Some properties of soils on sandstone, granite and dolerite in relation to dry and wet eucalypt forest types in northern Tasmania

M.D. Laffan[1,3]*, J.C. Grant[2,4] and R.B. Hill[2,5]
[1] Forest Practices Unit,
30 Patrick Street, Hobart 7001
[2] Forestry Tasmania
Present addresses: [3] Forestry Tasmania
[4] 17 River Street, Ulmarra NSW 2462
[5] Soil, Plant and Ecological Sciences Division,
Lincoln University, PO Box 84,
Canterbury, New Zealand

Abstract

Eleven soils in northern Tasmania formed on sandstone, granite and dolerite under dry and wet eucalypt forests are described. Soils formed on similar substrates but under differing forest types show significant differences in profile morphology and chemical properties, and this has important implications for forest management. Soils under wet forest generally occur at higher elevations with higher mean annual rainfall (> 1000 mm) than corresponding soils under dry forest. They are mainly characterised by gradational texture profiles, moderate or high levels of organic matter and nutrients, low or moderate susceptibility to soil degradation and high site productivity. In contrast, soils under dry forest typically have texture-contrast profiles, low levels of organic matter and nutrients, low site productivity and are susceptible to various forms of soil degradation.

Introduction

Recent studies in Tasmanian native forests have shown that soils formed on the same rock substrate but under different native forest communities often have contrasting profile morphology and chemical properties. Differences in soil properties are generally most pronounced in soils formed under dry or wet eucalypt forests.

The term 'dry eucalypt forest' has been used to include open woodland as well as forest, and 'wet eucalypt forest' to refer to forest dominated by a eucalypt overstorey with an understorey of mainly broadleaved shrubs. Soils under mixed forest (Gilbert 1959), where scattered eucalypts occur over a rainforest understorey, are not considered here. Summary descriptions of the general floristics and structure of these forest types can be found in Forestry Commission (1994) and Forestry Tasmania (1998).

This paper outlines the relevant properties of 11 soils formed on sandstone, granite and dolerite occurring under both dry and wet eucalypt forests in northern Tasmania. The soils are described and discussed in terms of environmental features, profile morphology and some chemical and physical features. They are classified according to Stace *et al.* (1968) and Isbell (1996), and the implications for forest management are discussed.

* Corresponding author:
e-mail: michael.laffan@forestry.tas.gov.au

Table 1. Soil sample sites in relation to parent material, topography, mean annual rainfall, broad native forest type and drainage class.

Soil name	Parent material	Slope (%)	Altitude (m)	MAR[1] (mm)	Forest type[2]	Drainage class	Grid reference[3]
Dulverton	Ordovician sandstone	8	145	1000	Dry	Moderately well drained	Sheet 8115 514253
Sheffield		17	170	1100	Wet	Well drained	Sheet 8115 463191
Retreat	Silurian–Devonian sandstone and siltstone	15	135	900	Dry	Moderately well drained	Sheet 8315 144481
Piper		11	125	900	Dry	Imperfectly drained	Sheet 8315 152476
Maweena		16	290	1000	Wet	Moderately well drained	Sheet 8315 130465
Jensen	Devonian granite	14	170	800	Dry	Moderately well drained	Sheet 8415 596579
Stronach		28	290	1200	Wet	Well drained	Sheet 8415 504383
Paris		14	360	1200	Wet	Moderately well drained to well drained	Sheet 8415 672423
Eastfield	Jurassic dolerite	13	320	950	Dry	Imperfectly drained	Sheet 8315 165209
Holloway		21	440	1000	Dry	Moderately well drained	Sheet 8315 183214
Excalibur		40	500	1200	Wet	Well drained	Sheet 8315 204271

[1] Mean annual rainfall. [2] Dry = dry eucalypt woodland and forest, Wet = wet eucalypt forest.
[3] For 1:100 000 topographic map sheets published by the Department of Environment and Land Planning.

Methods

The 11 soils were characterised, sampled and mapped during regional forest soil surveys in the area covered by the *Pipers*, *Forester* and *Forth* 1:100 000 topographic map sheets (Laffan *et al.* 1995; Grant *et al.* 1995a; Hill *et al.* 1995). They generally have wide areal distribution and cover a range of climate and topography. On undulating (0–10%) and rolling (10–30%) slopes, they are mapped as soil associations, complexes or undifferentiated groups. On steep (> 30%) slopes, related soils are mapped as miscellaneous soils. Apart from one site which occurs on steep dolerite slopes, all soil sample sites are on undulating or rolling slopes.

Site features and soil-profile morphology were described according to McDonald *et al.* (1990). Chemical analyses include pH and levels of organic carbon (C), total phosphorus (P) and total nitrogen (N). The only physical property included for all soils is the proportion of water-stable soil aggregates assessed using a wet-sieving procedure. Laboratory analytical methods are given in Herbert *et al.* (1995).

Location, parent materials and topography

The soils studied occur at widely scattered localities in northern and north-eastern Tasmania between Sheffield in the west and Weldborough in the east. Grid references at a

1:100 000 scale for the sample sites are given in Table 1.

The soil parent materials are derived from four different substrates: Ordovician sandstone, Silurian–Devonian sandstone and siltstone (Mathinna beds), Devonian granite and Jurassic dolerite (Table 1). The degree of weathering of substrates varies from weak or moderate for soils formed on dolerite to mainly strongly weathered for substrates on granite and sedimentary rocks.

Soils sampled under wet forest all occur at higher altitudes than their counterparts under dry forest. Soil drainage class varies from imperfectly drained to well drained. Soils under dry forest are either moderately well or imperfectly drained whereas under wet forest nearly all the soils are well drained (Table 1).

Climate and vegetation

The rainfall values in Table 1 apply to sample sites only. All soils cover a range of mean annual rainfall (MAR). For dry forest, the MAR range is generally between 800 mm and 1000 mm, although Eastfield soils in the Midlands and on the east coast occur under a MAR of between 600 mm and 800 mm and, in north-western Tasmania, Jensen soils (see Table 1) occur with a MAR up to 1400 mm. For wet eucalypt forest, the MAR range is typically 1000–1400 mm. Above these rainfall limits, mixed forest or rainforest often predominate.

The MAR figures (Table 1) were estimated from Meteorological Service isohyet maps and hence are approximate only. They cover a limited range from 800 mm to 1200 mm, with most sites having a MAR between 900 mm and 1100 mm. In the areas studied, the boundary between dry and wet eucalypt forest appears to occur where the MAR is approximately 1000 mm.

The dry eucalypt forests at the study sites are dominated by *Eucalyptus obliqua* and *E. amygdalina,* with *E. viminalis* often locally dominant. Understoreys are characterised by a wide variety of species, often including *Banksia marginata, Leptospermum scoparium, Acacia terminalis*, *Leucopogon australis*, *Epacris impressa*, *Exocarpos cupressiformis, Lomandra longifolia*, *Lepidosperma* spp. and *Pteridium esculentum*. Eastfield soils (Table 1) typically occur under an open forest or woodland, usually with a grassy ground cover.

The wet eucalypt forests at the study sites are characterised by *Eucalyptus obliqua* and / or *E. regnans,* with *E. delegatensis* often dominant at elevations above about 400 m. Understoreys are usually dominated by broadleaved shrubs which typically include *Pomaderris apetala, Zieria arborescens, Olearia lirata, O. argophylla, Coprosma quadrifida, Acacia dealbata, Polystichum proliferum, Monotoca glauca* and *Goodenia ovata.* More specific information on canopy and understorey species is given for each soil in Laffan *et al.* (1995), Grant *et al.* (1995a, b) and Hill *et al.* (1995).

Results and discussion

Profile morphology

Some clear trends in profile morphology between soils formed under dry and wet eucalypt forests are shown in Table 2. Soils formed under dry forest generally have A2- and / or A2e-horizons, texture-contrast profiles, very firm or strong subsoil strength and slow permeability. Textures are dominated by sandy loams and loamy sands in upper layers, overlying light medium clays in subsoils (Photo 1). Exceptions are the Piper soil which has a gradational texture profile without A2-horizons, and the Holloway soil which is gradational, with weak to firm subsoil strength and moderate permeability. In contrast, most soils under wet forest have gradational profiles, with A1-, AB- or B1-, and B2t-horizon sequences, firm or weak subsoil strength and moderate permeability. Textures are typically sandy clay loams in upper horizons and sandy light clays in subsoils (Photo 2). The exception is the Paris soil, with a bleached A2-horizon and texture-contrast profile.

Table 2. Soils in relation to horizon sequence, texture profile, subsoil strength and permeability class.

Soil	Horizon sequence	Texture profile	Subsoil strength[1]	Permeability class
Soils under dry forest				
Dulverton	A1, A2e, B2t	Texture-contrast; sandy loams and sands over clays	Firm	Slow
Retreat	A1, A21, A22e, B2t	Texture-contrast; sandy loams and loamy sands over clays	Strong	Slow
Piper	A1, B1t, B2t, Bgt	Gradational; fine sandy loams over sandy clay loams over clay	Very firm	Slow
Jensen	A1, A21, A22e, B2t	Texture-contrast; coarse sandy loams and loamy coarse sands over medium clays	Strong	Slow
Eastfield	A1, A2, B2t	Texture-contrast; clay loams over medium heavy clays	Firm	Slow
Holloway	A1, A2, B2t	Gradational; clay loams over light and medium clays	Weak / firm	Moderate
Soils under wet forest				
Sheffield	A1, B1, B2t	Gradational; sandy clay loams over light clays	Weak	Moderate
Maweena	A1, AB, B2t	Gradational; sandy loams over sandy clay loams and clays	Firm	Moderate
Stronach	A11, A12, B1t, B2t	Gradational; coarse sandy clay loams over light to medium clays	Firm	Moderate
Paris	A1, A21, A22e, B1, B2t	Texture-contrast; coarse sandy loams and loamy coarse sands over sandy light clays	Firm	Moderate
Excalibur	A1, B1, B2t	Gradational; clay loams over light medium clays	Firm	Moderate

[1] For moist samples.

Similar trends occur in size of subsoil structure and degree of faunal activity. Under dry forests, subsoils typically have coarse (50–100 mm or 20–50 mm) primary blocky or prismatic breaking to 10–20 mm blocky structure. Conversely, under wet forests, subsoils are characterised by finer (10–20 mm or 20–50 mm) primary blocky breaking to 2–5 mm blocky or < 2 mm granular structure. Very low levels of earthworm activity are a distinctive feature of texture-contrast soils, particularly under dry forests, whereas relatively large populations of earthworms occur in gradational soils under wet forest and in the Piper soil with gradational texture profile under dry forest. A recent study including the Retreat, Piper and Maweena soils highlights the close association between texture profiles and earthworm numbers and biomasses (Laffan and Kingston 1997). Earthworms are responsible for significant bioturbation between topsoils and subsoils, and earthworm burrows undoubtedly have a beneficial effect on the porosity and permeability characteristics of these soils.

The predominance of texture-contrast soils under dry forests is probably related to several factors such as more intense and prolonged processes of clay translocation and lower levels of faunal mixing than in associated soils under wet forest. Evidence from Australia and overseas indicates that soils occurring in environments with alternating strong wet and dry seasons invariably show more advanced clay translocation than soils with weak dry

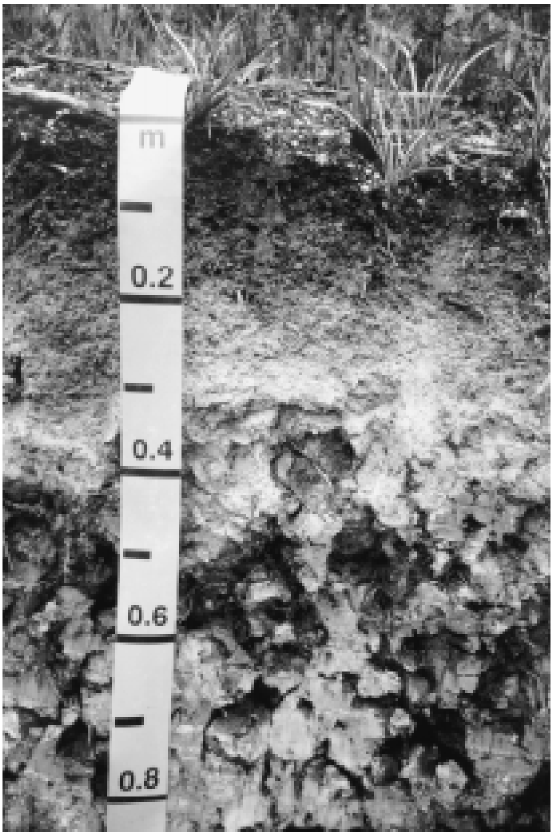

Photo 1. Jensen soil formed on granite under dry forest. It has a texture-contrast profile characterised by a dark-coloured A1-horizon overlying pale-coloured A2-horizons down to about 35 cm which, in turn, overlie yellowish brown, coarse-blocky structured B2t-horizons.

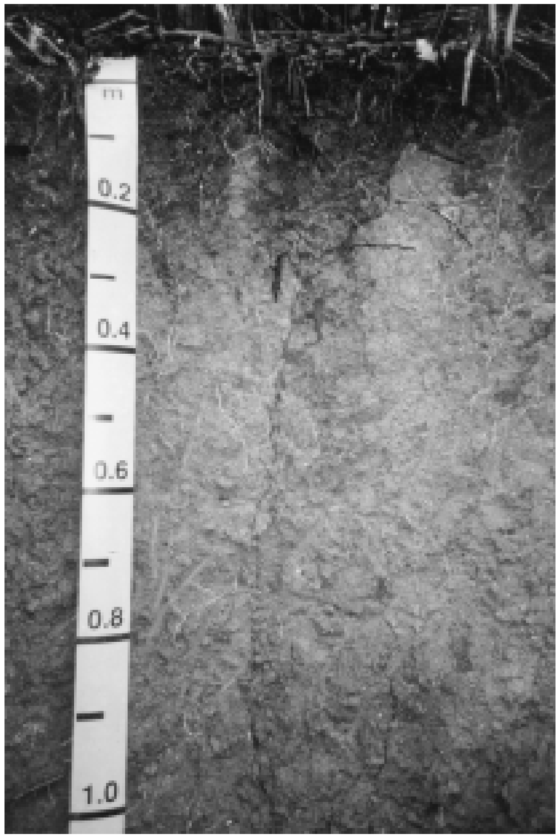

Photo 2. Stronach soil formed on granite under wet forest. It has a gradational texture profile characterised by a dark-coloured sandy clay loam A1-horizon overlying brown clayey B1t- and B2t-horizons.

seasons or that are continuously wet or dry (Isbell 1980). Texture-contrast profiles are more strongly developed in soils from siliceous parent materials (sandstone, siltstone, granite) than in soils from basic substrates (dolerite). This difference is attributed mainly to the much higher content of quartz in siliceous rocks and to restricted clay translocation in dolerite soils caused by relatively high levels of iron and aluminium oxides which promote flocculation of clay particles.

Chemical properties and water-stable aggregates

Results of selected chemical properties and proportion of water-stable aggregates are shown in Table 3. There are no consistent trends in pH between soils under dry and wet forests. However, there are marked differences between dry and wet forest soils in the concentrations of total P and, to a lesser extent, in total N and organic C.

Low levels of total P (< 100 ppm) occur in all surface soil horizons under dry forest except for the Eastfield soil with moderate levels (100–250 ppm). Conversely, under wet forests, all soils have surface layers with moderate or high (> 250 ppm) concentrations of total P except for the Paris soil with low levels. Similarly, levels of total N are low (< 0.1 %) or medium (0.1–0.2%) in surface layers under dry forest and medium or high (> 0.2%) under wet forest. Organic C levels in surface layers range

Table 3. Selected chemical properties and water-stable aggregates for surface and subsurface horizons.

Soil	Horizon	Depth (cm)	pH	Total P (ppm)	Total N (%)	Organic C (%)	Water-stable aggregates (% > 0.25 mm)
Soils under dry forest							
Dulverton	A1	0–8	5.8	42	0.10	1.1	25
	A2e	8–30	6.4	12	0.009	0.21	9
Retreat	A1	0–13	4.7	55	0.12	1.1	59
	A21	13–24	4.8	32	0.06	1.5	6
Piper	A1	0–13	4.7	52	0.08	1.2	90
	B1	13–29	4.9	47	0.03	0.4	35
Jensen	A1	0–9	4.9	43	0.08	2.9	36
	A21	9–20	4.8	28	0.04	1.0	31
Eastfield	A1	0–10	5.9	176	0.25	4.9	73
	A2	10–25	6.1	107	0.03	1.5	61
Holloway	A1	0–16	6.0	76	0.06	1.5	63
	A2	16–32	5.5	74	0.03	0.8	27
Soils under wet forest							
Sheffield	A1	0–8	4.2	308	0.50	8.4	34
	B1	8–19	5.1	137	0.16	3.0	76
Maweena	A1	0–14	5.2	179	0.19	2.4	67
	AB	14–26	4.9	104	0.06	0.9	30
Stronach	A11	0–12	5.9	348	0.31	5.3	84
	A12	13–39	5.6	246	0.21	3.0	87
Paris	A1	0–17	4.5	89	0.12	3.9	na
	A21	17–31	4.5	47	0.06	1.6	na
Excalibur	A1	0–15	5.9	195	0.21	4.1	90
	B1	15–47	5.9	145	0.07	1.1	90

from low (< 2%) to moderate (2–5%) under dry forest and from moderate to high (> 5%) under wet forest. Higher levels of total P, total N and organic C throughout the soil profiles under wet forest reflect greater accumulation of soil organic matter than under dry forests due to greater leaf litter accumulation from the predominantly broadleaved understorey, higher productivity and lower fire frequency. This higher input of organic matter is incorporated into the soil through the more active microbial decomposition and mixing by soil fauna under wet forest.

The proportion of water-stable aggregates is a measure of soil resistance to erosion by rainfall and runoff and reflects mainly the level of soil organic matter and clay. It can be used with other soil characteristics such as soil strength, stone content, permeability class and drainage class to derive an index of soil erodibility (Laffan *et al.* 1996). Table 3 shows that nearly all soils under dry forest have subsurface layers with low (< 30%) or moderate (30–70%) levels of water-stable aggregates, whereas soils under wet forest have moderate or high (> 70%) levels.

Table 4. Soil classification according to Great Soil Group (Stace et al. *1968) and the Australian Soil Classification (Isbell 1996).*

Soil	Soil classification	
	Great Soil Group	Australian
Soils under dry forest		
Dulverton	Yellow Podzolic	Bleached, Mesotrophic, Brown Kurosol
Retreat	Yellow Podzolic	Bleached, Dystrophic, Brown Kurosol
Piper	Yellow Podzolic	Acidic-Mottled, Dystrophic, Yellow Dermosol
Jensen	Yellow Podzolic	Bleached-Mottled, Dystrophic, Brown Kurosol
Eastfield	Grey-Brown Podzolic	Vertic-Eutrophic, Brown Chromosol
Holloway	Krasnozem	Haplic, Mesotrophic, Red Ferrosol
Soils under wet forest		
Sheffield	Brown Podzolic	Acidic, Dystrophic, Brown Dermosol
Maweena	Xanthozem	Acidic-Mottled, Mesotrophic, Brown Dermosol
Stronach	Yellow Earth / Podzolic	Melanic-Acidic, Dystrophic, Brown Dermosol
Paris	Yellow Podzolic	Bleached-Mottled, Brown Kurosol
Excalibur	Krasnozem	Haplic, Eutrophic, Red Ferrosol

Soil classification

The soils have been classified (Table 4) according to both Great Soil groups (Stace *et al.* 1968) and the Australian Soil Classification (Isbell 1996). The Australian Soil Classification is to subgroup level.

Soils under dry forest are predominantly Brown Kurosols (Isbell 1996) or yellow podzolic soils (Stace *et al.* 1968). Kurosols are defined as soils with strong texture contrast and strongly acid (pH < 5.5) B-horizons (Isbell 1996). Under wet forest, the soils are more diverse, particularly according to the classification by Stace *et al.* (1968). Using the Australian Classification, most soils are keyed out as Brown Dermosols. Dermosols are defined as soils with structured B-horizons and lacking strong texture-contrast between A- and B-horizons (Isbell 1996).

Implications for forest management

Soil degradation potential

The soils have been rated for degradation potential in Table 5. They are rated according to inherent erodibility and their susceptibility to compaction and puddling, mixing of A- and B-horizons, and nutrient depletion. These characteristics are described in Brown and Laffan (1993) and Grant *et al.* (1995b).

The soils show marked trends in soil degradation potential, particularly in relation to erodibility, compaction and puddling, and nutrient depletion. Under dry forest, soil erodibility is mostly in the range moderate to high, high or very high. These ratings reflect the high proportion of slowly permeable soils with sandy A2-horizons which have weak strength and low levels (< 30%) of water-stable aggregates. Conversely, under wet forest, soil erodibility is low or moderate, reflecting mainly moderate permeability and moderate or high proportions of water-stable aggregates.

Susceptibility to compaction, puddling and nutrient depletion is mainly high in soils under dry forests and moderate or low in soils under wet forests. These differences are related mainly to soil structural development and reserves of soil nutrients held in lower layers. Soils under dry forest generally have weak structural development in upper layers

Table 5. Ratings for soil degradation potential and site productivity.

	Soil degradation potential				Site productivity
	Erodibility	Compaction and puddling	Mixing	Nutrient depletion	
Soils under dry forest					
Dulverton	High	High	Low	High	Low
Retreat	High – moderate[1]	High	Low	High	Low
Piper	Moderate to high	High	Moderate	High	Low
Jensen	Moderate to high – very high[2]	High	Low	High	Low – very low
Eastfield	Moderate – moderate to high[3]	High	High	Moderate	Low – very low
Holloway	Moderate	Moderate	Moderate	High	Low
Soils under wet forest					
Sheffield	Low	Moderate	Low	Low	High
Maweena	Moderate	Moderate	Low	Moderate	High
Stronach	Low	Moderate	Moderate	Moderate	High
Paris	Moderate – moderate to high	Moderate	Moderate	Moderate	Low
Excalibur	Low	Low – moderate	Moderate	Low	Low – high[4]

[1] Depending on stone content. Rating is moderate for soils with many stones.

[2] Depending on strength and thickness of A2. Rating is very high where A1- and A2-horizons are thicker than 50 cm, have weak strength and < 30% water-stable aggregates.

[3] Depending on texture of A2 and stoniness. Rating is moderate to high where A2-horizons are sandy and have only few or common stones.

[4] Depending on stone content. Rating is high for soils with only few or common stones throughout the profile.

which makes them more susceptible to damage by machinery than soils under wet forest. Likewise, under dry forest, nutrient reserves are mainly low in both upper and lower layers, predisposing the soils to severe nutrient depletion by erosion or inappropriate use of machinery.

Site productivity

Site productivity is a measure of the relative productive capacity of a site for tree growth. It is applied broadly here to cover all commercial eucalypts in both native forests and plantations as well as radiata pine. Site productivity is dependent on various environmental factors such as temperature, rainfall, soil depth, drainage and nutrient status. Criteria for assessing and rating site productivity are described in Laffan (1997).

Site productivity ratings for the soils are given in Table 5. All soils under dry forest are assessed as having low or low to very low productivity, whereas under wet forest most soils have high productivity. The exceptions are the Excalibur soil formed on dolerite, where site productivity varies from low to high depending on stone content, and the texture-contrast Paris soil on granite. Differences in site productivity between soils under dry and wet forests reflect significant variation in moisture availability, effective rooting depth and nutrient availability. Under dry forests, texture-contrast soils have limited rooting depth due to poorly structured clayey subsoils and, in some cases, very hard subsurface pans in A2-horizons. They invariably have moderate to severe limitations of moisture availability because of low effective summer rainfall combined with sandy layers with low water-holding capacity. Nutrient status is nearly always low (low total P, N and organic C) in both texture-contrast and gradational soils under dry forest. In contrast, soils under wet forest generally have few or negligible limitations for tree growth, apart from very stony soils with restricted rooting volume and texture-contrast soils with low nutrient status. However, some soils under wet forest have only moderate levels of nutrients which may limit the productivity of present and future rotations.

Distribution of dry and wet eucalypt forests

The boundary between wet and dry eucalypt forests occurs where MAR is approximately 1000 mm but it is also dependent on other factors such as soil water-holding capacity, nutrient status, topography and the frequency of past fires. Where MAR is below 1000 mm, wet forest is generally restricted to topographically protected sites (e.g. hillslopes with shady aspect, moist drainage lines, gullies), with dry forests occurring on less protected sites (Duncan 1985).

In north-western Tasmania, both dry and wet eucalypt forests occur where MAR exceeds 1400 mm on granite soils with texture-contrast profiles and low nutrient status. The reasons for the occurrence of dry forests under such relatively high rainfall is uncertain, but it may relate to a history of more frequent fires than under adjacent wet forests and / or to summer moisture deficits related to the low water-holding capacity of sandy surface and subsurface soil layers.

Conclusions

The comparison of soils under dry and wet eucalypt forests on similar substrates shows marked differences in profile morphology and chemical properties which, in turn, have important implications for forest management. The type of forest (whether dry or wet) is determined largely by climate (mean annual rainfall) but can be strongly modified by the effects of topography (landform, aspect and elevation) and soil properties (water-holding capacity and nutrient status). The frequency of fires is also probably important on some sites.

Soils under dry forest generally have texture-contrast profiles characterised by sandy topsoils overlying clayey subsoils with coarse blocky structure and very firm or strong soil strength. Their nutrient status is generally poor, with low levels of organic matter, total P and total N. Most soils are highly susceptible to various forms of soil degradation and they all have low site productivity. Texture-contrast soils have limited potential for plantation development mainly because of severe constraints of shallow rooting depth and low nutrient status, and some are highly susceptible to severe summer moisture deficits. The gradational soils under dry forest also have low nutrient status but, apart from profiles with high stone content, they generally have more favourable rooting conditions. Silvicultural treatments such as deep ripping, mounding and fertilisation may help ameliorate soil constraints, but thorough economic appraisal is required to determine costs and benefits. This is essential for soils where frequent applications of fertilisers (e.g. nitrogen) are required for optimum tree growth. Deep cultivation of some texture-contrast soils in northern Tasmania has so far led to mainly disappointing plantation growth. These results may be attributable to severe soil structural degradation following seasonal wetting and drying which can lead to the development of hard, structureless and relatively impenetrable subsoils. Under dry forest, gradational soils with a main limitation of low nutrient levels appear to have the best potential for plantations.

In contrast, soils under wet forest are characterised by gradational texture profiles with finer structure and weaker strength in subsoils. They generally have moderate or high levels of nutrients, low or moderate susceptibility to soil degradation and high site productivity. Except for the relatively few soils with texture-contrast profiles and low levels of nutrients, or gradational profiles with high stone content or severely impeded drainage or occurring at high altitudes, soils under wet forest are invariably highly suitable for plantations provided appropriate fertilisers are applied to soils with lower levels of nutrients.

Acknowledgements

Richard Doyle (University of Tasmania, Hobart) is thanked for comments on the manuscript.

References

Brown, G. and Laffan, M.D. (1993). *Forest Soil Conservation Manual.* Forestry Commission, Tasmania.

Duncan, F. (1985). Tasmania's vegetation and its response to logging operations. *Working Paper No. 6, EIS on Tasmania Woodchip Exports Beyond 1988.*

Forestry Commission (1994). *Silvicultural Systems.* Native Forest Silviculture Technical Bulletin No. 5. Forestry Commission Tasmania. (Reprinted 1998 by Forestry Tasmania)

Forestry Tasmania (1998). *Lowland Wet Eucalypt Forest.* Native Forest Silviculture Technical Bulletin No. 8. Forestry Tasmania.

Grant, J.C., Laffan, M.D. and Hill, R.B. (1995a). *Soils of Tasmanian State Forests. 2. Forester Sheet, North-East Tasmania.* Forestry Tasmania.

Grant, J.C., Laffan, M.D., Hill, R.B. and Nielsen, W.A. (1995b). *Forest Soils of Tasmania. A Handbook for Identification and Management.* Forestry Tasmania, Hobart.

Gilbert, J.M. (1959). Forest succession in the Florentine Valley, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 93: 129–151.

Herbert, A.M., Laffan, M.D., Hill, R.B. and Grant, J.C. (1995). *Laboratory Procedures for Soil Analysis and Preparation of Plant Materials.* Soils Technical Report No. 2 (2nd edn). Forestry Tasmania.

Hill, R.B., Laffan, M.D. and Grant, J.C. (1995). *Soils of Tasmanian State Forests. 3. Forth Sheet, North-West Tasmania.* Forestry Tasmania.

Isbell, R.F. (1980). Genesis and classification of low activity clay alfisols and ultisols: A selective review. In: *Soils with Variable Charge* (ed. B.K.G. Theng), pp. 397–410. New Zealand Society of Soil Science.

Isbell, R.F. (1996). *The Australian Soil Classification.* CSIRO Publishing, Melbourne.

Laffan, M.D. (1997). *Site Selection for Hardwood and Softwood Plantations in Tasmania. A Methodology for Assessing Site Productivity and Suitability for Plantations using Land Resource Information.* Soils Technical Report No. 3 (2nd edn). Forestry Tasmania and Forest Practices Board, Hobart.

Laffan, M.D., Grant, J.C. and Hill, R.B. (1995). *Soils of Tasmanian State Forests. 1. Pipers Sheet North-East Tasmania.* Forestry Tasmania.

Laffan, M.D., Grant, J.C. and Hill, R.B. (1996). A method for assessing the erodibility of Tasmanian forest soils. *Australian Journal of Soil and Water Conservation* 9(4): 16–22.

Laffan, M.D. and Kingston, T.J. (1997). Earthworms in some Tasmanian forest soils in relation to bioturbation and soil texture profile. *Australian Journal of Soil Research* 35(6): 1231–1245.

McDonald, R.C., Isbell, R.F., Speight, J.C., Walker, J. and Hopkins, M.S. (1990). *Australian Soil and Land Survey Field Handbook* (2nd edn). Inkata Press, Melbourne and Sydney.

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.H., Sleeman, J.R., Mulcahy, M.J. and Hallsworth, E.G. (1968). *A Handbook of Australian Soils.* Rellim Technical Publications, Glenside, South Australia.

Tasforests