. It is most probable that both these factors would have led to the export of bases, curtailed recycling and alteration of the chemical content of the woodland floor.

Soil analysis confirms that the soils from all fourteen sites are acid, low in bases and generally coarse textured. Typically, pH ranges between 3.5 and 4.5 in the O horizons while values for the deepest mineral horizons never exceed 5.5. Organic matter by loss on ignition varies between 27 and 95% in the O horizons, with most values between 50 and 80%. Values between 0.5 and 16% were recorded in the underlying mineral layers, the lowest values occurring in E horizons. Base saturation values range from circa 50 to 90% in the O horizons and from 10 to 30% in the mineral horizons. Most of the soils are classified texturally as fine to coarse sandy loams or sandy silt loams with low clay content, the latter never exceeding 25% of the fine earth fraction. A typical example is Brackloon near Westport, County Mayo (Tables 1, 2 & 3). The surface organic layer is very acid with a progressive increase in pH with soil depth (Table 2). Organic matter content is highest in the surface layer, decreasing with depth, with a second peak in the Bh horizon.

At Brackloon there is much schist in the parent material, which weathers to a fine sandy silt loam; the proportion of silt throughout the profile

Table 1: Profile description of a podzol at Brackloon, Westport, Co. Mayo.

Horizon	Depth	Profile description
Of	7-0cm	Dark brown (10YR 3/3-2/2); very fibrous, undecomposed and layered; variable depth containing many fine roots; clear wavy boundary to;
Ah	0-6cm	Very dark brown (10YR 2/2-3/2); greasy/plastic texture; very weak fine crumb structure, some mineral material inter-mixed; abundant fine roots; clear wavy boundary to;
Ea	6-12/32cm	Light grey (10YR 7/2); very fine sandy silt loam; apedal massive structure; stony, mostly platy; fine vertical and horizontal roots; clear wavy boundary to;
Bh	12-15cm	Very dark brown to black (10YR 2/1-2/2); (discontinuous horizon); very fine silty clay; apedal massive structure; stony; fine vertical and horizontal roots; abrupt boundary to;
Bs	15/32-54cm	Reddish yellow (matrix) to strong brown (streaks) (7.5YR 5/8-6/8); fine sandy silt loam; apedal massive structure; stony/bouldery; many fine and coarse multi-directional roots; clear wavy boundary to;
C1	54-64/78cm	Dark greyish brown (10YR 4/2); fine sandy silt loam; apedal massive structure; moderately stony; few fine roots; diffuse wavy boundary to;
C2	78-81cm	Pale brown to light yellowish brown (10YR 6/3-6/4); coarse sandy silt loam; apedal single grain structure; no roots; abrupt boundary to bedrock.

amounts to circa 50% of the total fine earth (Table 2). Where the parent material is derived from schist and/or sandstone the silt content tends to be highest e.g Uragh and Derrycunihy in County Kerry and Lismore in County Waterford. Where granites and shales dominate the parent material, the textures are decidedly sandy. At most sites, the maximum clay content within the soil profile occurs in the B1 horizon and is usually less than 12% of the total fine earth fraction. A typical example is Tomies, County Kerry, where clay content in the Bh is circa 10%.

Table 2: Soil data inclusive of pH, and percentage organic matter (OM), stones, sand, silt and clay for Brackloon podzol.

Horizon	pH	OM %	Stones %	Sand %	Silt %	Clay %
Of	4.1	83.8	–	–	–	–
Ea	4.4	1.1	28.7	33.3	59.6	7.1
Bh	4.4	16.3	12.5	26	48.9	25.1
Bs	4.7	9.9	25.1	39.6	51.5	9
C	5.1	3.6	25.9	40.5	50.7	8.8

Cation exchange capacity (CEC) is closely correlated with organic matter content and a strong relationship also exists between exchangeable bases and both of these parameters (Table 3). The CEC values for Brackloon are quite typical for sites located in western seaboard counties (Gardiner & Radford, 1980). It is apparent from the base saturation data that the O horizon is an especially important source of nutrients leading to an abundance of fine roots in this zone. It is also notable that exchangeable sodium and magnesium values are higher in sites situated on the western seaboard, where the input of these elements in precipitation is high, compared with midland and eastern sites. Magnesium values in the O horizon at western sites range from 4.5 to 11.2 $cmol_c. kg^{-1}$ whereas the corresponding value at Derryad, near Tullamore, County Offaly – which is a midland oakwood site with characteristic podzol morphology – was 3.5 $cmol_c. kg^{-1}$. The corresponding values at the two eastern sites (Glendalough and Clara Vale) were 0.8 and 1.5 $cmol_c. kg^{-1}$. A similar trend for sodium is evident: at western sites exchangeable sodium values in the O horizon range from 1.3 to 3.1 $cmol_c. kg^{-1}$, whereas at Derryad, exchangeable sodium was 1.0 $cmol_c. kg^{-1}$ in the O horizon. The corresponding figures for the eastern sites (Glendalough and Clara Vale) were both 0.5 $cmol_c. kg^{-1}$. The highest values of exchangeable magnesium and exchageable sodium were recorded at sites closest to north-west, west and south-west coasts, especially at high elevation where precipitation is greatest.

Table 3: Exchangeable cations, cation exchange capacity (CEC) and percentage base saturation (BS) data for Brackloon podzol.

Horizon	Ca	Mg	K	Na	H+Al	CEC	BS
			$cmol_c.kg^{-1}$				[%]
Of	11.9	8	3	2.6	1.8	28	92
Ea	0.2	0.2	0.1	0.1	1.6	2.2	24
Bh	0.6	0.8	0.2	0.4	8.2	11	18
Bs	0.1	0.3	0.1	0.4	5	6.2	14
C	0.1	0.2	0.1	0.2	2.4	3	18

Data for extractable iron using the three methods outlined previously are given in Table 4 for Brackloon. The highest values of iron recovered for any of the methods used occur in the B horizons. As humic iron complexes are extracted by both the sodium tetraborate (Fe_b) and ammonium oxalate (Fe_o) extractants, high values for these extracts in the B horizon indicates that there is downward translocation of humic iron complexes. When all the iron values in the B horizons of the three sites chosen for iron analysis (Clara Vale, Uragh and Brackloon) are compared (Table 5), it is interesting to note that even though the value of total iron oxides (Fe_d) is relatively high at Clara Vale (especially in the Bs), the relatively low values of Fe_o and Fe_b indicate that currently there is poor translocation of humic iron complexes. This suggests that podzolisation is at present not as dominant a process at Clara Vale compared to the other two sites i.e. Uragh and Brackloon.

Table 4: Extractable iron data (mg/g) for Brackloon podzol.

Horizon	Fe_d	Fe_b	Fe_o
Of	0.6	0	0.5
Ea	0.4	0	0.2
Bh	48.9	–	32.9
Bs	37.3	0.8	24
C	3.3	0.2	1.6

The ratio of oxalate extractable iron to the total free iron oxide content, which may vary between near zero and 1.0 has proven useful in connection with pedogenetic studies, particularly in humid temperate soils (Schwertmann & Murad, 1990). The closer the ratio is to 1.0, the greater the contribution of iron involved in podzolisaion is to the total iron oxide content present. Calculated ratios for the three soils, Clara Vale, Uragh and Brackloon, were analysed and the ratios calculated accorded well with their observed morphology in the field (Table 4). Clara Vale has a ratio of Fe_o

to Fe_d of 0.2 in the Bs horizon which suggests that translocation of humic iron complexes is not occurring to any great extent here. In contrast, Uragh and Brackloon have ratios of Fe_o to Fe_d of 0.7 in the Bir and Bh horizons, indicating the presence of much larger quantities of the iron forms involved in podzolisation.

The ratio of Fe_d to organic carbon (OC) is calculated for the B horizons (Table 4) in order to classify soils into their sub-groups using the U.S.D.A. classification system (Wiechmann, 1981). The ratios derived indicate that Clara Vale is a ferric podzol while Uragh and Brackloon are orthic podzols.

Table 5: Extractable iron data (mg/g) with Feo:Fed and Fed:OC ratios for three oak woodland podzols.

	Clara Vale		Uragh		Brackloon	
Horizon	**Bs**	**Bw**	**Bir**	**Bhs**	**Bh**	**Bs**
Fe_d	43.2	13.1	30.9	19.0	48.9	37.3
Fe_o	9.5	4.0	21.4	12.8	32.9	24.0
Fe_b	0	0.1	0.7	0.7	–	0.8
Fe_o:Fe_d	0.2	0.3	0.7	0.7	0.7	0.6
Fe_d:OC	10.0	5.6	5.7	4.9	5.3	5.6

Discussion and Conclusion

Regional pollen diagrams suggest that most of the country has supported woodland of some description for a considerable portion of the post-glacial and that *Pinus sylvestris* has been an important component of much of the woodland, including the oakwoods, along the western seaboard (Jessen, 1949). It is concievable then that pine has had a major influence in the formation of many of these podzols.

From about the twelfth century onward, clearance for agriculture and for the utilization of timber resulted in there being only one-eighth of the country wooded by 1600 (McCracken, 1971). As historical records generally date from about 1500 for most of the sites investigated and regional pollen diagrams are not site specific, it is not possible to say with any degree of certainty that all these sites had continuous forest cover. Also, clearance and/or the formation of heath followed by re-invasion of secondary woodland cannot be ruled out at many of these sites. However, the use of local and extra-local pollen diagrams, as in the Killarney woodlands (Mitchell, 1988), help to elucidate the vegetational history within existing woodlands. Thus further paleovegetational analysis could probably be used to determine the vegetational history of many of the sites in this study as they all have mor-moder humus types. This would shed light on whether podzolisation was initiated under woodland or under heath.

After 1500, there is enough evidence to conclude that all these woods have been disturbed mainly through grazing and felling. It is impossible to quantify the influence of historical factors involved in the soil forming process, such as the presence of pine or various forms of disturbance. However, they must be included in any discussion on the formation of these soils as their influence may well outweigh factors which are currently more obvious, such as parent material or present vegetative cover. In addition, the main climatically driven trend of soil development in freely drained soils in north-west Europe is for progressive leaching, with consequent acidification and, in susceptible soils, (e.g. coarse textured soils on acid parent materials), eventual podzolisation (Ball, 1975).

The sites investigated all have acidic parent materials and have annual precipitation values exceeding 1,000 mm. When species composition is compared with other soil types e.g. grey-brown podzolics, brown earths and low-humic gleys, it is found that the podzolised sites support a smaller number of species and a more acidophillous ground vegetation. Unlike the other soil types mentioned above, podzols do not appear to support *Fraxinus excelsior* or *Ulmus glabra* while *Corylus avellana* occurs less frequently.

Podzolisation may have been initiated independent of the presence of oak, around 4,500 years ago, when the climate became much cooler and wetter, with or without clearance due to human impact, encouraging the spread of heath, or even earlier during the pine maximum. The propensity of these siliceously derived soils to nutrient loss render them susceptible to podzolisation.

The iron extracts provide an improved understanding of the podzolisation process in these ecosystems. The data suggest, for two of the three sites analysed (Uragh and Brackloon), that there are, in the B horizons, relatively large quantities of the iron fractions involved in the podzolisation process (Farmer et al, 1983). Data for the third site (Clara Vale), by contrast, suggest that podzolisation is not the dominant process at this site. Further investigations will be carried out to determine if podzolisation is ongoing in these soils.

ACKNOWLEDGEMENTS

Thanks are due to the Office of Public Works and Coillte Teo. for access to forests and help given. Funding for the project is provided by Science and Technology Germany – Ireland.

REFERENCES

BALL, D. F. 1975. Processes of soil degradation: a pedological point of view. In: The Effect of Man on the Landscape: the Highland Zone (eds J. G. Evans, S. Limbrey and H. Cleere), pp. 20-27. Council for British Archaeology Research Report No. 11.

BRUCKERT, S. and SOUCHIER, B. 1975. Pedologie. C.R. Acad. Sci. Paris 280D:1361-1364.

CROSS, J. 1987. Status and value of native broadleaved woodland. Irish For. 44: 81-88.

DIMBLEBY, G. W. and Gill, J. M. 1955. The occurrence of podzols under deciduous woodland in the New Forest. For. 28: 95-106.

DIMBLEBY, G. W. 1962. The development of British heathlands and their soils. Oxford Forestry Memoirs No.23.

FARMER, V. C., RUSSELL, J. D. and SMITH, B. F. L. 1983. Extraction of inorganic forms of translocated Al, Fe and Si from a podzol Bs horizon. J. Soil Sci. 34: 571-576.

GARDINER, M. J. and RADFORD, T. 1980. Soil associations of Ireland and their land use potential. A.F.T. Soil Survey Bull. No. 36.

JESSEN, K. 1949. Studies in late Quaternary deposits and flora-history of Ireland. Proc. R. Ir. Acad. 52B: 85-290.

KUBIENA, W. 1953. The Soils of Europe. Thomas Murby, London.

MACKNEY, D. 1961. A podzol development sequence in oakwoods and heath in central England. J. *Soil Sci.* 12: 23-40.

McCRACKEN, I. 1971. The Irish woods since Tudor times. David and Charles, Newton Abbot.

McKEAGUE, J. A. and DAY, J. H. 1966. Dithionite-and oxalate- extractable Fe and Al as aids in differentiating various classes of soils. Can. J. *Soil Sci.* 46: 13-22.

MEHRA, O. P. and JACKSON, M. L. 1960. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. Clays Clay Miner. 7: 317-342.

MILES, J. 1985. The pedogenic effects of different species and vegetation types and the implications of succession. J. Soil Sci. 36: 571-584.

MITCHELL, F. J. G. 1988. The vegetational history of the Killarney oakwoods, SW Ireland: evidence from fine spatial pollen analysis. J. Ecol. 76: 415-436.

PAGE, G. 1968. Some effects of conifer crops on soil properties. Commonwealth Forestry Review 47: 52-62.

SCHWERTMANN, U. and MURAD, E. 1990. Forms and translocation of iron in podzolised soils. Proc.5th. International Soil Correlation Meeting. 319-342.

STONE, E. L. 1975. Effects of species on nutrient cycles and soil change. Proc. R. Soc. Lond. B. 271: 149-162.

WIECHMANN, H. 1981. Unterscheidung der Subtypen Humus-, Eisenhumus- und Eisenpodsol. Z. Pflanzenernaehr. Bodenkd. 144: 174-180.

WILDE, S. A. 1964. Changes in soil productivity induced by pine plantations. Soil Sc. 97:276-278.