USE OF FERTILISERS AT ESTABLISHMENT OF EXOTIC FOREST PLANTATIONS IN NEW ZEALAND

R. BALLARD*

Forest Research Institute, New Zealand Forest Service, Rotorua

ABSTRACT

This paper reviews New Zealand research and experience with fertilisers at establishment of plantations of exotic tree species and outlines current management practice.

The first commercial use of fertilisers at establishment was made in the mid-1960s during planting of radiata pine on P-deficient clay soils. Currently **c.** 6000 ha of new plantings are fertilised annually. The main fertiliser elements are P, N and B. All are applied manually on an individual basis in order to minimise stimulation of competing vegetation. The most common practice is to place the fertiliser in a spade slit some 15 cm from the base of the seedling within 3 to 8 weeks after planting.

Phosphorus is applied to radiata pine at establishment mainly on weathered and leached clays and podsolised sands in the Auckland region and on strongly leached alluvial gravels in the Nelson region. With minor variations application rates are (as P) 17 g/seedling in the Auckland region and 6-10 g/seedling in the Nelson region. Most P is applied as superphosphate (8-10% P). Responses to P tend to be enhanced by site preparation methods involving weed control and deep soil cultivation. Spot applications of P at establishment are usually effective for only 3 to 4 years.

Nitrogen is applied at establishment of radiata pine on podsolised soils, skid sites where topsoil has been removed and on strongly leached alluvial gravels. The most common application rate is **c.** 15 g/seedling of N applied as urea, or diammonium phosphate where both N and P are required. Nitrogen is used in the establishment of **Eucalyptus** spp. on a range of sites with up to 30 g/seedling of N (as urea) being used. Establishment applications of N tend to be effective for only 1 to 2 years.

Boron is used to a limited extent in the establishment of radiata pine on strongly leached soils formed from alluvial gravels and granite in the Nelson region. It is usually applied in the form of boronated superphosphate to give 0.8 g/seedling of B. These applications are usually effective for only 3 to 4 years.

INTRODUCTION

Fertilisers have been used on a routine basis in some New Zealand exotic forests since the mid-1950s (Conway, 1962). During the first decade of commercial forest fertilisation operations the emphasis was placed on the fertilisation of established stands; principally the aerial application of superphosphate to P-deficient stands of *Pinus radiata*

---

* Present address: Department of Forestry, N.C. State University, NC27607, U.S.A.

N.Z. J. For. Sci. 8(1): 70-104 (1978).

D. Don on highly weathered clay soils in the Auckland region. However, it became apparent in the late 1950s, following establishment of the second crop on poor sites in both the Auckland and Nelson regions, that the growth rate of exotic pines could be seriously limited by nutritional deficiencies from time of planting. As large tracts of 1926-33 plantings began to be logged and re-established in the early 1960s the emphasis in the nutritional research programme shifted towards evaluating the use of fertilisers at establishment. As a result of this research, management operations started on a small scale in the Auckland and Nelson regions in the mid-1960s. The magnitude of these operations increased dramatically in the early 1970s, developing into a major programme which today involves several thousand hectares a year (Ballard, 1977a).

The main nutrient elements used in establishment applications are phosphorus (P), nitrogen (N) and boron (B). Although their use is not restricted exclusively to any particular region, most of the P is applied to weathered clay soils in the Auckland region, most of the N to rhyolitic-pumice soils in the Rotorua region (supporting *Eucalyptus* spp.), and most of the B to highly weathered soils formed from gravels and granite in the Nelson region (Ballard, 1977a; Will, 1978).

This paper reviews New Zealand experience and research on use of fertilisers at establishment of plantations, outlines current management practices and discusses likely future trends. For the sake of clarity each of the three main elements will be treated individually, although research developments were often linked and interactions between elements are common. Unless otherwise mentioned all work was carried out with radiata pine, the most important of New Zealand's exotic pines.

PHOSPHORUS

Auckland Region

One of the first major trials examining the use of fertilisers in exotic plantations was an establishment trial laid out in Riverhead Forest in 1951 (Mead and Weston, 1972). The trial was ambitious, examining species (*P. radiata, P. elliottii, P. taeda*), site preparation, and P fertiliser resources and methods of application, but because of a lack of adequate replication most differences in early years were not significant, and results from this trial had little influence on the development of fertiliser treatments. However the results are of interest because the trial is situated on one of the most P-deficient soil types in New Zealand (Waikare clay loam — Table 1) and illustrates three points (Table 2): over the first 4 years individual-tree applications produced as good a response as the heavier (per-hectare basis) broadcast applications; there was little difference in response between superphosphate and rock phosphate treatments up to 15 years after treatment, and none of the treatments maintained adequate foliar P concentrations for more than 7 years.

In the latter half of the 1950s an attempt was made to improve the establishment of radiata pine on P-deficient sites by puddling the roots of lifted stock in a mixture of 18 litres of mud and 0.45 kg of superphosphate. Although improved growth was reported on some soils, the method was abandoned because of excessive mortality associated with the treatment (St. John, 1961). Of greater practical significance was a pilot trial established in 1960 on a poor cutover site in Maramarua Forest in which 85 g of a 3 : 1 mix of superphosphate and ammonium sulphate was surface broadcast

TABLE 1—Chemical properties of particular soils commonly used for forestry in the Auckland region

Soil type	Parent material	Depth	pH	Total N	Bray 2 P	P retention	Exchangeable cations Ca	Mg	K	C.E.C.	Location
		(cm)		(%)	(ppm)	(%)	(me/100 g)				
Waikare clay loam	Sandstone	0-10	4.8	0.15	3	70	2.0	1.5	0.3	25	Riverhead S.F.
Marua clay loam	Greywacke	0-10	4.7	0.21	8	30	1.5	0.5	0.2	17	Glenbervie S.F.
Mangewheau clay loam	Argillite	0-10	5.1	0.15	3	20	1.5	1.5	0.2	—	Maramarua S.F.
Rangiuru clay loam	Andesite	0-10	5.1	0.24	2	55	3.0	4.0	0.4	16	Paerangaranga
Waitakere hill soil	Andesite	0-10	4.8		4	60					Whangapoua S.F.
Whangamata gravelly loam	Andesite	0-10	5.8	0.35	3	90	2.1	1.3	0.3	15	Tairua S.F.
Wharekohe silt loam	Greywacke	0-10	4.1	0.25	6	0	0.5	2.2	0.2	18	Whitecliffs
Te Kopuru sand	Sand	0-10	4.3	0.10	2	1	0.8	1.2	0.1	17	Waipoua S.F.
Pinaki sand	Sand	0-10	6.0	0.05	40	8	1.2	0.8	0.1	3	Woodhill S.F.

TABLE 2—Response of radiata pine to rock phosphate and superphosphate applied at time of planting on a Waikare clay loam (A144, Riverhead S.F.; Mead and Weston, 1972)

Treatment	Application rate	Height (cm) at age 4 y	Mean dbh (mm) at age 15 y	Foliar P (%)	
				7 yrs	15 yrs
Superphosphate	376 kg/ha	145 a	168 a	0.08	0.08
(9% P)	627 kg/ha	148 a	168 a	0.09	0.07
	57 g/tree	126 a	113 b	0.07	0.07
Rock phosphate	376 kg/ha	147 a	173 a	0.09	0.07
(16% P)	627 kg/ha	128 a	191 a	0.11	0.09
	57 g/tree	144 a	147 ab	0.09	0.08
Control		75 b	88 c	0.07	0.10

In each column of this and subsequent tables, values with the same alphabet suffix do not differ significantly at the 5% level.

round individual seedlings. A good response was obtained (Table 3) and this somewhat arbitrarily chosen rate and method of application was used in management operations until the mid-1960s in the Auckland region and to the present day in the Nelson region.

Although the limited areas fertilised with the 3 : 1 mix (less than 250 ha prior to 1968) had shown obvious benefits from the treatment some responses were disappointing and problems had occurred with stimulation of competing vegetation (Armitage, 1969). A number of trials were established to examine the effectiveness of different fertiliser sources, rates, timing and methods of application.

By 1968 interim results from many of these trials on P-deficient soils began to reveal a pronounced interaction between N and P fertilisers: N suppressed growth when applied alone or with small amounts of P, but produced a small response when applied

TABLE 3—Height growth of radiata pine seedlings treated 6 months after planting with 85 g/seedling of a 3 : 1 mix of superphosphate and ammonium sulphate (A241, Maramarua S.F.)

Treatment	Mean height increment (cm)			
	60/61	61/62	62/63	60/63
Control	6	16	26	48
3 : 1 mix	14	13	43	90

with larger amounts of P (Fig. 1; Table 4). Based on these interim results use of the 3 : 1 mix was dropped and an application of 112 g/seedling of superphosphate (11 g P), the highest application rate tested in the initial trials, was adopted for routine management applications. The small additional response indicated as likely from applying N fertiliser with this larger application of P was not considered sufficient to justify the use of expensive N fertilisers on the primarily P-deficient soils of the Auckland region (Armitage, 1969).

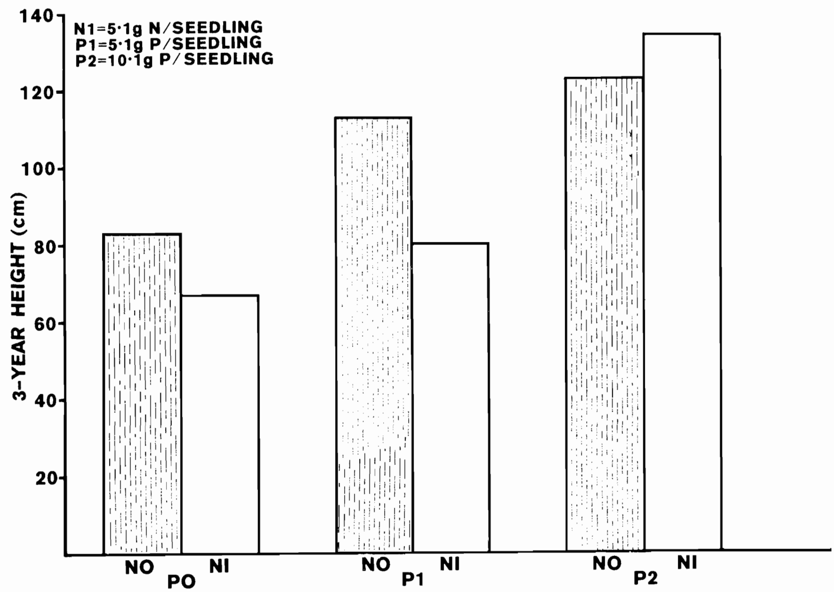


FIG. 1—Interaction of N and P fertilisers applied at establishment of radiata pine on a P deficient soil (A280, Maramarua S.F.).

TABLE 4—Response of radiata pine on a Waikare clay loam to N and P applied at time of planting in 1966 (A364, Riverhead S.F.)*

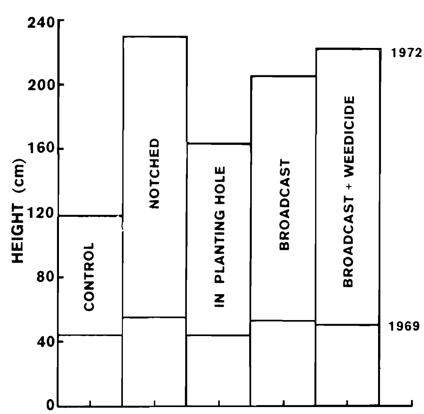
Treatment (per seedling)	Mean height (cm)		Foliar P (%)			
	1968	1970	1967	1968	1969	1970
Control	81 a	165 a	0.10	0.08	0.07	0.07
28 g superphosphate	85 a	195 b	0.12	0.10	0.07	0.07
56 g superphosphate	100 b	227 cd	0.12	0.11	0.07	0.07
112 g superphosphate	111 b	252 d	0.13	0.14	0.08	0.08
56 g superphosphate + 28 g ammonium sulphate	106 b	210 cb	0.12	0.10	0.07	0.07

* Data from Ballard, 1969a; 1971a.

All fertilisers applied at establishment in the Auckland region from the late 1960s to the present have been applied manually by the spade-notch method; placement of fertiliser in a slit made in the soil with a spade some 15 cm from the seedling. The adoption of this method was based on results (Fig. 2) from a trial examining different methods of placement (Ballard, 1969a), and on field experience which identified problems caused by weed competition and fertiliser loss in run-off where fertiliser had been broadcast on the soil surface around seedlings.

By 1970 response and foliar analysis data from the trials established in the mid-1960s indicated that even the highest application rate tested (112 g/seedling of superphosphate) was inadequate for optimum growth of radiata pine on the poorest sites — response to rates up to 112 g/seedling of superphosphate was essentially linear and foliar P concentrations, even at the highest rate, fell to marginal levels ($<0.12\%$) 3 years after fertiliser application (Table 4). At this time a soil testing service for identifying P-deficient sites was introduced for forestry (Ballard, 1971b) and on the basis of soil test results application rates of 0, 56, 112 or 172 g/seedling of superphosphate were applied. The top rate was chosen on the arbitrary basis that a rate greater than 112 g/seedling was required on the poorest sites. Trials were established at this stage to identify more precisely what the optimum application rates were for a range of sites.

The results from fertiliser trials and the introduction of a soil testing service gave management the confidence to considerably expand the programme of fertilising at establishment: between 1970 and 1976 the area fertilised annually in the Auckland region increased from 350 ha to over 4000 ha (Ballard, 1977a). This was despite the



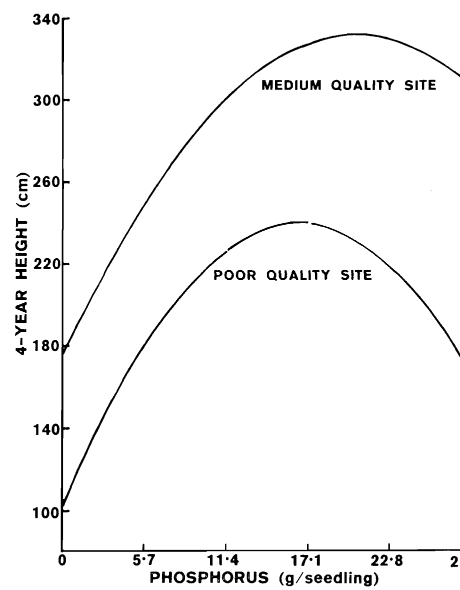


FIG. 2 (left)—Response of radiata pine on a Waikare clay loam to P (85 g superphosphate/seedling) applied by differnet methods (A285, Riverhead S.F.).

FIG. 3 (right)—Fitted quadratic response curves of radiata pine to increasing rates of P applied at establishment on poor and medium quality sites (A267, Riverhead S.F.).

rather limited range of sites for which trial results were available (most trials were concentrated on the poorest sites) and the rather coarse calibration of the soil test method (Ballard, 1971b).

Management practice in the Auckland region changed little between 1970 and 1976 except in 74/75 the previous maximum rate of 172 g superphosphate was adopted for all sites identified by soil analysis as responsive to P (less than 12 ppm Bray-2-extractable P in surface 10 cm). This move was based on two lines of evidence:

1. In nearly all the rates trials established in the late 1960s the optimum application rate worked out at *c.* 170 g/seedling of superphosphate, irrespective of site conditions, provided it was a responsive site. Types of response curves obtained are shown in Fig. 3 for medium and poor quality sites in Riverhead Forest (Ballard, 1975). These data vindicated the earlier arbitrary decision to use 172 g superphosphate as the highest rate. They also indicated that fertiliser treatment alone cannot always convert poor sites into good ones — which spawned a series of trials examining site preparation × fertiliser interactions (Ballard and Mead, 1976).
2. Work studies on fertiliser applications at establishment indicated that fertiliser costs were less than 50% of the total cost of the operation (Table 5). Since superphosphate is relatively cheap and labour and overhead costs are apparently little influenced by alteration in rates of application (Eversfield, 1974), it was felt that the insurance value of using the high rate on all responsive sites justified the small extra cost on those few sites which did not require it.

TABLE 5—Costs ($/ha) involved in applying 113 g/seedling of superphosphate soon after planting under easy and moderate to heavy slash conditions (from Eversfield, 1974)

Cost component	Riverhead Forest		Maramarua Forest	
	Easy	Mod-heavy	Easy	Mod-heavy
Overheads	4.44	4.44	6.07	6.07
Labour ($1.85/hr)	3.68	5.42	10.44	17.66
Fertiliser ($1.30/50 kg)	6.69	6.69	5.24	5.24
Total	14.81	16.55	21.75	28.97

Two aspects of fertilisation at establishment which have received only a moderate amount of attention are the effect of timing of application and the relative effectiveness of different P sources. Trial results have indicated that provided P is applied within the first growing season after planting, timing of the application has little effect on response over the next 3 to 4 years (Ballard, 1975). It is possible that timing may be more critical on sites exhibiting extremes of P-retention but in practice timing is dictated very much by availability of labour. In most areas the same labour is used for both planting and fertilising, the operations being done consecutively which means the fertiliser is usually applied 4-8 weeks after planting.

In most of the early fertiliser trials and management operations ordinary superphosphate (8-10% P) was used as the P source — being the principal P source used in agriculture, it was the most readily available and cheapest P source on the market. Because it appeared to give good rapid responses of reasonable duration on most sites and is available in a granulated form suitable for handling in management operations there was little incentive to examine alternative sources. In the few trials examining the effect of different P sources on seedling growth superphosphate has performed as well as or better than other sources on a unit P basis, and considerably better on a unit cost basis (Armitage, 1969; Knight and Will, 1971; Mead and Weston, 1972; Ballard, 1976). All these trials however were carried out on P-deficient clays with a medium to high P-retention capacity (which do represent the majority of our P-deficient forest soils); under these conditions the potential advantages of P fertilisers such as slowly soluble sources, are not fully realised. Trials have been established recently to examine the effectivness of calcined Christmas Island C grade rock phosphate (Calciphos) on sites of extremely low P-retention capacity. The only fertiliser to have shown a highly significant advantage over superphosphate on clay soils in the Auckland region is liquid ammonium polyphosphate (Table 6). Unfortunately this fertiliser is not available at a competitive price on the New Zealand market but new trials have been established to investigate more fully the advantages of polyphosphates and liquid fertilisers.

The research approach in the establishment field trial programme prior to 1973 was somewhat uncoordinated. Designs of trials, even those examining the same factors, tended to differ in terms of factor levels examined and degree of control of other variables. Also there was little attempt to replicate trials examining a particular factor over a range of site conditions — most trials were unique to one locality and even where they were replicated at other sites only a few sites were used, and these usually represented only the poorest sites. All these factors made it difficult to extrapolate trial results to the normal range of forest sites and also prevented results being used for effective calibration of diagnostic aids such as soil tests (Ballard, 1974). An appreciation of these limitations led, in 1973, to the establishment of a standardised design trial on a wide range of sites. The trial was designed to examine interactions between site preparation and N and P fertilisers and define N and P response curves (Ballard and Mead, 1976). Interim results from the initial series of this trial in the Auckland region have (1) confirmed that an application rate of *c.* 17 g/seedling of P is optimal for most P-responsive sites (Fig. 4 and 5; Ballard and Mead, 1976), (2) identified N-responsive sites (see later) and (3) showed that cultivation (deep ripping + weed control) considerably enhances the response to P. fertiliser on a range of sites (Fig. 4 and 5), although the effect is usually more pronounced on root-collar diameter than height (Fig. 4). The enhanced response on soils which do not respond to N, such as the Waikare clay loam (Fig. 4) appears to be associated with improved root growth resulting from shattering of typically structureless and compacted soils, while on N-responsive soils (Fig. 5) part of the enhanced response must be attributed to cultivation increasing the availability of indigenous soil N. Some form of soil cultivation, either deep ripping or bedding, is now being used on many P-responsive sites in the Auckland region (Berg, 1975).

Monitoring of P concentrations in foliage following fertiliser application has recently indicated two problems apparently associated with the spot application of

TABLE 6—Heights (cm) and root-collar diameters (mm) of radiata pine seedlings 2 years after treatment with liquid ammonium polyphosphate and superphosphate + urea at equivalent rates of N and P*

Treatment	Tairua Forest (A581)		Riverhead Forest (A541)	
	Height	Collar diam.	Height	Collar diam.
Control	132 a	33 a	72 a	17 a
Ammonium polyphosphate	205 b	53 b	151 b	41 b
Superphosphate + urea	154 c	38 c	131 b	34 c

* Data from Ballard (1976a), and Ballard and Mead (1976).

TABLE 7—Response of radiata pine seedlings on a Rosedale hill soil to P and B fertiliser applied at time of planting (N213, Waiwhero)*

Treatment (per seedling)	Mean height (cm) at age:		Die-back (incidence %)
	2 yrs	4 yrs	
Control	60	125	53
0.4 g B	53	105	23
0.3 g B + 8.5 g P	115	268	

* Data from Jacks and Keizer (1971).

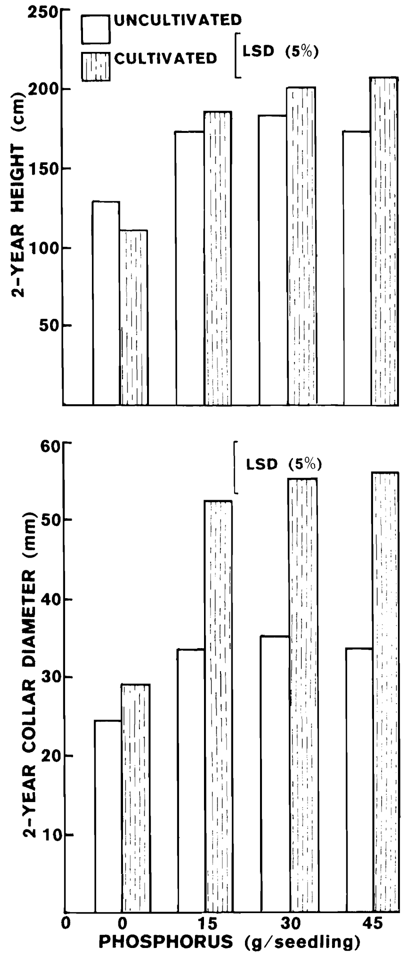


FIG. 4 (right)—Effect of cultivation and rates of P on height and root-collar diameter growth of radiata pine on a Waikare clay loam (A580, Riverhead S.F.).

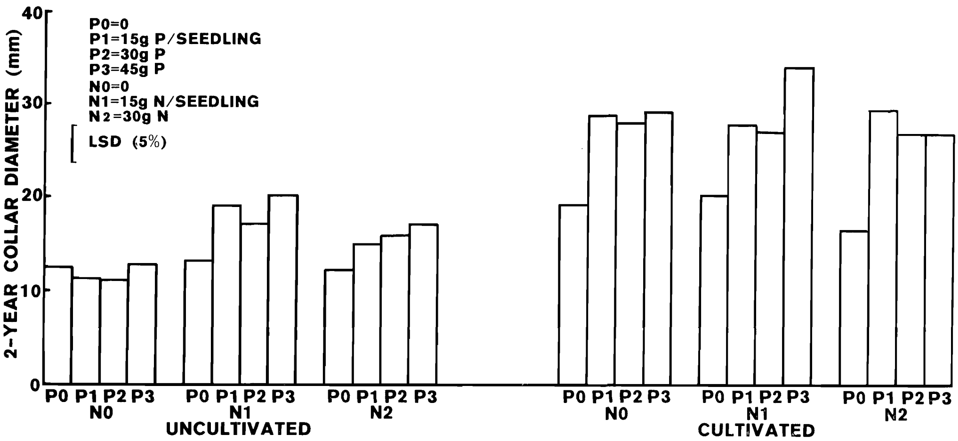


FIG. 5—Response of radiata pine on a Rangiuru clay loam to cultivation and N and P fertilisers applied at establishment (A578/A, Paerangaranga).

P fertiliser on highly P-retentive soils; (1) application rates above 17 g/seedling of P do not further increase P concentrations in the foliage, and (2) when trees enter their rapid growth phase (typically in the third year) foliar P concentrations drop dramatically at all application rates and even the highest application rates are apparently incapable of maintaining foliar P levels above the minimum (0.12% P) required for normal vigorous growth of radiata pine (Fig. 6; Ballard, 1975; Ballard and Mead, 1976). Where growth rates of radiata pine have been greatly accelerated by both cultivation and fertilisation foliar P levels have fallen to sub-optimal levels during the second year of growth even where fertiliser has been applied at up to 45 g/seedling of P (Ballard and Mead, 1976). Various reasons have been advanced to account for this rapid decline in foliar P including the reducing proportion of the active feeder roots in contact with the fertiliser-enriched zone as the root system expands (Ballard, 1975) and an interaction between water and mineral nutrient uptake — the concentration of fine roots in the fertiliser-enriched zone causes it to dry out more rapidly than the surrounding soil leaving the tree to rely on the unfertilised part of the solum for supplies of both moisture and nutrients (Humphries, 1977). In Australia, broadcast applications at establishment are advocated to overcome this problem (Humphreys, 1977), but because of the weed competition and run-off factors our approach has been to examine alternative methods of soil incorporation and/or to apply a subsequent aerial topdressing as soon as the young trees are above the competing vegetation.

Nelson Region

The Auckland experience created an awareness of nutritional problems and in the early 1960s the Forest Research Institute (FRI) was asked to investigate the slow growth of regeneration on deeply weathered and strongly leached soils formed from the Moutere gravels, and a disorder producing retarded growth and shoot die-back on soils formed from granite. Over the next four years a large number of simple fertiliser trials,

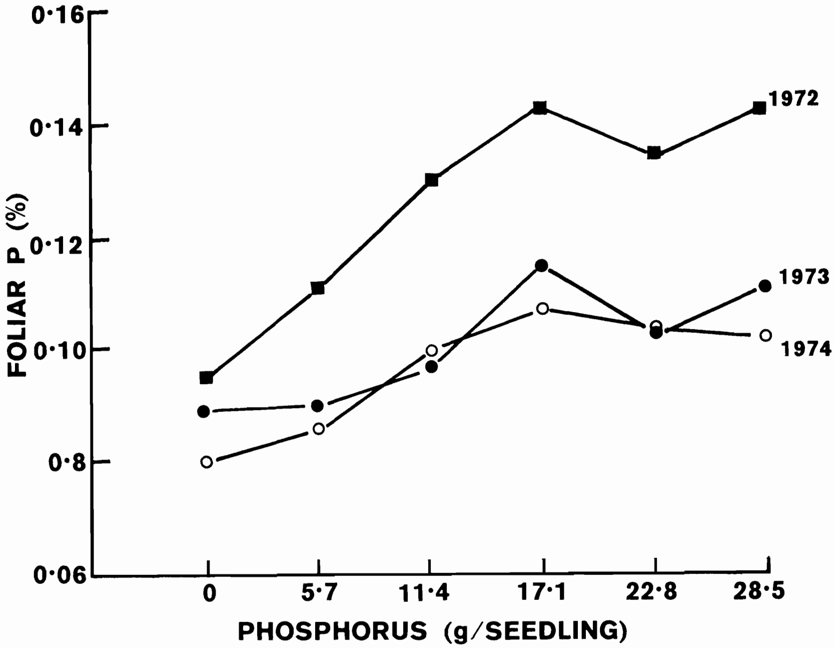


FIG. 6—Effect of spot applications of P fertilisers on P concentrations in foliage of radiata pine 2, 3 and 4 years after application on a Waikare clay loam (A287, Riverhead S.F.).

examining the effects of N, P, S, K, Mg and S in both existing stands and at time of planting, were established in a co-operative effort between private and State forestry groups in the region. These initial trials clearly established the existence of N, P and B deficiencies in the region (Stone and Will, 1965a, 1965b; Appleton and Slow, 1966; Jacks and Keizer, 1971).

Although rates, methods and timing of fertiliser applications were examined for N and B fertilisers in the initial series of trials, P tended to be included at a standard rate of 85 g/seedling of superphosphate or boronated superphosphate broadcast on the soil surface around the seedling.

Initial results, typified by data in Table 7, showed a good response from this application on many sites and roughly defined the P-responsive soils as the Mapua and Rosedale hill soils formed from Moutere gravels and the Kaiteriteri and Pokoroa hill soils formed from granite (Table 8).

Results from these early trials stimulated a very limited programme in the mid-1960s of fertilising seedlings with 85 g/seedling of boronated superphosphate (Appleton and Slow, 1966), but there was concern over the effect this application was having on the vigour of competing vegetation, in particular gorse (*Ulex europaeus*) a legume which often showed a dramatic response to P + B applications. However results from trials established in the mid-1960s to examine the competitive effect of gorse indicated that provided trees had access to the applied fertiliser their response to fertiliser was

TABLE 8—Chemical properties of soils commonly used for forestry in the Nelson region†

Soil type	Parent material	Depth	pH	Organic C	Total N	Citric P	Bray 2 P	C.E.C.	Exchangeable			Response to P*
									Ca	Mg	K	
		(cm)		— (%) —		— (ppm) —		—(me/100 g) —				
Mapua hill soil	Moutere gravel	0-8	5.0	2.0	0.09	10	2	8.6	6.9	0.5	0.2	3
Rosedale hill soil	Moutere gravel	0-5	4.8	4.8	0.21	10	3	16.3	2.8	1.4	0.4	2
Stanley hill soil	Moutere gravel	0-5	5.4	3.7	0.18	30	—	16.3	8.9	1.9	0.6	2
Spooner hill soil	Moutere gravel	0-8	5.5	3.2	0.17	60	17	18.8	6.5	2.1	0.3	1
Korere hill soil	Moutere gravel	0-10	5.0	2.8	0.15	30	—	18.4	2.1	1.3	0.5	1
Kaiteriteri hill soil	Granite	0-8	4.7	0.2	0.08	4	2	9.3	0.8	1.0	0.3	3
Pokororo steepland soil	Granite	0-15	5.3	3.5	0.10	10	2	12.0	2.5	1.0	0.7	2
Dun steepland soil	Serpentine	0-10	7.4	8.6	0.40	10	—	43.0	5.6	35.6	0.3	
Tahunanui sand	Sand	0-25	6.6	1.7	0.12	20	20	8.0	6.0	1.1	0.2	1

† Information extracted from Chittenden *et al.* (1966) and FRI records.

* Based on information in Jacks and Keizer (1971) and Jacks *et al.* (1972).

1 = infrequent response; 2 = variable response; 3 = frequent response

not unduly restricted by vigorous gorse growth and in some instances was actually enhanced by it (Table 9; Jacks *et al.,* 1972). Foliar analysis results from trial N230 (Table 9) showed concentrations of P in the foliage of fertilised trees to have almost fallen to that in the foliage of unfertilised trees only 3 years after fertilisation — a common phenomenon for both P and B in many Nelson and Auckland establishment trials (Jacks *et al.,* 1972).

TABLE 9—Response of radiata pine on a Mapua hill soil to gorse control and P + B fertiliser applied at planting in 1966 and again in 1970 (N230, Waiwhero; data from Jacks *et al.,* 1972)

Treatment	Mean height		Foliar analysis (1969)		
	1970	1973	N	P	B
	— (cm) —		— (%) —		(ppm)
Gorse control (g.c.)	103	401	1.60	0.08	15
No g.c.	108	368	1.63	0.07	14
g.c. + (P + B)*	264	801	1.38	0.08	31
No g.c. + (P + B)	243	688	1.55	0.09	24

* (8.5 g P + 1.1 g B)/seedling at establishment and (112 kg P + 8.8 kg B)/ha broadcast in 1970.

Because of the pilot-trial nature and restricted distribution of the early establishment trials in the Nelson region — the majority were located on the poorest sites — they failed to provide the necessary information required to give management the confidence to embark on large scale routine operations. As a result, between 1967 and 1973 only 20-100 ha/year of radiata pine were fertilised with P (as boronated superphosphate at 60-85 g/tree) at planting time, all of which was on Mapua hill soils, the most infertile soil type in the region. Some indication of the opportunity cost of not having applied fertiliser to radiata pine at establishment on other infertile soils in the region is illustrated by the response obtained in a trial established on a Rosedale hill soil in 1968 (Table 10).

In the late 1960s, several trials were established to quantify interaction of ground cultivation and fertiliser treatments. Of the cultivation methods examined — ripping, line-blading, discing, root raking; ripping (Jacks and Keizer, 1971; Jacks *et al.,* 1972) proved the most effective, often dramatically increasing the response to P + B fertilisers (Table 11).

Current practice in the Nelson region, insofar as P fertilisation at establishment is concerned, is still the application of 60-80 g/seedling of boronated superphosphate on only the worst sites: areas to be fertilised are selected on the basis of soil type with no use being made of soil analysis. Recent trials established in the region have been designed to examine the P-response curve on a range of sites which should help delineate more precisely the P-responsive soils and check the suitability of the current application rate.

TABLE 10—Response of radiata pine planted in 1968 on a Rosedale hill soil to N, P and B fertilisers (N193, Motueka S.F.)

Treatment*	Height at age 3 yrs (m)	Height at age 5 yrs (m)	Age 7 BA (m^2/ha)	Age 7 Volume (m^3/ha)
Control	0.92 a	2.1 a	4.09 a	12.88 a
B	1.00 a	2.3 a	4.32 a	14·36 a
N + B	0.89 a	2.1 a	4·00 a	13.59 a
P + B	1.64 b	4.0 b	12.66 b	52.49 b
N + P + B	2.03 c	4.5 b	13.82 b	58.40 b

Data from Mead **et al.** (1976).
* P broadcast at 100 kg P/ha in 1968.
B broadcast at 2 kg B/ha in 1968 and 4 kg B/ha in 1971.
N applied at 4 g N/seedling in 1968 and 13 g N/seedling in 1969.

TABLE 11—Response of radiata pine planted in 1968 on a Rosedale hill soil to site preparation and fertilisation (N195, Motueka S.F.)

Treatment*	Height at age 3 yrs (m)	Height at age 5 yrs (m)	Age 7 BA (m^2/ha)	Age 7 Volume (m^3/ha)	Foliar P Age 3 (%)	Foliar P Age 5 (%)
Control	1.3	2.2	4.60	15.79	0.10	0.07
Fert.	1.2	3.0	8.91	32.34	0.16	0.11
Rip	1.1	2.9	7.28	26.89	0.11	0.07
Rip + Fert.	1.7	4.4	13.25	56.74	0.17	0.10
Disc	1.0	2.7	6.57	22.62	0.12	0.08
Disc + Fert.	1.5	3.8	10.58	42.98	0.19	0.10
Rip + Disc	1.1	2.8	7.38	27.60	0.12	0.08
Rip + Disc + Fert.	1.6	4.2	13.59	55.68	0.18	0.11

Data from Mead **et al.** (1976).
*Fertiliser: (100 kg P + 2 kg B)/ha broadcast in 1968, B at 4 kg/ha broadcast in 1971.

Rotorua Region

Forests in the Rotorua region are grown principally on ash beds (almost all rhyolitic) deposited over the last 90 to 2000 years by a series of paroxysmal eruptions (Vucetich, 1960). Although several nutrient deficiencies limit their usefulness for agricultural purposes (During, 1972) exotic conifers grown on these soils generally do not suffer from any overt nutritional disorders.

Following logging of the first tree crop in Kaingaroa Forest difficulty was experienced in restocking skid sites which had been denuded of topsoil and badly compacted. Ripping to reduce compaction partially overcame the problem, but even this did not give growth rates equivalent to those in adjacent cutovers. In 1965 a trial was established to examine the possibility of boosting growth by using fertilisers on these sites; pot trials had demonstrated that many of the sub-surface layers of pumice soils in the Rotorua region were deficient in N, P and Mg for growth of radiata pine seedlings (Will and Knight, 1968). Results from this trial clearly indicated the benefits to be achieved from fertilising these sites (Table 12), but did not identify the limiting element(s) because N, P and Mg were applied in all fertiliser treatments. Although MagAmp, a slow-release magnesium ammonium phosphate fertiliser, gave a better response than a mix of conventional fertilisers, its use in practice was ruled out because of its high cost (Mead, 1968). A fertiliser treatment using a broadcast application of 100 g/seedling of ammoniated superphosphate (7-5.5-0) was adopted for routine fertilisation of skid sites.

Shortly after adoption of the practice of fertilising skid sites, the timing of the application was switched from soon after planting to the second spring after planting. Evidence from 19 sites in Kaingaroa Forest indicated (not statistically tested) that second-spring applications gave a superior response over the first three growing seasons to first-spring applications (Fig. 7). The difference was mainlv associated with the loss in effectiveness during the third growing season of the fertiliser applied in the first spring.

The current prescription for amelioration of skid sites in Kaingaroa Forest is (1) deep rip to a depth of 0.6 m at 7 m spacings and (2) fertilise in the second spring with 60 g of di-ammonium phosphate (DAP) placed in a spade slit 15 cm away from the root collar of each tree. The switch to DAP from ammoniated superphosphate was

TABLE 12—Response of radiata pine on a pumice soil skid site to ripping and fertiliser applied at planting, 3 years previously (R916, Kaingaroa S.F.)

Treatment/seedling	Ripped		Unripped	
	Height (cm)	Survival (%)	Height (cm)	Survival (%)
1. Control	88	97	34	65
2. 5.2 g N + 10 g P + 4.5 g Mg	135	95	102	67
3. As per 2, but placed in a perforated plastic bag	133	95	79	49
4. 4.5 g N + 9.5 g B + 7.9 g Mg	168	92	124	79
5. 9 g N + 19 g P + 15.8 g Mg	180	94	145	84

Data from Mead (1968).
Treatments 2 and 3 applied as urea, superphosphate and epsom salts, treatments 4 and 5 applied as MagAmp (8-17-0-14).

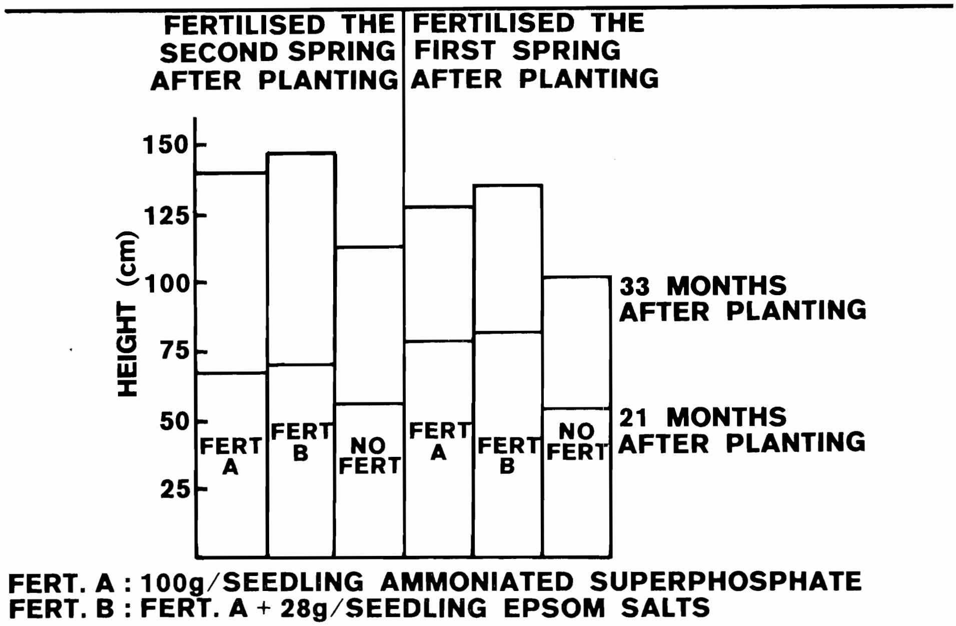


FIG. 7—Response of radiata pine on pumice skid sites to ammoniated superphosphate applied in either the first or second spring after planting (Kaingaroa S.F.).

based on the superior performance of DAP in trials examining N sources on skid sites (Ballard, 1976). The change to placing the fertiliser in a spade slit rather than broadcasting it on the surface was brought about following observation of considerable surface wash and irregular growth on some skid sites (D. A. Elliott, pers. comm.). There has been insufficient time to determine whether this treatment is achieving the objective of producing and maintaining growth rates equivalent to those in normal cutovers.

In 1972-73 fertiliser trials at establishment of radiata pine on pumice soils were extended onto normal cutover sites. Trials in Kaingaroa Forest examining a range of N + P fertilisers and N × P × Mg interactions revealed no significant response to P and N × P interactions (R. C. Woollons, pers. comm.). In these trials carefully graded, hand-lifted 1/0 radiata seedlings have been planted in cultivated, weed-free plots protected from noxious animals. Responses to P alone have been transitory typically fading to non-significance by the end of the second growth season, but when applied in conjunction with N, P has usually given an additional and sustained response (Fig. 8). Because of uncertainty over the extent to which experimentally obtained responses would be realised in routine operations and difficulties in placing an economic value on early responses, results from these trials have not yet led to any routine applications of P fertiliser.

Other than on skid sites, the only routine use made of phosphatic fertilisers at establishment is by the Fletcher Timber Co. Ltd. They routinely apply boronated

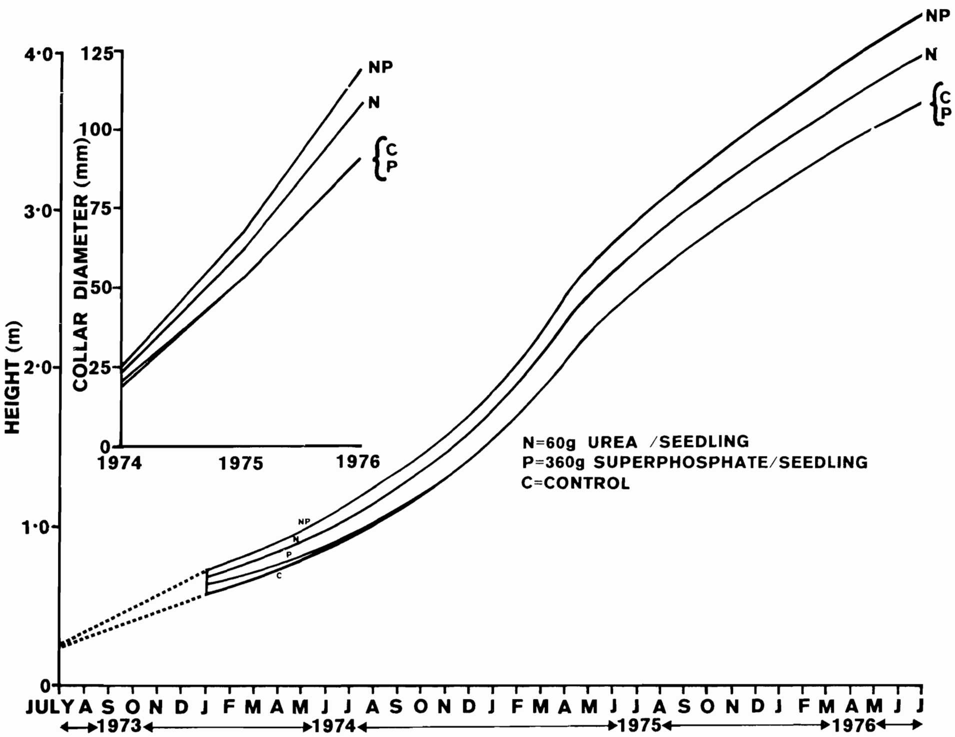


FIG. 8—Response of radiata pine on a pumice soil to N and P fertiliser applied at establishment (Mustang Rd, N.Z.F.P. Ltd).

serpentine superphosphate at 100 g/seedling to all new land plantings. Most of this new land is at relatively high altitudes (*c.* 600 m) and requires ripping because of a fairly shallow compacted pan, and on such sites it is felt (D. Evans, pers. comm.) that the serpentine superphosphate promotes early root development and reduces the hazard from frost damage and seasonal drought. In this context it is of interest to note that experience in Kaingaroa Forest with mixed fertilisers containing N, P, K and Mg has indicated that application of such a mix increases the degree of frost damage incurred by young radiata pine seedlings on hard sites (Brunsden, 1971).

Other Regions

Some of the earliest investigational work with fertilisers at establishment was done in Westland. During the 1950s trial plantings, involving a number of species, site preparation techniques and fertiliser treatments, were established on the "pakihi" terrace (relic podsol-gleys) soils (Washbourn, 1972). These, and later trials on the same soils, demonstrated the need for drainage and N + P fertilisers to obtain reasonable growth of exotic pines on these difficult soils. Typical results are illustrated in Table 13 and further details can be found in Washbourn (1972) and Clyne (1975).

Because of the intractable nature of these soils and the availability of more suitable

TABLE 13—Response of radiata pine on a "pakihi" soil to drainage and fertilisers (WD109, Craigieburn)

Fertiliser treatment	Height (m) at age 6 years Mound	Flat
Control	2.172 (± 0.113)*	1.386 (± 0.113)
Rock phosphate (60 kg/ha P)	2.862 (± 0.148)	2.188 (± 0.122)
Superphosphate + Blood and bone (21 kg P + 8 kg N)/ha	3.872 (± 0.159)	3.233 (± 0.196)
Super + Blood and bone + potash (28 kg P + 10 kg N + 28 kg K)/ha	3.754 (± 0.129)	2.411 (± 0.146)

Data from Washbourn (1972).
* ± standard error of the mean.

soils in the region for forestry use they were not used for forestry purposes until very recently. The current fertiliser prescription for plantings on these "pakihi" soils is an application of 107 g/seedling of a mixture of DAP and reverted superphosphate to give 15 g P + 10 g N. This mixture is designed to give an immediately available source (DAP) and a more slowly available one (reverted super) which is considered expedient as these soils have a negligible P-retention capacity in surface horizons.

Phosphorus fertilisers are not used on a routine basis at establishment in any other regions (Wellington, Canterbury, Southland).

NITROGEN

Auckland Region

Eucalyptus spp. Fertiliser trials with eucalypts were carried out in Athenree Forest as far back as the 1930s (St. John, 1961) but records of these early trials were lost. In the late 1950s the possibility of using eucalypts as an alternative to pines on infertile sites in the Auckland region was examined in a series of establishment trials (Bunn, 1961). Incorporated in these trials were fertiliser treatments using individual tree applications of blood and bone, and dried blood (fertiliser sources commonly used on eucalypts in Australia at that time) which were designed to overcome the early growth stagnation eucalypts usually exhibited on these poor sites. Results from these trials showed the benefit of N + P applications, and the apparent optimisation of early growth at the 28 g/tree application rate of blood and bone (Table 14).

TABLE 14—Response of **E. delegatensis** at Tairua Forest to organic fertilisers applied at planting in 1960

Fertiliser	Application rate g/seedling	Height increment (cm) 62/63	Mortality (%)
Control	—	35	8
Dried blood (13-0-0)	28	58	—
Blood and bone (7-6-0)	28	85	19
	56	85	26
	84	74	40

Data from Moberly **et al.** (1975).

Because of the successful correction of P deficiency in radiata pine, large scale plantings of eucalypts were not undertaken in the Auckland region. However, the application of blood and bone at planting was a frequent practice in the limited management plantings of eucalypts on a range of sites throughout New Zealand during the 1960s and early 1970s.

Pinus radiata. Experience with use of N fertilisers on P-deficient clay soils in the Auckland region was outlined earlier in the discussion on the N × P interaction. Briefly, trial results indicated that responses to N could be achieved only after correcting the P deficiency (Ballard, 1969a). However, because the N response achieved in trials tended to be small, of short duration and to vary markedly between similar sites (Ballard, 1975) management has not accepted the principle of applying N fertilisers at establishment of radiata pine on clay soils.

Recent results from the N × P × Cultivation standardised design trials have indicated that there are certain soil types in Auckland region which are highly responsive to N and on which no appreciable response to P is obtained unless N is added. A summary of the main effects of N (over P and cultivation treatments) on root-collar diameter and mortality for the first five of these trials in the Auckland region show quite clearly the distinction between clay soils and podsolised sands in terms of N responsiveness (Table 15). Detailed results from one of these trials (Fig. 9) illustrate the need for fertilisers and cultivation to obtain maximum growth on these podsolised sands which in most cases suffer from poor drainage and possess low total N levels in the topsoil (Table 1) due to loss of the O horizon caused by fires and erosion. Based on these trial results, (15 g N + 15 g P)/seedling are applied at establishment on these podsolised soils. The fertiliser is applied either as a superphosphate/urea mix or as DAP which has an appropriate N : P ratio.

TABLE 15—Main effects of N fertiliser on root-collar diameter, mortality and foliar N of radiata pine 2 years after fertiliser application on clay soils and podsolised sands in the Auckland region

Soil type	Collar diameter (mm)			Mortality (%)			Foliar N (%)		
	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2
1. Clay soils									
Whangamata gravelly loam	38.5	38.4	37.7 NS	7.2	9.4	6.9 NS	1.80	1.82	1.83
Waikare clay loam	38.6	41.6	40.7 NS	5.3	9.4	16.9 **	1.77	1.77	1.66
Rangiuru clay loam	19.2	22.5	20.2 NS	31.3	40.9	43.8 *	1.52	1.51	1.52
2. Podsolised sands									
Ohia sand	25.0	29.0	28.0 **	7.8	14.1	19.1 **	1.68	1.64	1.62
Te Hapua sand	14.0	19.1	20.2 **	23.3	31.3	35.0 *	1.54	1.58	1.55

Data from Ballard and Mead (1976).
N_1 = 15 g/seedling of N applied as urea in a spade slit; N_2 = 30 g/seedling of N.
** Main effect of N significant at the 1% level.
* Main effect of N significant at the 5% level.

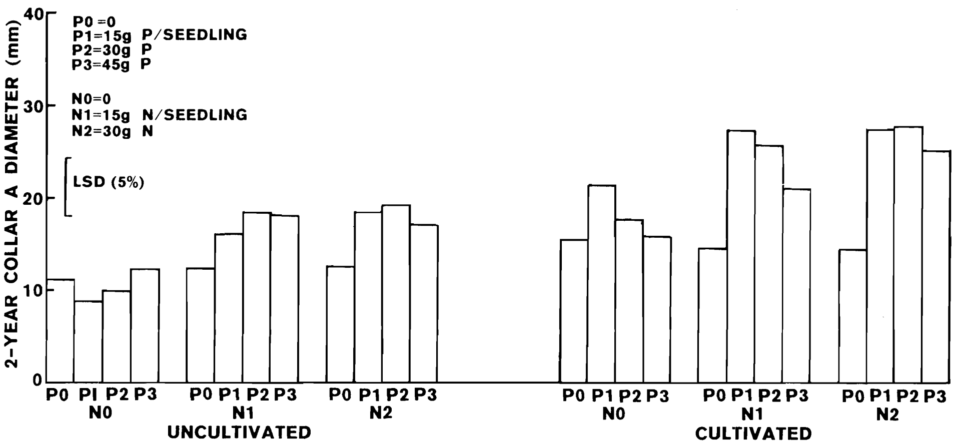


FIG. 9—Illustration of the need for N fertiliser and cultivation to maximise response of radiata pine to P fertiliser on a podsolised Te Hapua sand (A578, Paerangaranga).

Although the use of N fertilisers at establishment has been accepted as necessary to obtain reasonable initial growth on certain soils, there are still some problems with its use. The duration of the response is unknown, but analysis of foliage collected from the above five trials in March of the second growing season showed N concentrations in foliage of fertilised trees to be no higher than that in foliage of control trees (Table 15) which suggests the response may be relatively brief. Increased mortality could be another problem associated with the routine use of urea. Under trial conditions where care is taken to place the fertiliser exactly 15 cm from the seedling base, mortalities have been increased by 10-15% by adding *c.* 60 g urea/seedling (Table 15; Ballard, 1976). In routine operations where emphasis is placed (mistakenly?) on speed there is a likelihood of greater increases in mortality from applications inadvertently placed too close to seedlings. Trials on clay soils with slow-release N fertilisers, such as urea formaldehydes and sulphur-coated urea, have shown that mortality, particularly at higher application rates, can be avoided by using such fertilisers (Ballard, 1976). However, response and foliar analysis data from the same trials indicated that this was the only advantage these fertilisers have over urea, and it was not considered sufficient to justify the routine use of these much more expensive fertilisers.

In the Auckland region almost 50% of the annual planting is done on recently stabilised coastal sands, which being such immature soils should theoretically be N responsive. However, lupins (*Lupinus arboreus*) used in stabilisation appear to fix sufficient N in the ecosystem for the N requirements of radiata pine during the first 4-5 years of growth (Gadgil, 1976); this does away with the need for establishment applications of N. The transition of these coastal-sand sites from non-responsive for young seedlings to N-responsive as the pine stand develops and inter-tree competition becomes important is illustrated in Table 16.

Nelson Region

At the outset of the nutritional investigations in the Nelson region it was apparent, from chlorotic foliage, that N should be one of the first elements examined. Trials

TABLE 16—Response of radiata pine planted on a deep coastal sand to N fertiliser (A287, Woodhill S.F.)

Treatment*	Height (cm)	Basal area (m^2/ha)				
	2 yrs	3 yrs	4 yrs	5 yrs	6 yrs	7 yrs
Lupin	115.2	0.34	1.88	5.15	8.37	11.34
Lupin + fertiliser	115.8	0.23	1.57	5.02	9.46	13.07

Data from D. S. Jackson (Forest Research Institute (1976).

* Lupin allowed to develop naturally in both treatments. Fertiliser treatment included 56 kg/ha of N broadcast applied twice a year since establishment.

established during the 1960s conclusively demonstrated the responsiveness to N of established stands on a range of sites (Stone and Will, 1965a; Appleton and Slow, 1966; Jacks and Keizer, 1971; Mead, 1976) but for several reasons the results from applying N at establishment were not as clear-cut. Isolation of the effects of N on growth in many of the early trials was made difficult by inadequacies in design (confounding N effects with other element effects), weed competition and high mortality. Even where N effects could be identified responses were extremely variable with N sometimes suppressing growth (e.g. N215, Jacks and Keizer, 1971), sometimes having little effect (N193, Table 10), and occasionally giving a response by itself (N222) or when applied in conjunction with P (N223). Because there was a lack of association between N-response behaviour and any site characteristics and because of problems with mortality and weed stimulation, management did not use any N fertiliser at establishment during the 1960s and early 1970s.

Trials examining placement methods indicated the sensitivity of seedlings to damage from soluble N fertilisers applied too close to their root systems at time of planting (Table 17). Later trials showed that mortality, particularly that associated with higher application rates, could be reduced by delaying applications 6 to 12 months after planting (N275, Jacks and Fitzgerald, 1971).

TABLE 17—Effect of N fertiliser placement on mortality of radiata pine 1 year after application (N141/6, Motueka S.F.)

Fertiliser	Application g/tree	Placement method: In planting hole	In scrape 8-10 cm uphill of tree	In scrape 8-10 cm beside tree
		(mortality %)		
Control	—	5	5	5
Urea (46% N)	14	45	0	0
	56	95	40	0
Uramite (34% N)	14	25	5	10
	56	95	0	7
Ammonium sulphate (21%N)	28	55	0	0

Data from Jacks and Keizer (1971).

A series of trials established in 1969/70 to examine the effect of rates and timing of N applications showed that (1) responses to N could be obtained on a number of sites when applied in conjunction with P and B, (2) earlier applications tended to give the better response although they were associated with higher mortality, and (3) application rates greater than 28 g/tree of urea gave no marked additional benefit. These effects are illustrated by results from one of these trials in Table 18, results of the others (N266 and N276) can be found in Jacks and Fitzgerald (1971), and Jacks *et al.* (1972).

TABLE 18—Effect of rates and timing of application of N fertiliser on height (cm) of 3-year-old radiata pine (N275, Pigeon Valley)

Fertiliser* treatment/tree	Time of application At planting	6 months	12 months	Mean
28 g urea	213	204	198	205
57 g urea	192	186	173	184
115 g urea	232	189	168	196
Mean	212	193	180	
Control	171			

Data from Jacks and Fitzgerald (1971) and FRI files.
* All treatments, including control, received 85 g/tree superphosphate at planting, and 0.8 g/tree of B was applied with each N application. All fertiliser applied to the soil 10-15 cm from the base of the tree.

Although management is still concerned with the economics of applying N fertiliser at establishment, particularly in view of the short duration of the response to the relatively small quantities applied (see Mead *et al.*, 1976), limited use has been made of N fertilisers at establishment of radiata pine on Mapua hill soils (the most infertile of the soils formed from Moutere gravels) since 1974. The current prescription for these soils is 25 g urea + 60 g boronated superphosphate per seedling applied to the soil surface approximately 15 cm from the tree some 2 months after planting.

Several attempts have been made in the Nelson region to establish legumes on forest sites in the hope that they would alleviate the N problem as lupins have done so effectively on coastal sands. Trials with clovers, acacia, annual and perennial lupins, and also alder, have been largely unsuccessful. Where successful establishment was obtained by using large applications of P, K, B and Mo fertilisers the plants were invariably suppressed after 2-3 years by fertiliser-invigorated gorse (Jacks and Keizer, 1971; Jacks and Fitzgerald, 1971). Gorse is a legume and evidence from some trials suggests that trees growing in, but not suppressed by, fertilised (P + B) gorse have a higher growth rate and a higher N content in the foliage (Table 19). However, because of the chance of fertiliser-invigorated gorse suppressing growth of young trees and the restriction it places on access for silvicultural operations, its growth is not encouraged, although it does have some advocates (*see* Chavasse, 1976).

TABLE 19—Response of radiata pine on a Rosedale hill soil to N, P, K and B in the presence and absence of gorse (N149/1, Motueka S.F.)

Treatment*	Height (cm) at age			Basal area (m^2/ha)	Foliar N (%)		
	1 yr	2 yrs	6 yrs	7 yrs	5 yrs	6 yrs	7 yrs
Cleared + PKB	24	168	360	7.48	1.23	1.35	1.12
Cleared + NPKB	24	162	320	6.37	1.22	1.18	1.05
Gorse + PKB	24	235	524	11.83	1.48	1.38	1.48
Gorse + NPKB	24	189	408	7.54	1.38	1.39	1.25

Data from Jacks **et al.** (1972).
* Fertiliser broadcast at establishment, 75 kg/ha N, 56 kg/ha P, 50 kg/ha K, 1.1 kg/ha B.

Rotorua Region

Eucalyptus spp. The need to apply N to obtain satisfactory establishment and early growth of eucalypts on a range of sites was clearly established in a series of trials laid out in the early 1960s (as discussed earlier). The basic fertiliser prescription of 28 g/seedling of blood and bone established in these trials was used throughout the 1960s and early 1970s. Attempts to use more concentrated forms of N such as urea were initially unsuccessful due to excessive mortality (Franklin, 1971; Moberley *et al.*, 1975) — almost certainly due to placement of the urea too close to the stem.

More intensive trials examining methods and rates of urea application were initiated by N.Z. Forest Products Limited (NZFP), and the FRI in 1972. Results indicated that the mortality problem associated with use of urea could be avoided provided the urea was applied no closer than 15 cm from the seedling stem (Table 20). A number of establishment trials showed that on average the optimum application rate for first year

TABLE 20—First year height response and survival of **E. delegatensis** following application of urea at different rates and intervals after planting (Cpt 905, Kaingaroa S.F.)

Treatment*	Increment (cm)	Survival (%)	Unhealthy (%)
Control	31.8	100.0	20.0
28.3 g in slot at time of planting	56.8	90.0	0
56.6 g in slot at time of planting	50.0	85.0	0
28.3 g in slot 3 months after planting	55.5	95.0	10.0
56.6 g in slot 3 months after planting	64.1	85.0	0
28.3 g in circle 3 months after planting	66.2	95.0	2.5
28.3 g in slot 6 months after planting	37.9	92.5	15.0
56.6 g in slot 6 months after planting	37.1	97.5	10.0
56.6 g in circle 6 months after planting	46.8	85.0	25.0

Data from Moberly **et al.** (1975).
* Urea fertiliser applied 15 cm from base of stem.

response was in the vicinity of 57 g/tree of urea (Fig. 10). Subsequent data from these rates trials showed that although differences between treatments remained significant over the next 4 years, there was no further significant divergence between treatments after the first year (G. Fry, pers. comm.). It was however found that further responses could be achieved by re-applying N fertiliser at the beginning of the third and fourth growing seasons, although these responses got successively smaller and, like the application at planting, appeared only to give a 1-year boost in growth (Fig. 11). Re-application of fertiliser during the first growing season was found not to provide any further growth response (Moberly *et al.,* 1975; G. Fry, pers. comm.).

On the basis of these trial results the general establishment fertiliser prescription for eucalypts has evolved from 28 g blood and bone to 60 g/seedling of urea. NZFP, who have greatly expanded their plantings of eucalypts currently prescribe an application of 60 g/seedling of urea at planting (applied in a slit 15 cm from the tree) followed by an aerial application of 250 kg/ha urea at the beginning of the second growing season. They started routine applications in 1972 and in 1976 fertilised some 800 ha. In a trial examining the interaction of weed control and fertilisation on the growth of *E. regnans,* NZFP found that weed control is necessary to obtain the full benefits of fertilisation (Table 21), a well documented phenomenon for other species and localities (Waring, 1971; Revell and Deadman, 1976).

Pinus radiata. The current prescription for the treatment of pumice skid sites with N and P fertilisers was given earlier. A major concern with the use of N on these and other sites has been with the short-term effectiveness of the N fertilisers used; in practically no establishment trials has N fertiliser been able to maintain foliar N levels above those in control plots for more than one to two growth seasons (Ballard, 1976; Ballard and Mead, 1976). Attempts to improve the long-term effectiveness of N applications at establishment have to date been directed principally at trying out slow-release N fertilisers. However in several trials on pumice skid sites and on clay soils slow-release N fertilisers have proved to be no more effective in terms of response or in maintaining foliar N levels than conventional ammoniacal sources (Ballard, 1969b; Mead, Ballard and Mackenzie, 1975; Ballard, 1976). Nitrogen sources encompassing

TABLE 21—Response of **E. regnans** to weedicide and fertiliser treatments

Treatment*	Age 2 yrs	
	Height (m)	Diameter (mm) at 1 m
Control	4.32	49.0
Weedicide	4.75	59.0
Fertiliser	5.34	68.6
Weedicide plus fertiliser	5.60	78.9

Data from Moberly **et al.** (1975).

* Weedicide — post planting application of simazine at 6.7 kg/ha fertiliser — at planting fertiliser treatments received 60 g/seedling of urea. At the beginning of the second growing season **all** treatments received 375 kg/ha of urea.

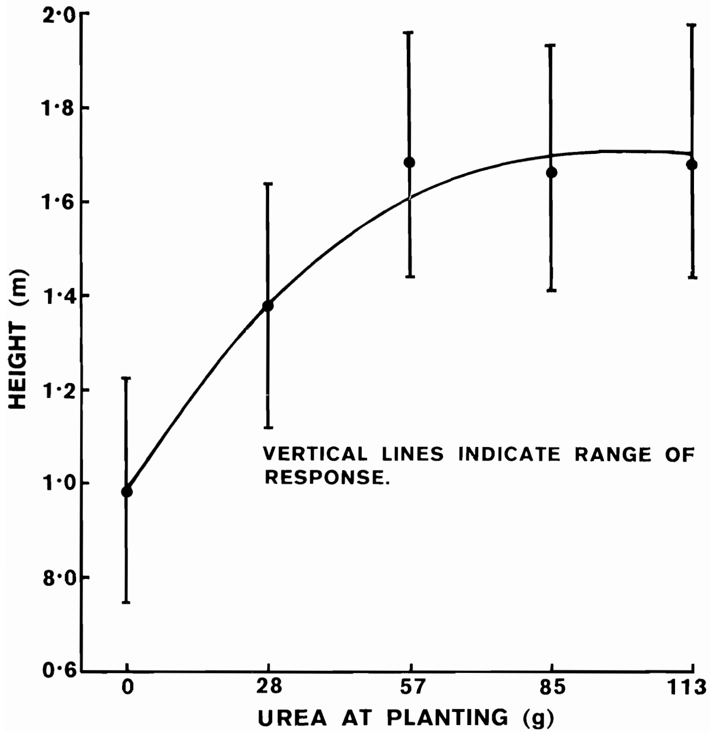


FIG. 10—Average N-response curve, 1 year after fertilising, for a number of establishment trials with **E. regnans** on pumice soils (G. Fry, pers. comm.).

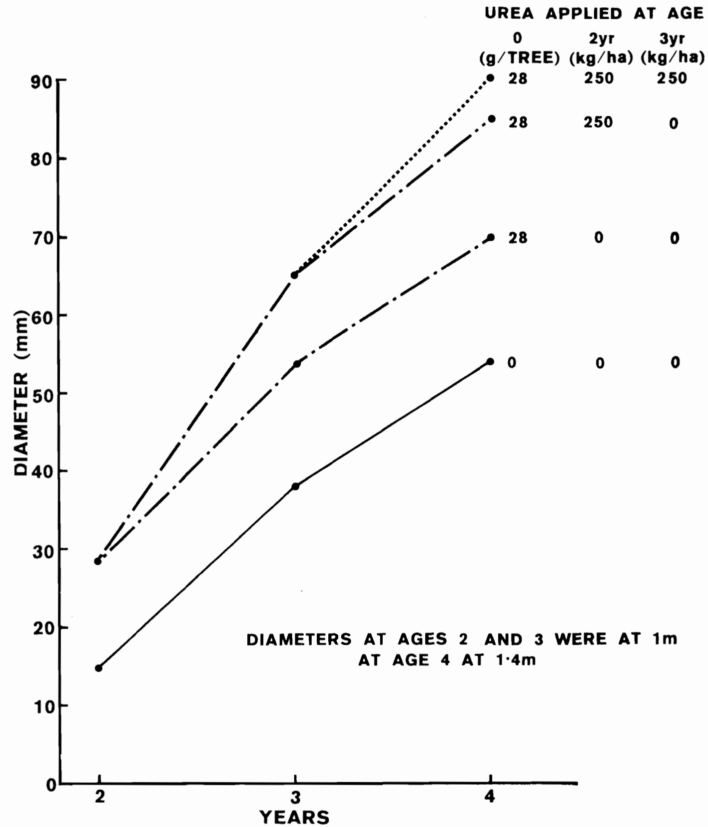


FIG. 11—Response of **E. regnans** on a pumice soil to various frequencies of N application (G. Fry, pers. comm.).

all the techniques of controlling release — coarse granulation, water-insoluble inorganic N compounds, organic N polymers, microbial inhibitors and coated pellets — were examined. The only apparent practical advantage these slow release sources have is that high application rates can be used without fear of excess mortality — an advantage which is not sufficient to justify their much higher cost. One point clearly established by these N-source trials is that, on the soils examined at least, ammoniacal N fertilisers are much more effective than nitrate sources (Ballard, 1976a).

Fertiliser trials with N on normal cutover or new land pumice sites have shown that significant responses to N can be achieved. In Kaingaroa Forest growth advantages of 30-50 cm in height and 7-8 mm in collar diameter have been achieved over three growing seasons following the application of 22 g/seedling of urea (Ballard, 1976a). N.Z. Forest Products Limited have produced an additional 27 cm in height and 14 mm in collar diameter over 3 years from the application of 60 g/seedling of urea in carefully controlled trials (Fig. 8). Current trials are examing the question of optimum rates — interim results from one trial indicate that although 15 g urea gives almost as good a response over 2 years as 60 g urea, in the second year the higher application rate starts to show an advantage which it is anticipated may further increase with time (Table 22).

TABLE 22—Response of radiata pine on a pumice soil to different rates of N applied at establishment (Cortina Rd, N.Z. Forest Products Limited)

Urea application g/tree	Collar diameter (mm) 1 yr	2 yrs	Increment
0	19.6	49.0	29.4
15	21.5	52.1	30.8
30	22.7	53.4	30.7
60	21.9	54.8	33.1

Data from R. C. Woollons (pers. comm.).

The N fertilisation of radiata pine at establishment on normal pumice sites has not been accepted yet as a viable management practice. However, management has recently used N fertilisers in two situations where a component of the crop needed a boost to produce a more even overall crop. Urea at 60 g/tree has been applied to blanking stock in Kaingaroa Forest in an attempt to boost their development up to that of the main crop. Where *E. delegatensis* has been planted adjacent to windrows in radiata pine compartments in Kaingaroa Forest the growth advantage of the eucalypts has been such that gross branch development has occurred. In an attempt to boost the growth of the radiata pine and so avoid the need to prune, which can result in heart rot in *E. delegatensis,* the radiata pine component has been fertilised with urea at 60 g/tree. The success of these two operations will largely dictate future practice in these situations.

Other Regions

Nitrogen fertilisers are not used in any other regions of New Zealand at the establishment of exotic conifer plantations. However, several of the standardised design

N × P × Cultivation trials have recently been established in the Wellington, Canterbury, Westland and Southland regions which should give an indication of the potential of N fertilisers on a wider range of soil types. Interim results from some of these trials indicate that responses to N can be obtained on most sites although it is too early to determine the exact magnitude and duration of the responses.

Nitrogen fertilisers are routinely used in the establishment of poplars on wet sites in the Canterbury region. The standard application is 230 g/tree of sulphate of ammonia applied in a 50 cm circle around the tree. Good responses have also been obtained from applying fertiliser at the establishment of poplars in Esk S.F. (Table 23).

TABLE 23—Response of poplars at Esk S.F. to weedicide and fertiliser treatment

Treatment*	3 yr height increment (m)	
	Poplar I 30	Poplar I 78
Control	0.37	0.89
Fertiliser	1.05	1.65
Weedicide	1.76	2.10
Fertiliser + weedicide	2.22	3.0
L.S.D. (5'%)	± 0.82	± 1.02

Data from Revell and Deadman (1976).
* 375 g/tree of 12-10-10 fertiliser at planting and at the beginning of the second growth season.

BORON

Nelson Region

A boron deficiency was identified in the early 1960s as the cause of shoot die-back observed on many soils in the Nelson region (Stone and Will, 1965b; Appleton and Slow, 1966). The most deficient areas are on soils formed from granite where tree growth can be completely stunted by shoot die-back in successive years. The incidence of die-back is much lower on soils formed from Moutere gravels but can be quite pronounced on the more weathered members, particularly where erosion had removed topsoil.

Fertiliser trials with B were established concurrently and often in conjunction with those examining N and P. Thus in common with the early N and P trials they were generally poorly designed with little attempt at replication either within or over different sites. Nevertheless, results from these early trials did have a significant effect on subsequent practice. They showed (Jacks and Keizer, 1971; Jacks and Fitzgerald, 1971):

1. Die-back could be alleviated by applying boron fertiliser.
2. Boron fertilisers could be placed in the planting hole or applied at high rates close to the stem without producing excessive mortality (Table 24).
3. It was difficult to introduce sufficient B into seedlings in the nursery to provide protection from die-back once planted out. Better success was achieved by dipping

TABLE 24—Influence of rates and methods of placement of boron fertilisers on the mortality of radiata pine 1 year after application (N141/6, Motueka S.F.)

Fertiliser	Application g/tree	Placement method: In planting hole	In scrape 8-10 cm uphill of tree	In scrape 8-10 cm beside tree
		(mortality %)		
Borax (11% B)	2.8	45	10	10
	14.0	87	20	5
Rasorite (20% B)	2.8	65	—	—
	14.0	90	—	—
Borax glass (20% B)	2.8	80	—	—
	7.0	70	—	—
Boron frit (12% B)	2.8	0	—	—
	7.0	5	—	—

Data from Jacks and Keizer (1971).

roots in a puddle mixture containing B fertiliser, although this method produced unacceptable mortality (Appleton and Slow, 1966).

4. Individual tree applications of B as low as 0.3 to 0.4 g could considerably reduce the incidence of die-back for 3 to 4 years after planting (*see* Table 7).
5. Boron alone seldom increased growth of young trees, it only reduced malformation. Either P or N were required along with B to produce a growth response.
6. Applications of P and N usually increased the incidence of die-back where they increased growth rates.

Based on these findings, and those discussed earlier for P, initial management prescriptions called for the use of P + B fertilisers at establishment. Boronated superphosphate (containing *c.* 1% B, or about twice the B of the normal mix used for agricultural purposes) is the principal fertiliser used on combined P + B deficient sites. At an application rate of 60-85 g/seedling, this fertiliser gives *c.* 0.8 g/seedling of B.

Results from better designed trials established in the late 1960s confirmed most of the tentative findings from the earlier trials (Jacks *et al.,* 1972; Mead *et al.,* 1976). Additionally they showed, principally from results of foliar analysis, that gorse is a strong competitor for applied B, tending to reduce utilisation by radiata pine (*see* foliar analysis, Table 9), and that establishment applications appear to maintain foliar B levels above marginal values (*c.* 11 ppm) for a period of only 3 to 4 years (Table 25; Jacks *et al.,* 1972).

The incidence of die-back on any particularly B-deficient site tends to increase with tree age during the early establishment years. Also die-back which occurs during the first 2 or 3 years, does not have a particularly adverse effect on stem form. Therefore there is not much pressure to apply B at establishment particularly as later aerial

TABLE 25—Effect of fertiliser treatment on foliar boron concentrations and die-back incidence of radiata pine on a Rosedale hill soil (N193, Motueka S.F.)

Treatment*	Foliar B (ppm) at age				Incidence (%) of die-back
	3 yrs	4 yrs	5 yrs	6 yrs	
Control	8	7	8	8	38
B	18	11	8	12	3
B + B	16	11	12	10	1
P + B	17	13	10	11	1
N + P + B	18	11	11	11	0

Data from Mead **et al.** (1976).
* P and B broadcast at 100 and 2 kg/ha respectively at establishment. B re-applied at 4 kg/ha in third year. N applied at 4 and 4 and 13 g/seedling in first and second years respectively.

applications have to be made irrespective of whether B is applied at establishment only on those sites where P is applied — Mapua hill soils and some soils formed from granite. Current application rates of boronated superphosphate used in the region range from 60 to 100 g/tree depending on the land tenure.

Other Regions

Foliar analysis surveys have revealed incipient B deficiencies in exotic forests in all regions of the South Island. The worst areas are those on gravelly alluvial soils in low rainfall areas (Will, 1977) — the association between drought conditions and the occurrence of B-deficiency symptoms and/or low tissue B concentrations is common both in New Zealand and overseas (Stone, 1968). However, as the deficiency in these areas is not severe and symptoms only appear intermittently, B fertiliser is usually applied as a precautionary rather than a corrective measure. As such the timing of fertilisation is governed mainly by convenience and cost factors, as well as a desire to give protection during the period of development when any stem malformation would be most costly. Consequently very little B is applied at time of planting outside the Nelson region, most of that which is applied is aerially broadcast onto 4- to 10-year-old stands.

Marginal foliar B concentrations have been occasionally detected in radiata pine growing on rhyolitic pumice soils in the Rotorua region, mainly in areas where effective rooting depth is limited by an impenetrable pan and surface horizons have a high content of coarse lapilli (conditions enhancing drought stress). It is on such sites that the Fletcher Timber Co. apply serpentine superphosphate at 100 g/seedling to aid establishment and as a precautionary measure they use the boronated variety of this fertiliser.

OTHER ELEMENTS

Other than N, P and B the only elements identified as being deficient for growth of exotic pine plantations in New Zealand are copper (Cu) and potassium (K). Deficiencies of these two elements are restricted to reasonably well-defined areas; Cu to sand dune forests in the northern part of the North Island (Will, 1972) and K to the "mineral belt" in the Nelson region. Copper deficiency is corrected by aerial applications of liquid Cu salts to established stands; no applications are made at establishment.

The "mineral belt" soils are formed from ultramafic rocks (serpentine and dunite), and have an extremely high magnesium (Mg) content (Table 8), which apparently inhibits K uptake (Table 26) inducing K deficiency. Potassium fertilisation is essential for establishment of exotic pines on these soils and responses to P have also been obtained (Table 26). Foliar analysis data indicate that N could limit growth of pines on these soils (Table 26). The current fertiliser prescription at establishment of radiata pine on these soils is 25 g potash (KCl) + 25 g superphosphate + 25 g urea per seedling. These soils are of limited extent (Chittenden *et al.,* 1968) and so are of little commercial importance.

TABLE 26—Growth response and foliar nutrient concentration (1971) of radiata pine treated with P and K fertilisers at establishment in 1968 on a Dun steepland soil (N237, Les Valley)

Fertiliser* treatment	Years applied	Height (m) at 1971	Height (m) at 1973	Foliar concentrations (%) N	P	K	Ca	Mg	Ratio K/Mg
Control	—	0.68	1.47	0.95	0.12	0.23	0.20	0.32	0.72
P, Ca, S	1968	0.86	2.04	1.15	0.14	0.28	0.24	0.31	0.90
	1968, 1969	0.78	1.99	1.00	0.15	0.21	0.26	0.31	0.68
	1968, 1969, 1970	0.73	2.09	1.23	0.16	0.23	0.29	0.30	0.77
K, Ca, S	1968	1.01	2.15	1.15	0.11	0.52	0.20	0.26	2.00
	1968, 1969	1.18	2.89	1.28	0.12	0.62	0.20	0.24	2.79
	1968, 1969, 1970	1.17	2.94	1.30	0.13	0.85	0.21	0.23	3.70
P, K	1968	1.10	2.71	1.20	0.13	0.53	0.17	0.26	2.04
	1968, 1969	1.05	2.46	1.23	0.15	0.73	0.23	0.27	2.70
	1968, 1969, 1970	0.94	2.41	1.23	0.15	0.72	0.20	0.23	3.13
P, K, Ca, S	1968	1.02	2.60	1.34	0.14	0.49	0.25	0.31	1.58
	1968, 1969	1.14	2.97	1.28	0.13	0.65	0.23	0.46	1.41
	1968, 1969, 1970	1.03	2.76	1.16	0.16	0.84	0.22	0.25	3.36

Data from Jacks *et al.* (1972) and FRI records.

* 112 kg/ha P in superphosphate, 126 kg/ha K in potassium chloride, 291 kg/ha Ca and 224 kg/ha S in calcium sulphate.

DISCUSSION

The increase in fertiliser usage at establishment from 1970 (600 ha treated) to 1976 (6000 ha treated) has been substantial. The increase has taken place in areas where severe deficiencies exist (P and B with radiata pine) and where more satisfactory initial establishment and growth is achieved (N with eucalypts). Any further increase is going to require expansion of fertilisation operations onto more productive sites. Any such expansion will require more certain definition of the long term benefits (including non-volumetric aspects such as reduced tending costs and reduced damage by pests and climatic factors) from applying fertilisers to productive sites. Data are accumulating to resolve this point. Data are also required to determine the extent which experimental results can be realised in operations.

The outstanding problems associated with current practice are:—

1. The short-term effectiveness of spot applications. With N this is probably associated partially with mobility of applied N in soils (if not utilised it is readily leached below the rooting zone) and partially with the small quantities applied in relation to requirements during the early establishment years. Biomass studies have shown (Madgwick, 1977) that during the first 5 years of stand development, radiata pine accumulates some 200 kg N/ha in its above-ground portion; thus quantities typically applied at establishment (20-45 kg N/ha) are only a fraction of the demand during the early development years. There appears to be little alternative to applying more frequent N applications if sustained N responses are to be obtained because of (1) the tendency of N to kill the plants if applied too liberally at establishment, and (2) the likelihood of leaching losses if excess quantities are applied. This is unattractive because of considerably increased costs, and efforts are being made to utilise biological N fixation as a means of providing a cheaper and more sustained N supply (*see* Gadgil, 1977). Neither of these explanations can account for the short-term effectiveness of establishment applications of P fertilisers. On all but a very few soils (raw sands and strongly podsolised soils in New Zealand) P mobility is very limited, and net demand for P by radiata pine over the first 5 years is only in the vicinity of 20 kg/ha which is about equal to the amount applied in typical establishment applications. Excess immobility in the soil and poor root exploitation of the restricted fertiliser-enriched zone, because of either limited feeder-root contact or localised water deficits (see earlier discussion), are more likely explanations of the long-term ineffectiveness of spot applications of P. Possible methods of improving the utilisation of establishment P applications, under current investigation, include the use of alternative P sources to superphosphate — more mobile sources (Polyphosphates) and slowly soluble sources (rock phosphates) which react less rapidly with soil constituents — and alternative methods of application such as row drilling and incorporation in cultivated strips or beds prior to planting. However too much advantage from alternative methods of application should not be anticipated. In two trials on P-retentive soils in which P fertiliser was broadcast applied at establishment, foliar analysis data (Tables 2 and 11) showed that on such soils even broadcast applications up to 100 kg/ha P can maintain an adequate P supply for only 5 to 7 years. At present it is accepted that establishment applications of P can only provide an initial boost to growth, and to maintain the growth rate broadcast applications have to be made as soon as feasible — normally at age 4-5 years once trees have a clear advantage over competing vegetation. The poor utilisation of establishment applications of P particularly in relation to N utilisation — at least on N responsive sites — is illustrated by biomass data in Table 27 which were collected 3 years after fertilisation. It should be noted that these data underestimate utilisation as the roots were not included.

2. The reliance on manual application. This creates problems with cost — labour is the major cost of the operation — and also with precision of application. In this latter respect the problem occurs because the job of applying solid fertilisers, particularly

TABLE 27—Uptake over a 3-year period of establishment applications of N and P fertilisers into the above-ground portion of radiata pine on N- and P-responsive sites (A267, Riverhead)

Fertiliser* treatment	Dry matter age 3 years	Phosphorus Total uptake	Phosphorus fertiliser P uptake	Phosphorus Utilisation applied P	Nitrogen Total uptake	Nitrogen fertiliser N uptake	Nitrogen Utilisation applied N
	(g)	(mg)	(mg)	(%)	(mg)	(mg)	(%)
(1) N and P-responsive site (A267/1)							
P_0N_0	190	115	—	—	1595	—	—
P_0N_1	161	98	—	—	1490	105	0
P_1N_0	472	339	224	1.98	3809	—	—
P_1N_1	1242	535	437	3.85	8405	4596	35.24
P_2N_0	797	396	281	1.24	5072	—	—
P_2N_1	1334	678	680	3.00	9164	4092	31.38
(2) P-responsive site (A267/2)							
P_0N_0	51	25	—	—	537	—	—
P_0N_1	104	38	—	—	585	48	0.37
P_1N_0	540	303	278	2.45	3768	—	—
P_1N_1	520	297	259	2.28	4116	348	2.67
P_2N_0	263	244	219	0.97	2086	—	—
P_2N_1	348	252	214	9.94	2513	427	3.27

Trial details in Ballard (1975). Details of biomass study available from the author.

*P_1 = 11340 mg/seedling of P, P2 = 2 P_1, N_1 = 13041 mg/seedling of N. Applied as superphosphate and urea in spade slots 15 cm from base of seedling.

superphosphate, at planting involves heavy and dusty work as well as traversing the area for a second time (usually the same labour does the planting) which makes it an unpopular task with little incentive to do a good job. Variation in amounts applied per seedling and in position of placement may not be a serious disadvantage with P but they could be with N. Efforts are being made to find methods of mechanising the operation. The most promising approach appears to be the use of liquid fertilisers as their application is more amenable to mechanisation; their use also offers the advantage that weedicides can be mixed with and applied simultaneously with the fertiliser, which could help another persistent problem with establishment applications of fertiliser — that of stimulating excess weed growth.

3. Imprecise techniques for delineating responsive sites. This problem has been dealt with fully elsewhere (Ballard, 1977b). Foliar analysis is the most accurate method of diagnosing nutrient deficiencies, but cannot be used prior to the establishment of trees. A soil analysis technique has been developed and calibrated which can delineate P-responsive sites with some accuracy, but the selection of sites requiring N or B fertiliser is based on the identification of similar soils to those on which responses have been achieved in field trials. Because it is physically impossible to establish trials on all soil types encountered in forest areas, and considerable variation in response to any element can be found within any soil type, this method is coarse and imprecise.

Management is cognisant of this fact which is unlikely to give it the confidence to embark on large routine operations. The problem is not as great with B where, other than for the most severely deficient sites which have been clearly defined, it is acceptable to delay the first fertiliser application until some years after planting at which point foliar analysis can be used. It is hoped to use response data from our standardised design trials, which have been established on a wide range of sites, to develop useful correlations between some identifiable or measurable site characteristic and responsiveness to N fertiliser. The same trials will also be used to calibrate more precisely the relationship currently used between responsiveness to P and soil test values. Well calibrated diagnostic techniques are essential to any fertilisation programme if resources are not to be wasted.

REFERENCES

APPLETON, E. J. and SLOW, L. J. 1966: Nutritional disorders and fertiliser trials in **Pinus radiata** stands in Waimea county, Nelson. **N.Z. J. For. 11:** 185-201.

ARMITAGE, I. P. 1969: The establishment of second-rotation radiata pine in Riverhead Forest. **N.S. J. For. 14:** 184-94.

BALLARD, R. 1969a: Response of radiata pine in Auckland Conservancy to fertiliser applied at time of planting — Interim report. **N.Z. For. Serv., For. Res. Inst., Soils and Nutrition Rep. 7** (unpubl.).

——— 1969b: An evaluation of the effectiveness of various sources of fertiliser on a skid site at Kaingaroa Forest (R913). **N.Z. For. Serv., For. Res. Inst., Soils and Nutrition Rep. 8** (unpubl.).

——— 1971a: 1970 progress report A364, Riverhead Forest. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Internal Rep. 9** (unpubl.).

——— 1971b: Soil P testing in forestry. 2. At establishment. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 30** (unpubl.).

——— 1974: Use of soil testing for predicting phosphate fertiliser requirements of radiata pine at time of planting. **N.Z. J. For. Sci. 4:** 27-34.

——— 1975: Effect of rates and times of application of N and P fertilisers on response of young radiata pine (A267). **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 65** (unpubl.).

——— 1976: Trials evaluating the effectiveness of different N and P fertiliser sources at establishment (R930, R366, A288, A541). **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 68** (unpubl.).

BALLARD, R. and MEAD, D. J. 1976: Uniform fertiliser-site preparation trials in the Auckland Conservancy. Results after 2 years (A578, A580, A581). **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 73** (unpubl.).

BALLARD, R. 1977a: Past fertiliser use in New Zealand forests. **In** Use of fertilisers in New Zealand forestry. **N.Z. For. Serv., For. Res. Inst., Symposium 19.**

——— 1977b: Predicting fertiliser requirements of production forests. **In** Use of fertilisers in New Zealand forestry. **N.Z. For. Serv., For. Res. Inst., Symposium 19.**

BERG, P. J. 1975: Developments in the establishment of second rotation radiata pine at Riverhead Forest. **N.Z. J. For. 20:** 272-82.

BRUNSDEN, G. J. 1976: Hard site establishment: the effect of fertiliser on the survival and growth of 1½/0 radiata pine. **N.Z. For. Serv., For. Res. Inst., Forest Establishment Rep. 79** (unpubl.).

BUNN, E. H. 1961: Pilot fertiliser trials with **Eucalyptus** spp. **In** Use of fertilisers in New Zealand forestry. **N.Z. For. Serv., For. Res. Inst., Symposium 1.**

CHAVASSE, C. G. R. (compiler) 1976: The use of herbicides in forestry in New Zealand. **N.Z. For. Serv., For. Res. Inst., Symposium 18.**

CHITTENDEN, E. T., HODGSON, L. and DODSON, K. J. 1966: Soils and agriculture of Waimea county, New Zealand. **N.Z. D.S.I.R., Soil Bureau, Bulletin 30.**

CLYNE, N. L. 1975: An evaluation of exotic pine species, fertilisers and drainage on intermediate terrace soils — North Westland. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 61** (unpubl.).

CONWAY, M. J. 1962: Aerial application of phosphate fertilisers to radiata pine forests in New Zealand. **Commonw. For. Rev. 41:** 234-45.

DURING, C. D. 1972: Fertilisers and soils in New Zealand farming (2nd ed.). **N.Z. Dep. Agri., Bull. 409.**

EVERSFIELD, A. L. 1974: Further work studies on fertiliser application soon after planting. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 60** (unpubl.).

FOREST RESEARCH INSTITUTE, 1976: Nitrogen and soil moisture in coastal sand forest. **N.Z. For. Serv., Rep. For. Res. Inst. 1975.**

FRANKLIN, D. A. 1971: The enrichment with eucalypts of logged podocarp-beech forest on the West Coast. **N.Z. For. Serv., For. Res. Inst., Indigenous Silviculture Rep. 9** (unpubl.).

GADGIL, R. L. 1976: The influence of lupins, fertiliser application and stocking reduction on the nitrogen nutrition of **Pinus radiata** in plot A287, Woodhill. 3. 3-6 years. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 71** (unpubl.).

——— 1977: Alternatives to fertiliser use. **In** Use of fertilisers in New Zealand forestry. **N.Z. For. Serv., For. Res. Inst., Symposium 19.**

HUMPHREYS, F. R. 1977: Fertilisers in New South Wales State forests. **In** Use of fertilisers in New Zealand forestry. **N.Z. For. Serv., For. Res. Inst., Symposium 19.**

JACKS, H. and KEIZER, R. 1971: Past soils and nutrition trials in the province of Nelson. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 25** (unpubl.).

JACKS, H. and FITZGERALD, R. E. 1971: Results of soils and nutrition experiments in Nelson for 1971. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 34** (unpubl.).

JACKS, H., FITZGERALD, R. E., KEIZER, R. and PHIBBS, S. B. 1972: Results of soils and nutrition experiments in Nelson for 1972. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 41** (unpubl.).

KNIGHT, P. J. and WILL, G. M. 1971: Pot trial evaluation and comparison of six potential sources of phosphate for forestry. **N.Z. J. For. Sci. 1:** 22-36.

MADGWICK, H. A. I. 1977: Nutrient uptake by an age series of radiata pine plantations. **In** Use of fertilisers in New Zealand forestry. **N.Z. For. Serv., For. Res. Inst., Symposium 19.**

MEAD, D. J. 1968: The use of fertilisers on skid sites at Kaingaroa Forest. **N.Z. For. Serv., For. Res. Inst., Silviculture Rep. 120** (unpubl.).

MEAD, D. J. and WESTON, G. C. 1972: Results of a fertiliser and cultivation trial with radiata, slash and loblolly pines at Riverhead Forest. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 38** (unpubl.).

MEAD, D. J., BALLARD, R. and MACKENZIE, M. 1975: Trials with sulphur-coated urea and other nitrogenous fertilisers on **Pinus radiata** in New Zealand. **Soil Sci. Amer. Proc. 39:** 978-80.

MEAD, D. J. 1976: Fertiliser response in 14-year-old radiata pine at Harakeke, Nelson (N191). **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 69** (unpubl.).

MEAD, D. J., FITZGERALD, R. E., OLIVER, G. R. and KEIZER, R. 1976: The response of radiata pine to fertilisers and cultivation at Waiwhero, Nelson (N193 and N195). **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 70** (unpubl.).

MOBERLY, B. W. A., WILL, G. M., FRY, G. and BRAGG, D. 1975: The use of fertilisers in the establishment of eucalypts. **N.Z. For. Serv., For. Res. Inst., Forest Establishment Rep. 70** (unpubl.).

REVELL, D. and DEADMAN, H. 1976: Planted hardwoods and weed competition **In** The use of herbicides in forestry in New Zealand. **N.Z. For. Serv., For. Res. Inst., Symposium 18.**

ST. JOHN D. 1961: Auckland Conservancy, summary of fertiliser work, 1949-1961. **In** The use of fertilisers in New Zealand forestry. **N.Z. For. Serv., For. Res. Inst., Symposium 1.**

STONE, E. L. 1968: Microelement nutrition of forest trees: a review. **In** "Forest Fertilisation, Theory and Practice" T.V.A., Muscle Shoals AL.

STONE, E. L. and WILL, G. M. 1965a: Nitrogen deficiency of second generation radiata pine in New Zealand. Pp. 117-39. **In** "Forest-soil Relationships in North America". C. T. Youngberg (ed.), Oregon State University Press, Corvallis, Oregon.

——— 1965b: Boron deficiency in **Pinus radiata** and **P. pinaster. For. Sci. 11:** 425-33.

VUCETICH, C. G. 1960: Soils, forestry and agriculture of the northern part Kaingaroa State Forest and the Galatea basin. **N.Z. D.S.I.R., Soil Bureau Bull. 18.**

WARING, H. D. 1971: Some soil relationships of **Pinus radiata**. Proc. **P. radiata** Symposium 1970, 1B, 1-18. **For. and Tim. Bureau, Canberra.**

WASHBOURN, R. W. 1972: The rehabilitation of induced pakihi sites in Westland. **N.Z. J. For. 17:** 232-48.

WESTON, G. C. (ed.) 1961: The use of fertilisers in New Zealand forestry. **N.Z. For. Serv., For. Res. Inst., Symposium 1.**

WILL, G. M. 1965: Increased phosphorus uptake by radiata pine in Riverhead Forest following superphosphate application. **N.Z. J. For. 10:** 33-42.

WILL, G. M. and KNIGHT, P. J. 1968: Pumice soils as a medium for tree growth. 2. Pot trial evaluation of nutrient supply. **N.Z. J. For. 13:** 50-65.

WILL, G. M. 1972: Copper deficiency in radiata pine planted on sands at Mangawhai Forest. **N.Z. J. For. Sci. 21:** 217-21.

——— 1978: Nutrient deficiencies in **Pinus radiata** in New Zealand. **N.Z. J. For. Sci. 8(1):** this issue.