SOIL RESOURCES OF THE MARLBOROUGH SOUNDS AND IMPLICATIONS FOR EXOTIC PRODUCTION FORESTRY

1. Soil Resources and Limitations to Exotic Forest Growth

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ABSTRACT

The soils of the Marlborough Sounds are briefly described in terms of three broad soil-physiographic units based on climate: (1) Soils of the lowlands with weak dry season, (2) Soils of the lowlands with very weak or negligible dry season, and (3) Soils of the cool uplands with negligible dry season. Each of these units is further subdivided on the basis of parent material and topography. Overall morphological and physical properties and nutrient status of the soils are outlined together with a summary of soil physical and soil nutrient limitations to exotic forest growth.

Soils of the lowlands formed from greywacke, schist or basic volcanic rocks generally have slight physical limitations and moderate nutrient limitations to exotic forest growth. Soils of the uplands formed from greywacke or schist have moderate to severe physical limitations and moderate nutrient limitations. Soils formed from serpentine generally have moderate or moderate to severe physical limitations and severe nutrient limitations to exotic forest growth.

INTRODUCTION

Exotic production forestry is predicted to have an important role in the development of both the Marlborough Sounds and the Marlborough region as a whole (Duckworth *et al.*, 1976). It has been estimated, mainly on the basis of present vegetation patterns, that about 40 000 ha of mainly hilly and steep land are suitable for afforestation in the Marlborough Sounds (Wilkes,

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1980). Since 1920 about 5000 ha have been planted in mainly radiata pine (*P. radiata*), most of the afforestation occurring since 1963.

The original vegetation throughout the Marlborough Sounds was indigenous forest. In the areas adjacent to Cook Strait and Tasman Bay coastal broadleaf forest predominated, while elsewhere at altitudes below about 550 m beech-podocarp (mainly rimu, *Dacrydium cupressinum*) forest was prevalent. At altitudes above about 550 m, rimu is rare or absent and the forests comprise mainly mixed beech (*Nothofagus* spp.) and kamahi (*Weinmannia racemosa*) with some rata (*Metrosideros umbellata*). Tree-borne mosses and lichens occur profusely at these altitudes reflecting both the greater annual rainfall and decreased evapotranspiration resulting from greater cloud cover and lower temperatures than at lower altitudes.

Nearly two-thirds of the natural forest cover in the Marlborough Sounds was cleared for pastoral farming in the late 1800s and early 1900s. However, extensive areas have since reverted to scrub and regenerating indigenous forest and it is mainly these areas which are proposed for exotic afforestation.

Information on the soils of the Marlborough Sounds region has been collected during a soil survey initiated in 1978 and this paper summarises the regional soil properties and limitations to exotic forest growth. A more detailed assessment of individual soils together with a soil map will be published later as a Soil Survey Report. The area covered during the soil survey comprises the region north of a line extending from Cape Souci in the west through near Havelock, to Rarangi in the east. This line follows the catchment boundaries of the streams draining directly into the Sounds.

SOIL RESOURCES

Environmental Features

The broad pattern of soils in the Marlborough Sounds is determined largely by topography, parent material, and climate. For soils formed from siliceous rocks, climate is the dominant factor influencing their development and distribution.

Topography

The region comprises a partly drowned landscape dominated by steep hillsides rising abruptly from sea level to altitudes

>1000 m. Land higher than 600 m a.s.l. occurs extensively. Major ridges trend NE-SW forming a landscape with pronounced aspect differences between sunny north-west facing slopes and shady south-east facing slopes. Steep land (slopes >30°) and hilly land (13-30°) occur on about 90% of the region while flat and rolling land (0-12°) covers about 5-10% of the total area.

Parent Material

Parent materials are varied and reflect lithology and the pattern of rock weathering and slope deposits.

The lithology is dominated by a central zone of indurated siltstone and sandstone (greywacke) which merge eastwards into schist. Bands of basic volcanic rocks and ultramafic (mainly serpentine) rocks including associated serpentinised sedimentary rocks occur within the greywackes along the western side of the region. Small areas of conglomerate and red volcanogenic siltstones and sandstones also occur in the western and central parts of the region. Faulting has occurred extensively throughout the Marlborough Sounds and shattered rock is common. The degree of weathering of the rocks is variable but, particularly for sedimentary rocks, is related mainly to altitude, with strongly weathered rocks occurring near sea level and weakly or moderately weathered rocks generally occurring at higher altitudes. Relatively soft, very strongly and deeply weathered rocks (saprolite), including red saprolite, occur on some lower spurs and promontories. The strongly weathered rocks occurring at low altitudes are interpreted as being remnants of Late Pleistocene interglacial or interstadial weathering.

On hill and mountain slopes formed in greywacke or schist two main types of regolith (soil plus weathered rock mantle) have been differentiated on the basis of weathering and altitude: (1) slope deposits derived from strongly weathered rocks, together with minor saprolite, occurring at altitudes below about 200 m, and (2) slope deposits derived from weakly or moderately weathered rocks occurring at altitudes above about 200 m. Small deposits of undisturbed loess have been recognised at several localities in the region, and it is probable that reworked loess occurs in the upper profiles of both types of regolith. The distribution of the slope deposits is complex but is determined partly by aspect and length of slope. Slope deposits from weakly or moderately weathered rocks generally occur to lower altitudes on shady aspects and often reach to near sea level on long, shady aspect slopes associated with major ridges. Thickness of the two main types of slope deposits is highly variable but on average is >1 m. Saprolite thickness is also variable but thicknesses >2 m occur in some road cuttings in Port Underwood.

Stream and fan alluvium is confined mainly to the heads of the larger bays and inlets. Most of the alluvium is derived from greywacke or schist and is weakly weathered.

Climate

Climate varies from mild and humid to cool and superhumid. Mean annual rainfall increases from about 1 000 mm in areas adjacent to Cook Strait and Tasman Bay to over 2000 mm in the area adjacent to Mt Stokes and the inner Pelorus Sound (N.Z. Meteorological Service isohyet maps). Rainfall also appears to increase markedly with increasing altitude. Rainfall from the north or south-east occasionally produces high intensities and high total falls (N.Z. Meteorological Service, 1973a). North-west gales are frequent in the spring, summer and autumn period, and a soil moisture deficit is common in summer in the lower rainfall coastal areas.

The nearest climatological station is Rai Valley (80 m a.s.l.) some 12 km south-east of the region where mean annual air temperature is 11.3°C with mean July temperature of 5.9°C and mean February temperature of 16.0°C (N.Z. Meteorological Service 1973b).

Three broad climatic zones have been recognised on the basis of altitude, mean annual rainfall and the presence or absence of a dry season:

(1) A mild humid zone occurring at altitudes below about 150-250 m where mean annual rainfall range is 1 000-1 500 mm. A weak dry season normally occurs during the summer period when soil moisture falls below wilting point. Water balance calculations indicate a slight soil moisture deficit of up to 150 mm; however, the severity of the dry season and corresponding soil moisture status may vary markedly from year to year. This zone includes all the coastal areas of the Marlborough Sounds except the western side of inner Pelorus Sound, Tennyson Inlet, eastern side of Hikapu Reach and inner parts of Endeavour Inlet.

(2) A mild humid to superhumid zone with very weak or negligible dry season. This zone comprises two distinct subzones:

(a) A mild humid to superhumid subzone occurring at altitudes between 150-550 m in areas adjacent to zone 1 where mean rainfall probably lies within the range 1300-2000 mm. Because of higher mean annual rainfall and lower evapotranspiration than in zone 1 only a very weak or negligible dry season occurs in most years. During the summer months soils are mostly above wilting point with negligible soil moisture deficit. In the drier areas adjacent to Cook Strait and Tasman Bay the boundary between zones 1 and 2(a) extends up to altitudes of about 300 m, while elsewhere the boundary occurs at altitudes of about 250 m on slopes with sunny aspect, and about 150 m on slopes with shady aspect.

(b) A mild superhumid subzone occurring at altitudes from sea level to 550 m in areas where mean annual rainfall range is >2000 mm. In most years rainfall exceeds potential evapotranspiration in all months and a dry season does not occur. This subzone includes most of the area on the western side of inner Pelorus Sound, Tennyson Inlet, the eastern side of Hikapu Reach, inner Endeavour Inlet and a comparatively large area adjacent to Mt Stokes.

A mild humid to superhumid transition zone also occurs adjacent to zones 1 and 2 (b), but because of its limited occurrence this zone is included within 2 (b).

(3) A cool superhumid zone occurring at all altitudes above 550 m throughout the region. Rainfall is probably much greater than potential evapotranspiration in all months and dry periods are rare in this zone. The cooler temperatures result in slower plant growth and a shorter growing season than at altitudes below 550 m.

Regional Soil Pattern

The soils of the region have been subdivided into three major soil-physiographic units based on the three broad climatic zones:

(1) Soils of the lowlands with weak dry season, occurring at altitudes below 150-250 m in the humid climatic zone, and comprising about 40% of the region.

(2) Soils of the lowlands with very weak or negligible dry season, occurring at altitudes between 150-550 m in the humid to superhumid climatic subzone, and from sea level to 550 m in the superhumid climatic subzone. This zone covers about 45% of the region.
(3) Soils of the cool uplands with negligible dry season, occurring at all altitudes above 550 m throughout the Marlborough Sounds, and comprising about 15% of the region.

The soils have been further subdivided into two main topographic units:

(1) Soils on flat and rolling land,
(2) Soils on hilly and steep land.

A third subdivision has been made on parent material where three main lithologic units have been separated:

(1) Soils from greywacke or schist,
(2) Soils from basic volcanic rocks,
(3) Soils from serpentine.

The relationship between the climatic, topographic and parent material units are outlined in Table 1 as a regional soil-physiographic legend.

TABLE 1: REGIONAL SOIL-PHYSIOGRAPHIC LEGEND FOR MARLBOROUGH SOUNDS SHOWING MAJOR SOIL-PHYSIOGRAPHIC UNITS ACCORDING TO CLIMATE, TOPOGRAPHY AND PARENT MATERIAL

Soils of the lowlands with weak dry season
— on flat and rolling land
soils from greywacke or schist
— on hilly and steep land
soils from greywacke or schist
soils from basic volcanic rocks
soils from serpentine
Soils of the lowlands with very weak or negligible dry season
— on flat and rolling land
soils from greywacke or schist
— on hilly and steep land
soils from greywacke or schist
soils from basic volcanic rocks
soils from serpentine
Soils of the cool uplands with negligible dry season
— on hilly and steep land
soils from greywacke or schist
soils from serpentine

rock outcrops or large boulders. Deeper soils (>50 cm) formed from serpentine slope deposits occur in accumulative sites, particularly in areas with a weak dry season.

Stoniness of the soils is also highly variable, but usually few to many (5-35% by volume) stones occur throughout the profile. On very steep slopes ($>38°$) soils are generally much shallower and stonier and rock outcrops more numerous than on less steep slopes. Very steep slopes occur sporadically throughout the region but they are more common adjacent to the coastline and at altitudes >250 m.

A feature of most soils on hilly and steep land in the Marlborough Sounds is their relatively high silt and clay content. Textures are dominantly clay loams or silty clays, with values of 35-45% clay (<0.002 mm) and 40-50% silt (0.002 to 0.05 mm) commonly occurring in subsoils.

Soil consistence and structure in subsoils varies from firm or friable to firm, blocky structure in soils of the lowlands with weak dry season, to very friable, nut structure in soils of the uplands. Soils of the lowlands commonly have a very firm layer, beginning at depths between 70-120 cm from the surface, which is impenetrable to fine roots. This layer is slowly permeable and forms a shear plane. Soil physical properties for soils of the hilly and steep land are summarised in Table 2.

Both superficial and deep seated forms of landslides occur extensively in the Marlborough Sounds. Their distribution has been related mainly to the presence of strongly weathered and/or highly shattered bedrock for deep seated landslides, and to the occurrence of relatively shallow shear planes in regoliths for superficial landslides. Superficial landslides occur preferentially in areas cleared of indigenous forest (Laffan, 1980a).

Soil Nutrient Status

The data in Table 3 are derived from characterisation analyses carried out on representative soil profiles collected during the soil survey of the Marlborough Sounds, plus some analyses carried out on the same samples for the assessment of nutrient status for tree growth. Analyses have not been completed for all representative soils in the region; no data are available for soils from basic volcanic rocks, or for soils from serpentine from two of the three major climatic groups. However, these soils represent only small areas and all the soils from serpentine will probably have similar properties to those given in Table 3. Data for all

Soil Properties

Exotic production forestry in the Marlborough Sounds is expected to be confined mainly to the hilly and steep land with other forms of land use predominating on the flat and rolling land. The discussion of soil properties and limitations has therefore been restricted to soils of the hilly and steep land.

Soil Physical Properties and Profile Morphology

Overall soil profile morphology generally reflects soil drainage, parent material and climate, particularly effective rainfall.

Soil drainage in the Marlborough Sounds is somewhat variable but on a broad basis it appears to be dependent largely on lithology. Soils formed from greywacke, schist or basic volcanic rocks are mainly well drained throughout the region. Soils formed from serpentine are generally well drained in areas with weak dry season, and imperfectly drained in areas with very weak or negligible dry season.

Soils formed from greywacke or schist typically have profiles characterised by thin, dark brown topsoils overlying thick yellowish brown subsoils. In lowland areas with superhumid climate and in upland areas soil profiles with well developed podzol features also occur sporadically. They are generally characterised by moderately thick organic horizons overlying greyish coloured eluvial horizons below which occur moderately thick yellowish brown illuvial horizons. In a few sites a very thin, hard iron pan occurs below the greyish coloured horizon (Laffan, 1980b).

Soils formed from serpentine with a weak dry season, and soils formed from basic volcanic rocks, generally have profiles characterised by thin dark brown topsoils overlying moderately thick or thick brown subsoils. Soils formed from serpentine with a very weak or negligible dry season typically have thin or moderately thick, olive coloured subsoils often with greyish and rusty coloured mottles.

Soil depth is extremely variable throughout the region but at altitudes below 550 m average soil depth is >75 cm. Shallow soils (<50 cm) formed from greywacke, schist or basic volcanic rocks occur widely but they are more common at altitudes above 550 m. They occur mainly in association with rock outcrops on ridges, spurs and very steep slopes. Soils formed from serpentine are generally shallow and occur in association with numerous

TABLE 2: SUMMARY OF SOIL PHYSICAL PROPERTIES FOR SOILS OF THE HILLY AND STEEP LAND, MARLBOROUGH SOUNDS

Soil-Physiographic Unit	*Overall Soil Drainage*	*Relative Occurrence of Rock Outcrops**	*Average Soil Depth Range† (cm)*	*Average Texture in Upper 1 m Profile (stones)*	*(<2 mm)*	*Consistence in Subsoils*	*Structure in Subsoils*
Soils of the lowlands with weak dry season							
— from greywacke or schist	well drained	few	>75	few to many	silty clay to clay loam	firm or friable to firm	blocky
— from basic volcanics	well drained	few to many	>75	few to many	clay loam	firm or friable to firm	blocky
— from serpentine	well drained	many to abundant	>50	few to many	clay loam to clay	friable to firm	blocky and nut
Soils of the lowlands with very weak or negligible dry season							
— from greywacke or schist	well drained	few to many	>75	few to many	silty clay to clay loam	friable to very friable	blocky breaking to nut, and nut
— from basic volcanics	well drained	many	>75	few to many	clay loam	friable to very friable	blocky breaking to nut, and nut
— from serpentine	imperfectly drained	abundant	<50	few to many	clay loam	friable to very friable	blocky breaking to nut, and nut
Soils of the cool uplands with negligible dry season							
— from greywacke or schist	well drained	many to abundant	>50	few to many	clay loam	very friable	
— from serpentine	imperfectly drained	abundant	<50	few to many	clay loam	very friable	

* Approximate percentage range of rock outcrops on an areal basis: <5% = few, 5-10% = many, >10% = abundant.
† Depth to a layer relatively impenetrable to tree roots; *e.g.*, very firm horizons or bedrock.

profiles within each group have been meaned to give the values in Table 3. Standard deviations (in parentheses) and ratings according to Blakemore *et al.* (1981) are also given for some of the properties.

Results for the soils formed from greywacke or schist show that they are moderately to strongly acid and mainly strongly leached (low % base saturation). The results for pH, %BS and exchangeable calcium show a significant decrease from soils of the lowlands with weak dry season to soils of the uplands. This trend results from an increase in soil leaching associated with increasing mean annual rainfall and decreasing evapotranspiration. The soils from serpentine, mainly because of very high levels of exchangeable magnesium (not shown here), are weakly leached and only slightly acid to near neutral.

Total nitrogen levels are low in all the topsoils in the region examined, as are Bray-2 P levels.

Acid soluble magnesium levels are similar in all topsoils apart from the soils from Mg-rich serpentine, which are markedly higher. Acid soluble potassium levels reflect the leaching status of the soils, with lowest levels occurring in soils of the uplands.

Soil Classification

Under the New Zealand Genetic Soil Classification (N.Z. Soil Bureau, 1968; Taylor and Pohlen, 1979), the soils formed from greywacke or schist are classified broadly as follows: (1) Soils of the lowlands with weak dry season — strongly leached lowland yellow-brown earths, (2) Soils of the lowlands with very weak or negligible dry season — very strongly leached lowland yellow-brown earths and lowland podzolised yellow-brown earths and podzols, (3) Soils of the uplands — very strongly leached upland yellow-brown earths and upland podzolised yellow-brown earths and podzols.

Soils formed from basic volcanic rocks and serpentine are tentatively classified as brown granular clays and intergrades with yellow-brown earths.

Under Soil Taxonomy (Soil Survey Staff, 1975), soils formed from greywacke, schist or basic volcanic rocks with very weak or negligible dry season classify broadly to great group level as Dystrochrepts. Soils formed from greywacke or schist with weak dry season are tentatively classified as Haplohumults and associated soils from basic volcanic rocks or serpentine are classified as Hapludalfs. Other soils formed from serpentine classify as Eutrochrepts.

TABLE 3: SUMMARY OF SOIL NUTRIENT STATUS FOR SOILS OF THE HILLY AND STEEP LAND, MARLBOROUGH SOUNDS

Soil-physiographic Unit	*No. of Profiles*	*pH*		*%BS profile*	*Exchangeable Ca (me.%)*		*Acid-soluble Mg (ppm)*		*Acid-soluble K (ppm)*		*Total Nitrogen %*		*Bray-2 Phosphorus ppm*		*Phosphate Retention %*	
		t.s.	*s.s.*		*t.s.*	*s.s.*	*t.s.*	*s.s.*	*t.s.*	*s.s.*	*t.s.*	*s.s.*	*t.s.*	*s.s.*	*t.s.*	*s.s.*
Soils of the lowlands with weak dry season																
— from greywacke or schist	4	5.3 (0.3)	5.4 (0.3)	24 (10) L	4.5 (2.2) L	1.2 (0.9) VL	1950 (390)	2380 (690)	1370 (260)	1220 (280)	0.23 (0.05) L	0.07 (0.03) VL	3 (1.5)	1.3 (1.6)	31 (4) M	58 (10) M
Soils of the lowlands with very weak or negligible dry season																
— from greywacke or schist	9	4.8 (0.5)	5.1 (0.3)	9 4 VL	2.3 (1.6) L	0.5 (0.3) VL	2200 (1010)	2570 (1400)	630 (200)	520 (140)	0.23 (0.14) L	0.12 (0.08) VL	5 (6)	2 (1)	61 (16) H	76 (12) H
— from serpentine	2	6.1	6.7	82 VH	2.4 L	1.2 VL	14800	23700	2480	1770	0.29 L	0.08 VL	1.2	0.3		
Soils of the cool uplands with negligible dry season																
— from greywacke or schist	6	4.6 (0.3)	5.0 (0.2)	6 (4) VL	1.8 (1.8) VL	0.4 (0.3) VL	2130 (1760)	3370 (1690)	460 (190)	420 (140)	0.30 (0.09) L	0.13 (0.05) VL	5 (3)	2 (1)	69 (13) H	88 (7) H

t.s. = topsoil = A horizon
s.s. = subsoil = B + C horizons
Ratings (Blakemore *et al.* 1981); VL = very low, L = low, M = medium, H = high, VH = very high
Figures in parenthesis are standard deviations.

SOIL LIMITATIONS TO EXOTIC FOREST GROWTH

Soil Physical Limitations

Table 4 summarises the major soil physical limitations to exotic forest growth. The limitation ratings are outlined at the foot of Table 4. The limitations for soil depth, texture and soil drainage have been adapted from the ratings of Adams and Mew (1976a, b) and Laffan and Adams (1977).

Steepness of slope is not considered to be a direct limiting factor to forest growth but it does have an indirect effect on other parameters such as soil depth, stoniness and occurrence of rock outcrops. Throughout the region, soils formed on very steep slopes (>38°) are likely to have a much higher limitation rating for soil depth and texture than is shown in Table 4. Also, the occurrence of rock outcrops has not been considered in this table. However, for soils formed from serpentine and for other soils formed on very steep slopes or on rocky ridges and spurs, the occurrence of abundant rock outcrops is likely to present a major limitation to the actual area which is plantable to exotic forestry.

Soils of the lowlands formed from greywacke, schist or basic volcanic rocks are assessed overall as having slight physical limitations to exotic forest growth. They relate mainly to soil texture (stoniness and clayey textures) and to summer soil moisture deficit for those soils with a weak dry season. Soils of the uplands formed from greywacke or schist have an overall moderate to severe limitation of cool soil temperatures. Soils formed from serpentine with a very weak or negligible dry season have moderate to severe limitations of soil depth, and for soils at altitudes above 550 m they have an additional moderate to severe limitation of cool soil temperatures.

Soil Nutrient Limitations

Although total nitrogen levels are low in all topsoils in the region, and very low in all subsoils, the topsoil levels are all above the critical level of 0.15% in the top 10 cm (Adams and Mew, 1975). It is worth noting that, below the topsoil, nitrogen levels are all below the critical level. This could become important if the top 10-20 cm of the soil is lost by erosion or by management practices such as root-raking or line-dozing.

Available phosphorus levels, as estimated by the Bray-2 method, are universally low, and below the critical 12 ppm

TABLE 4: SUMMARY OF SOIL PHYSICAL LIMITATIONS TO EXOTIC FOREST GROWTH FOR SOILS OF THE HILLY AND STEEP LAND, MARLBOROUGH SOUNDS

Soil-Physiographic unit	*Limitations to Effective Depth or Volume of Root Penetration*			*Limitations of Climate*	
	Soil depth to impenetrable layer[1]	*Soil texture*[2] *(stoniness and clay content)*	*Soil moisture surplus*[3] *(drainage impediment)*	*Soil moisture deficit*[4]	*Cool soil temperatures*[5]
Soils of the lowlands with weak dry season					
— from greywacke or schist	negligible	slight	negligible	slight	negligible
— from basic volcanics	negligible	slight	negligible	slight	negligible
— from serpentine	negligible to slight	slight	negligible	slight	negligible
Soils of the lowlands with very weak or negligible dry season					
— from greywacke or schist	negligible	slight	negligible	negligible to slight	negligible to slight
— from basic volcanics	negligible	slight	negligible	negligible to slight	negligible to slight
— from serpentine	moderate to severe	slight	moderate	negligible to slight	negligible to slight
Soils of the cool uplands with negligible dry season					
— from greywacke or schist	slight	slight	negligible	negligible	moderate to severe
— from serpentine	moderate to severe	slight	moderate	negligible	moderate to severe

[1] >75 cm = negligible limitation, 50–75 cm = slight limitation, <50 cm = moderate to severe limitation

[2] few to many stones = slight limitation, clayey textures = slight limitation

[3] well drained = negligible limitation, moderately well drained = slight limitation, imperfectly drained = moderate limitation

[4] negligible dry season = negligible limitation, weak dry season = slight limitation

[5] altitudes <300 m = negligible limitation, altitudes between 300-550 m = slight limitation, altitudes between 550-1000 m = moderate limitation, altitudes >1000 m = severe limitation

level for pine tree seedlings (Adams and Mew, 1975). Litter layer samples from three profiles collected under beech forest averaged 45 ppm phosphorus (data not shown).

Phosphate retention values range from medium in the lower rainfall soils to high in the higher rainfall soils. The high values imply that more phosphate topdressing may be required to give the same response as in soils with medium P-retention values.

Exchangeable calcium levels are all above the 0.2 me.% critical level, although it is possible that the very high Mg/Ca ratios of the soils derived from serpentine could decrease the availablity of calcium.

Acid soluble magnesium and potassium levels are both above the respective limiting levels for tree growth (500 ppm Mg — Adams and Mew, 1975; 300 ppm K — Raupach and Clarke, 1972).

The status of trace elements in soils of the region is not known, as foliar analyses were not undertaken. However, boron deficiencies in radiata pine have been recorded in some soils formed from schist south of the region (Jacks, 1973) and it is possible that similar deficiencies would occur in the Marlborough Sounds.

TABLE 5: SUMMARY OF SOIL NUTRIENT LIMITATIONS TO EXOTIC FOREST GROWTH FOR SOILS OF THE HILLY AND STEEP LAND, MARLBOROUGH SOUNDS

Soil-physiographic unit	*Phosphorus (Bray–2 P)*[1]	*Nitrogen (Total N)*[2]	*Cations (Ca, Mg, K)*[3]
Soils of the lowlands with weak dry season			
— from greywacke or schist	moderate	negligible	negligible
Soils of the lowlands with very weak or negligible dry season			
— from greywacke or schist	moderate	negligible	negligible
— from serpentine	severe	negligible	negligible
Soils of the cool uplands wth negligible dry season			
— from greywacke or schist	moderate	negligible	negligible

[1] Bray-2 P: >12 ppm throughout profile = negligible limitation
9–12 ppm in top 10 cm = slight limitation
<3 ppm in top 10 cm, >9 ppm below or
3–9 ppm in top 10 cm, <9 ppm below = moderate limitation
<3 ppm throughout profile = severe limitation

[2] Total N: >0.15 in top 10 cm = negligible limitation

[3] Cations: Exch. Ca: >0.2 me.% = negligible limitation
Acid-soluble Mg: >500 ppm = negligible limitation
Acid-soluble K: >300 ppm = negligible limitation

Table 5 summarises the limitations (of the same soils as in Table 3) for phosphorus, nitrogen and cations for radiata pine growth, according to the criteria given by Adams and Mew (1975). These limitations should be regarded as relating to potential deficiencies, as the analyses were carried out on samples from virgin sites or grassland sites with little or no topdressing. Management changes such as topdressing or burning can increase the short-term nutrient supply prior to tree planting.

Throughout the region, soils formed from greywacke or schist are assessed overall as having moderate nutrient limitations (low Bray-2 P levels) to exotic forest growth. It is likely that soils formed from basic volcanic rocks would have negligible or only slight nutrient limitations. Soils formed from serpentine have severe nutrient limitations of very low levels of Bray-2 phosphorus.

CONCLUSION

Consideration of soil physical and nutrient properties which affect potential exotic forest growth indicate that broadly, soils of the lowlands where formed from greywacke, schist or basic volcanic rocks have the potential for viable exotic production forestry. However, fertiliser applications may be required for optimum forest growth. Soils of the uplands which are formed from greywacke or schist have climatic limitations which will inhibit to varying degrees the potential for viable exotic forestry. Soils formed from serpentine appear to have limited potential for viable exotic production forestry in the region.

Proposals for exotic afforestation also need to take cognizance of potential impacts from forest practices on site disturbance and fine sediment production (Laffan *et al.*, 1985) and possible associated effects on the marine environment (Johnston *et al.*, 1981).

REFERENCES

Adams, J. A.; Mew, G., 1975. Soils of the Inangahua Depression, South Island, New Zealand. Part II. Soil chemistry and forestry appraisal. *N.Z. Soil Survey Rep. 17*: 39-78.

Adams, J. A.; Mew, G., 1976a. Interim report on the limitations for exotic forestry of the soils of the Grey Valley, South Island, New Zealand. *N.Z. Soil Bur. Rec. 47*. 26 pp.

————; ————, 1976b. Interim report on the limitations for exotic forestry of the soils of the Greymouth-Hokitika region, South Island, New Zealand. *N.Z. Soil Bur. Rec. 49*. 27 pp.

Blakemore, L. C.; Searle, P. L.; Daly, B. K., 1981. Methods for chemical analysis of soils. *N.Z. Soil Bur. Sci. Rep. 10A*.

Duckworth, L. C.; Fletcher, A. S.; Higham, J. R. G.; Pope, L. K., 1976. *Marlborough. A Survey of Present Resources and Future Potential.* Compiled for Marlborough Regional Development Council by Business Development Centre, University of Otago. 265 pp.

Jacks, H., 1973. Nutrient levels in *Pinus radiata* foliage, Nelson and Westland Conservancies. Unpublished *N.Z For. Res. Inst. Soil and Site Productivity Rep. No. 37.* 145 pp.

Johnston, A. D.; Mace, J.; Laffan, M. D., 1981. The saw, the soil and the Sounds. *Soil and Water, 17* (3-4): 4-8.

Laffan, M. D., 1980a. Some observations of regoliths and landslides in the Marlborough Sounds. *Soil News, 28* (2): 96-102.

———, 1980b. Podzols. Distribution and properties, Nelson and Marlborough. *In* R. Lee (Ed.), *Soil Groups of New Zealand. Part 5. Podzols and Gley Podzols.* N.Z. Society of Soil Science, Lower Hutt. 452 pp.

Laffan, M. D.; Adams, J. A., 1977: Interim report on the limitations for exotic forestry of the soils of the Charleston Punakaiki region, South Island, New Zealand. *N.Z. Soil Bur. Rec. 56.* 21 pp.

Laffan, M. D.; McQueen, D. J.; Churchman, G. J.; Joe, E. N., 1985. Soil resources of the Marlborough Sounds and implications for exotic production forestry. 2. Potential impacts on site disturbance and fine sediment production from various forest management practices. *N.Z. Jl For. 30:* 70-86.

New Zealand Meteorological Service, 1973a. Rainfall normals for New Zealand. *N.Z. Meteorol. Serv. Misc. Pub. 145*: 34 pp

———, 1973b. Summaries of climatological observations to 1970. *N.Z. Meteorol. Serv. Misc. Pub. 143*: 77 pp.

New Zealand Soil Bureau, 1968. General survey of the soils of South Island, New Zealand. *N.Z. Soil Bur. Bull. 27*: 404 pp.

Raupach, M.; Clarke, A. R. P., 1972. Deficiency symptoms, fertiliser responses and foliar levels of potassium in *Pinus radiata. Proc. Aust. Forest-tree Nutrition Conf. 1971*: 136-43.

Soil Survey Staff, 1975. Soil taxonomy. *U.S. Dept Agric., Agric. Handbk No. 436*: 754 pp.

Taylor, N. H.; Pohlen, I. J., 1979. Soil survey method. *N.Z. Soil Bur. Bull. 25*: 242 pp.

Wilkes, P. J., 1980: "Exotic Forestry and its Effects on Marine Farming in the Marlborough Sounds." Unpublished B.For.Sci. thesis, University of Canterbury. 93 pp.