THE ROLE OF FERTILISERS IN THE FUTURE OF WEST COAST EXOTIC FORESTS

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ABSTRACT

Exotic forestry on the West Coast faces difficulty in meeting wood demands after a reduction in the indigenous forest cut. The situation is acute because of the small size of the exotic estate (14 200 ha), its age distribution (only 1400 ha >20 years old), the species used, and their generally poor growth rates. Fertilizers offer one method of overcoming these difficulties.

The region is characterised by a moderately warm but extremely wet climate and by problems associated with topography, low soil fertility, and the influence of man. Recent soil surveys, backed by analyses of soil and of pine foliage,have identified the physical and nutrient limitations to growth of exotic tree species over a 4000 km² area in the region.

Trials have been established (maximum trial period, 14 years) to find ways of overcoming limitations of low levels of N, P, K, Mg, and B. Results indicate that, in order to produce sawlogs of pine on short rotations, heavy repeated dressings of N and P fertilisers will be required on many sites. In addition, wet podzolised soils usually require drainage and additions of K and Mg may sometimes be necessary. Gold-dredge tailings are often deficient in B as well as N and P; legumes have shown promise as a method of supplying N on such sites.

Fertiliser management prescriptions involve the use of soil analyses prior to planting and careful monitoring of foliage nutrient levels during rotations to ensure healthy trees and minimum fertiliser wastage. The choice of fertiliser materials must take into account the method of application and potential for leaching losses on the various sites.

INTRODUCTION

There is considerable pressure to increase the harvest from exotic conifers growing on the West Coast of the South Island in order to reduce the demand on native timbers being extracted from

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the limited indigenous forests. The problem is accentuated by the small size of the exotic estate (14 200 ha), the small proportion of older age classes (1400 ha older than 20 years), and the wide range of species planted, together with poor growth rates on some sites. Soil amelioration could provide substantial advantages to the forest industries, fertilisers could be applied to existing stands to boost growth rates, and trees in newly-planted areas could be grown on shorter rotations.

Early exotic plantings gave indications of the problems of growing pines in this superhumid mesothermal climate (Thornthwaite, 1948). Poor soil drainage and consequent waterlogging of the root zone, low fertility, and a high incidence of fungal pathogens all occur. However, site indices of 30 m at age 20 for *Pinus radiata* can be expected on well-drained, moderately fertile sites (Cutler and Berg, 1977).

SITES AND SOILS

Four landform categories are commonly being planted in exotic species on the West Coast.

1. *Dissected Lowland Blocks*

These are mixtures of hilly (15-30°) and steep slopes (>30°) underlain mainly by late Tertiary or early Quaternary sandstones, siltstones and conglomerates. The soils are largely yellow-brown earths or associated steepland soils, well drained except in the south towards Hokitika and close to the main ranges where some are imperfectly or poorly drained (Mew and Leamy, 1977). Natural fertility is low, but there are few physical impediments to rooting except shallowness to parent rock on some ridges and spurs. Erosion by soil slipping limits planting in certain areas.

Soil analyses indicate moderate (<3 ppm Bray-2 P in top 10 cm with 3-9 ppm below), or severe (<3 ppm throughout), potential phosphorus deficiency in the majority of the soils of the dissected lowlands (Adams and Mew, 1976a, b; Laffan and Adams, 1977; Heine *et al.*, 1977). Foliage analyses from trees already growing on a range of these soils shows the same trend, with levels being marginal or low for satisfactory growth (Table 1). Data were collected by the Forest Research Institute as part of a South Island survey of foliar nutrient levels in *P. radiata* (unpublished).

2. *Rolling Land, Fans, Low Glacial Outwash Terraces, and Terrace Dropovers*

Comparatively small areas in this category have been planted in exotic forests as much of the land is taken up for agriculture.

TABLE 1: TYPICAL *P. RADIATA* FOLIAR ANALYSES ON VARIOUS SOILS IN WESTLAND

Landform Category and Soils	*N%*	*P%*	*K%*	*Ca%*	*Mg%*	*B ppm*
Dissected lowlands						
Arahura hill soils	1.57	0.13	0.95	0.18	0.10	16
Blackball hill soils	1.26	0.09	0.89	0.21	0.10	15
Blackwater steepland soils	1.32	0.11	0.90	0.23	0.11	15
Callaghans steepland soils	1.50	0.11	0.83	0.22	0.09	15
Rolling land, fans, low glacial outwash terraces, and terrace dropovers						
Ahaura soils	1.64	0.15	0.87	0.30	0.08	18
Maimai soils	1.92	0.11	0.67	0.20	0.08	6
Flagstaff soils	1.67	0.12	0.87	0.16	0.08	11
Hochstetter soils	1.30	0.09	0.71	0.13	0.07	18
Intermediate and high glacial outwash terraces						
Denniston soils	1.86	0.08	0.81	0.22	0.09	11
Mawhera soils	1.48	0.08	0.56	0.24	0.08	13
Okarito soils	2.20	0.07	0.48	0.21	0.10	11
Hukarere soils	2.18	0.11	—	—	0.07	9
Dredge tailings (locations)						
Taramakau	0.73	0.12	0.53	0.86	0.10	13
Ikamatua	1.26	0.12	0.58	0.45	0.10	7
Tawhai	1.34	0.11	0.50	0.26	0.11	10
Maimai	1.50	0.09	0.62	0.24	0.08	7
Low levels*	<1.2	<0.12	<0.3	<0.1	<0.07	<8
Satisfactory levels	>1.5	>0.14	>0.5	>0.1	>0.10	>12

*Will (1978).

However, planted areas usually have complex mixtures of such soils as yellow-brown earths, imperfectly drained podzols, and poorly drained gleys on moraine, with podzols occurring on the older fans. The low glacial outwash terraces carry yellow-brown earths where the rainfall is below about 2500 mm, but where the rainfall is greater gley soils generally occur (Mew and Leamy, 1977). The yellow-brown earths have few physical limitations to exotic forest growth, but iron pans, high water-tables and extreme stoniness may occur in the others. Natural nutrient levels tend to be low throughout. Soil nitrogen levels are adequate, but there are moderate or severe potential limitations to growth from low levels of cations on all but the lowest terraces. These assessments are generally supported by foliar analyses which indicate especially low levels of P in trees on rolling land (Table 1). Other foliar nutrient levels are either satisfactory or only moderately limiting to growth.

3. *Intermediate and High Glacial Outwash Terraces*

The intermediate and high glacial outwash terraces are usually flat or have been slightly dissected to form easy rolling topography. The outwash gravels on them are commonly covered with an average of about 70 cm of dense fine-textured material thought to be loess (Young, 1967; Mew, in prep.) and their gleyed and/or podzolised soils are very poorly drained. Patches of organic soils are present in some areas. Where loess is absent, the soils still have very poor natural drainage and, in addition, are bouldery and may contain thick humus/iron pans. Natural nutrient levels are extremely low owing to extreme leaching, the soils being amongst the least fertile in New Zealand. Soil analyses indicate moderate to severe potential limitations to growth in terms of phosphorus and cations and slight to moderate limitations from nitrogen and trace element levels. These are largely supported by foliar analyses.

It has been found essential to ensure drainage by placing trees on artificially created mounds where these soils are used for exotic forestry.

4. *Dredge Tailings*

Tailings left where gold dredges have worked river flats or low outwash terraces usually form parallel mounds of coarse gravel burying sand or finer deposits. Drainage is commonly excessive because there is a lack of fines or organic matter in the upper layers. New soil development is minimal except on some of the oldest tailings where a scanty vegetation cover has led to accumulation of some organic material. Foliage nutrient levels in pines tend to be low in N, P, and B (Table 1); higher N levels occur where organic matter is accumulating or N-fixing plants are present.

SITE AMELIORATION

Most research has been concentrated on the worst possible growth sites, the intermediate and high glacial outwash terraces where drainage is most important. Washbourn (1972) showed how tree growth was increased by artificially draining Okarito soils even without the benefit of fertiliser. Heights were increased from 1.32 to 3.57 m and from 2.84 to 4.16 m for *Pinus contorta* and *P. muricata,* respectively, at age 12 years.

Where *P. radiata* and *P. muricata* have been planted on drained sites, they have responded very well to fertiliser treatment (Table 2). Phosphorus is the major limiting element although N is also

TABLE 2: BASAL AREA GROWTH (m^2/ha) OF *PINUS RADIATA* AND *P. MURICATA* AT AGE 14 YEARS ON IMPOVERISHED GLEY PODZOL SOILS (WD109).
Net figures are basal areas after second thinning to approx. 390 stems/ha

Treatment *	*P. radiata* *Gross BA*†	*Net BA*	*P. muricata*‡ *Gross BA*
Control	1.56c	1.45	2.76
P	13.61b	8.75	14.03
NP	19.43a	13.68	19.31
NPK	20.17a	15.96	9.48§

*Fertilizer treatments were:
P 13 g P/tree at planting; 75 kg P/ha at age 8; 100 kg P/ha at age 12
N 6 g N/tree at planting; 150 kg N/ha at age 8; 200 kg N/ha at age 12
K 12 g K/tree at planting; 75 kg K/ha at age 8; 75 kg K/ha at age 12
†Treatments followed by same letter do not differ at $P = 0.05$ using Duncan's test.
‡Only one replicate reported because of differences in planting dates.
§Low BA possibly results from animal damage.

required for maximum growth. Although foliage K levels were low while trees at the trial site were young, K is apparently not limiting growth. Foliar analyses do not indicate that other nutrients, except occasionally Mg, are likely to be limiting (Table 1 and unpublished trial results).

It is apparent that several dressings of fertiliser are necessary; over the first half of the rotation about 200 kg P/ha and 300-400 kg N/ha will be required to ensure good growth. However, it is anticipated that demand for additional nutrients will be lower in the later half of the rotation.

More recent trials on wet, podzolised soils on terrace and rolling country have been aimed at optimising rates of mixed N + P fertilisers. At planting, about 9 g N + 14 g P/tree should be adequate for most sites until about age 3 (Table 3).

TABLE 3: MEAN VOLUME INDEX (d^2h in cm^3) AT AGE 3 YEARS FOR *P. RADIATA* IN THREE TRIALS ON GLEYED AND/OR PODZOLISED SOILS

Trial No.	*Soils*	*Fertiliser Treatment** *0*	*54*	*107*	*214*
WD 180	Flagstaff hill soils	1458	2387	2505	2337
WD 223	Okarito soils	82	2510	1803	1948
WD 232	Maimai soils	819	1245	1169	1753

*Grams of a mixture of diammonium phosphate and serpentine-reverted superphosphate applied per tree at planting. The optimum level of 107 g/tree supplies 9 g N + 14 g P to each tree.

Experimental work has been limited on dissected lowland blocks and on better soils such as occur on terrace dropovers (Categories 1 and 2). On these sites both natural growth rates and fertiliser responses are variable. Thus, in a series of three pilot trials on dissected hill country, growth rates of *P. radiata* over the first 4 years varied by up to 70% in the control plots, with the growth response to 80 g DAP/tree ranging from 30 to 80 cm (Table 4). Various site factors influence these results, including aspect, weed control, and soil fertility. Similarly, a fertiliser trial in established stands on an impoverished site in Tawhai Forest (pre-treatment foliar analyses of 1.37% N and 0.11% P) showed a 36% response in basal area to N + P fertiliser (Table 5). In contrast, a trial on a more fertile site (pre-treatment foliar analyses of 1.54% N and 0.13 P) showed no significant increase in growth. It is apparent that forest managers should differentiate between sites when drawing up topdressing programmes.

TABLE 4: HEIGHTS AND DIAMETERS AT AGE 4 YEARS FOR THREE *P. RADIATA* FERTILISER TRIALS IN DISSECTED HILL COUNTRY (WD 206)

Treatment	*Site 1* *Ht(cm)*	*Dia(cm)*	*Site 2* *Ht(cm)*	*Dia(cm)*	*Site 3* *Ht(cm)*	*Dia(cm)*
Control	269	5.6	367	8.7	216	5.9
80 g DAP/tree	299	6.4	448	10.5	252	7.6
80 g DAP + K and micronutrients/tree	303	6.9	425	9.8	252	7.3

TABLE 5: BASAL AREA GROWTH AFTER FERTILISER APPLICATION TO ESTABLISHED STANDS OF *P. RADIATA*

Trial N 337 was on a strongly leached Blackball hill soil; WD 207 was on a more fertile terrace-dropover site (Deadmans hill soil).

Treatment *	*N 337*†	*WD 207*†
	m²/ha/yr‡	
Control	1.61a	4.20a
NP	2.11b	4.30a
NP+	2.12b	4.13a

*NP treatment: 200 kg N + 100 kg P/ha
NP+ treatment: as above, + 200 kg K_2SO_4 + 45 kg $ZnSO_4$ + 90 kg $MnSO_4$ + 700 kg dolomite + 45 kg $CuSO_4$ + 8 kg B/ha

†WD 207 was age 6 years at establishment of the trial. N 337 was age 23; both were thinned prior to treatment.

‡Adjusted by covariance analysis using initial BA as covariate. Treatments followed by same letter do not differ significantly at $P = 0.05$ using Duncan's test.

On dredge tailings, foliage analyses have been used to diagnose nutritional problems and to prescribe N, P, and B fertiliser treatments. The only detailed field trial has been one to study legume establishment. Seed inoculation with *Rhizobium* is essential to ensure good results. Legumes such as the clovers and *Lotus* spp. require phosphate dressings for fast establishment, while others such as Russell lupin, tree lupin, and tree lucerne will grow well without the addition of phosphate (Table 6).

TABLE 6: GROWTH OF LEGUMES ON GOLD-DREDGE TAILINGS AT KUMARA 2 YEARS AFTER SOWING (WD 186).

	kg DM/ha	
Species	*Fertilized with P **	*No P Fertilizer*
Red clover (*Trifolium pratense*)	8265	2033
White clover (*Trifolium repens*)	5508	1308
Subterranean clover (*Trifolium subterraneum*)	4732	1089
Lotus maku (*L. pedunculatus* var. *maku*)	5164	2712
Diploid alsike (*Trifolium hybridum*)	4705	3498
Russell lupin (*Lupinus polyphyllus*)	4302	4247
Tree lupin (*Lupinus arboreus*)	5764	11269
Tree lucerne (*Cytisus proliferus*)	48572	44154

*1200 kg/ha serpentine-reverted superphosphate (+Mo) at sowing followed by annual maintenance dressings of 250 kg/ha serpentine-reverted superphosphate. The second maintenance dressing also included 100 kg/ha potassium sulphate.

DISCUSSION

Fertiliser trial results, together with soil and foliar analyses and soil survey data, indicate the potential for improving exotic forest productivity through fertiliser applications. Three objectives to be achieved by using fertilisers on the West Coast are:

(1) To ensure a useful crop by correcting severe deficiencies. The application of P on gleyed and/or podzolised soils and B on some tailings falls into this category. In economic terms, fertiliser dressings should be considered as much a part of afforestation as planting the trees.

TABLE 7: SITE AMELIORATION PRESCRIPTIONS FOR WEST COAST EXOTIC FORESTS

		Remedial Action*		
Age	Monitoring Procedure	*Dissected Lowlands*	*Intermediate and High Terraces*	*Gold-dredge Tailings*
Pre-planting			Drainage	
Planting	Soil analyses	(14 g N + 16 g P/ha†)	9 g N + 14 g P/tree‡	6 g N + 10 g P/tree‡
1-2	—	—	—	6 g N + 10 g P/tree‡
3-4	Foliar analyses	(54 kg N + 60 kg P/ha†)	(25 g N + 40 g P/tree‡)	54 kg N + 60 kg P†/ha (3 kg B/ha)
1st and 2nd thinnings	Foliar analyses	(100 kg P + 200 kg N)	100 kg P/ha (200 kg N + K + Mg/ha)	(100 kg P + 200 kg N/ha§) (6 kg B/ha§)
3-yr intervals	Foliar analyses	—	as above	—
5-yr intervals	Foliar analyses	as above	—	as above

Explanations

*Parentheses indicate treatments that are not always required and which would usually be prescribed on the basis of the monitoring procedure

†Usually applied as diammonium phosphate.

‡Usually applied as a mixture of diammonium phosphate and serpentine-reverted superphosphate.

§These fertilisers should be applied as split dressings a year apart.

(2) To improve wood yields to meet short-term goals. This is necessary because of reduction in wood available from native forests. Nitrogen fertiliser can often be used to improve yields but cost-benefit analysis may be necessary to determine whether it is justified.

(3) To maintain productivity in the long term. Nutrients lost or removed from the site must be replaced, particularly where they are present in only limited quantities.

Fertiliser prescriptions to meet these objectives must take into account many factors. Natural fertility, physical and chemical limitations, and known responses from trials have already been discussed. In addition, it is important to plan for management objectives and silvicultural practices and to take account of fertiliser reactions in the soil, adverse features of the climate, the known nutrient-demand pattern of the species being grown, diseases, and the hydrology of sites.

Given sufficient information, it would be possible to evaluate alternative site amelioration practices using modelling and economic criteria. As yet, insufficient data are available to do this effectively. Thus present site amelioration prescriptions have been based on a broad knowledge of soils, fertilisers, and the growth of *P. radiata* (Table 7). It is assumed that most sites are planted in *P. radiata* grown on a pruning regime.

On the better sites such as lower terraces and terrace dropovers as well as some rollng country, yellow-brown earths occur which do not usually require ameliorative treatment. The dissected lowlands carry more leached and variable steepland yellow-brown earths. Ridges tend to have strongly leached soils with a less effective rooting depth. Fertiliser is beneficial in these situations not only to increase yields but also, particularly with regimes for board production, to achieve uniform stand growth. Clearwood yields which are obtained by pruning are very dependent on final tree size. Thus, slower growing parts of the stand may have to be felled too soon to benefit from this treatment (or, alternatively, rotation lengths may have to be increased) and so it is desirable to try to improve the growth rates of these less fertile areas. Foliage and soil analyses provide useful methods of delineating where and when fertiliser is required (Table 7). Physical limitatons such as soil slip erosion may in places limit the use of the soils of the dissected lowlands for exotic forestry.

Gleyed and/or podzolised soils on intermediate and high glacial outwash terraces are not usually erosion-prone, but under the high

West Coast rainfall have undergone intensive leaching, leaving them low in fertility. Repeated burning has also reduced N levels. Physical limitations of poor natural drainage and low pore space necessitate artificial drainage before planting, Fertilisers, particularly N and P, and sometimes K and Mg, are required. Treated correctly these terrace soils can be productive, although it is not known how windfirm trees will be in the long term. The flatness of the terraces gives the advantage of better access with lower maintenance costs. The soil properties and the high rainfall suggest that fertiliser movement may be rapid, particularly in topsoils, so slow-release fertilisers such as serpentine-reverted superphosphate are recommended (Table 7).

Dredge tailings, because of their coarse nature and a lack of both organic matter and interstitial fines, are also prone to leaching. They are very low in N, and often P and B are also required. Frequent small dressings are therefore advocated. The use of legumes, particularly those with low P demands, shows promise as a method of supplying N.

Methods of land preparation and the history of sites prior to planting to some extent determine later fertiliser requirements. Thus, soils directly converted to exotics from logged native forest, using fire to reduce the amount of slash, frequently show an ash-bed effect which temporarily increases the availability of nutrients (Adams and Mew, 1975). This may decrease the need for fertiliser at planting but probably not the long-term nutrient requirements. Burning does not increase the total amount of nutrients on the site — it may lead to a net loss and the ash-bed effect commonly disappears before mid-rotation. During soil surveys it was noted that where sites had been in scrub or rush and fern associations that had been frequently burnt, then the natural topsoil fertility was much lower than expected. Consequently greater amounts of fertiliser will be required on such areas for exotic tree growth to be successful.

The uptake pattern of the trees over the rotation also influences rates and timing of applications. Seedlings have relatively small demands for nutrients and so it is most efficient to apply small individual-tree dressings at planting. However, these initial applications are seldom adequate for a full rotation and additional fertiliser is often required at about age 3-4 years to meet the rapid increase in nutrient demand. Madgwick *et al.* (1977) have shown that periods of maximum demand in *P. radiata* plantations are related to canopy growth, and this is most rapid between ages 3 and 7 years and after thinning.

In the latter half of the rotation it is expected that fertilisers will not be required in large amounts, provided stands have been adequately treated up to that time, as nutrient demand is lower. However, fertilisers could be used with advantage on older, untreated stands, to meet short-term goals. Old nutrient-deficient stands of *P. radiata* are known to respond to fertiliser treatment (see Table 5, and Mead and Gadgil, 1978). In our prescriptions we therefore advise monitoring foliar nutrient levels at regular intervals in older stands. This is partly a precautionary measure as long-term trials have not continued beyond mid-rotation.

The concepts used in developing these fertiliser prescriptions may be used to advantage in other locations. To be successful such prescriptions must bring together soil survey data, tree nutrition research, and management goals. Thus, on the West Coast, information from soil surveys and foliar nutrient surveys has been used, first to recognise the main limiting factors, and secondly to identify where they occur, in terms of four broad categories. The fertiliser prescriptions incorporate all available information including that from fertiliser trials (local and national), studies of soil-fertiliser reactions, nutrient uptake patterns, etc. They also attempt to incorporate management requirements. Where needed, soil and foliar analyses have been prescribed as a tool to ensure efficient use of fertilisers. We do not see these regimes as unalterable; we consider they should be modified as results from future research, experience, and modelling procedures become available.

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