NUTRIENT DEFICIENCIES IN *PINUS RADIATA* IN NEW ZEALAND

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ABSTRACT

Deficiencies of N, P, K, Ca, Mg, B, Cu, Zn, and Fe have been found in nurseries and/or plantations of **Pinus radiata** in New Zealand. The visual symptoms are described and details of the soil types on which they occur are given. Deficiency-like symptoms due to other causes are described. While visual symptoms give an immediate and usually reliable indication of the presence of a nutrient deficiency, confirmation by foliage analysis is recommended. Deficiency foliage levels of each nutrient are given.

INTRODUCTION

Pinus radiata D. Don, a native of California, was introduced into New Zealand in the 1800s; it was planted in farm shelterbelts and woodlots in many parts of the country. Experience showed it to be an adaptable fast-growing tree species, so that when large scale exotic afforestation began in the 1920s it was one of the major species used. During the succeeding 50 years New Zealand's forest-based industries have come to rely almost entirely on *Pinus radiata* timber as a raw material and the proportion of area planted with this species in new plantings has gradually increased. Currently *Pinus radiata* is used in over 90% of new plantings and conversion plantings of land previously planted in less productive exotic species.

Today New Zealand's exotic forests are the basis of industries important to the country's internal economy and export trade; as a result forestry has recently been able to compete fairly effectively with other land uses for soils of at least medium fertility. This has not always been the position; in a country dominated by agricultural land use, exotic afforestation was thought to be appropriate only on land with little or no agricultural potential. As a result afforestation was confined to soils of low fertility and those with drainage or other problems. Not unexpectedly many cases of nutrient deficiency have occurred in forests planted on these soils, central North Island volcanic pumice soils being the outstanding exception. Before cobalt deficiency was found to be the cause of "bush-sickness" in animals grazing pastures on these soils, they were largely converted to forest plantings for which they have proved ideal (Will and Stone, 1967; Knight and Will, 1970).

This paper describes and reviews the nutrient deficiencies that have been identified in *P. radiata* in New Zealand and the soils on which they occur.

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DESCRIPTIONS

Nitrogen Deficiency

Seedlings

This deficiency causes an overall yellowish-green colour of the foliage and a reduced growth rate (Stone and Will, 1965a). Branching and diameter growth are reduced (Will, 1971a; 1977).

N deficiency is likely to occur in any nursery where soil nitrogen (usually held in the organic matter) is, or becomes, low or conditions prevail which restrict mineralisation (e.g., poor drainage or cold temperatures) and suitable fertilisers are not regularly applied. It shows up particularly in highly stocked beds, or where organic material low in N has been used as a soil amendment or mulch (e.g., sawdust).

Adult trees

Needles uniformly yellowish-green over their full length — in severe cases the needle colour is yellow; they are short and shed prematurely (Stone and Will, 1965a). Branches are small and stem diameter growth is reduced more than height growth giving characteristic narrow crowns and fine branches (Will and Hodgkiss, 1978). Terminal needles on the leader are often less affected (i.e., are greener and longer) but in severe cases leaders make little height growth, have few needles, clusters of cones closely spaced; and may eventually die back.

Occurrence — see Fig. 1

Several forests — mainly north of Auckland and in the Manawatu district — have been established on coastal sands after stabilisation; these sites are very N deficient. The same is true of skid sites and landings in most forests, where the topsoil has been removed and the soil compacted.

N deficiency is also present in plantations on podzolised sands in North Auckland, gley-podzols (pakihi soils) in Westland (Gibbs *et al.,* 1950; NZ Soil Bureau, 1968) and undrained peats in Southland. Besides these soils in which poor drainage inhibits the mineralisation of available N, deficiency is also found on the Moutere Gravel soils near Nelson — particularly on ridge sites from which the topsoil has been eroded. A combination of low organic matter and restricted rooting depth results in deficient N supplies in the stony soil of Canterbury (Ballard, 1978; Mead and Gadgil, 1978).

While a true N deficiency in terms of the symptoms described above does not exist in the central North Island pumice soils, it should be noted that substantial increases in growth can result from the addition of N fertiliser applied following thinning (Woollons and Will, 1975). Responses to N on other reasonably fertile sites have also been observed (Mead and Gadgil, 1978).

Phosphorus Deficiency

Seedlings

Slow growth with shortening of primary needles is caused by P deficiency: in severe cases the terminal needles are very short (giving a flat top to the seedling) and curled upwards. There is no marked colour change but severely P deficient seedlings can have a bluish-green colour and/or slight needle tip chlorosis (Will, 1961b).

Young trees

Needles on ends of branches are short and yellow tipped. The tree in Fig. 4 shows these characteristic features.

Adult trees

Needles are shed prematurely resulting in thin crowns; in more severe deficiency, leaders become spirelike — short branches with sparse short needles (Weston, 1956). Particularly from a distance the colour and lack of foliage give stands a dull green to greyish-green appearance. With increasing severity of P deficiency a greater number of trees are affected by "fused needle" (this is not confined to P deficiency — see later).

Occurrence — see Fig. 1

The most P-deficient soils are the highly weathered and leached clays formed from tertiary mudstones and sandstones in North Auckland (Gibbs, 1964) and rhyolitic and andesitic parent materials in the Coromandel Peninsula. Severest conditions are found on these clay soils where logging of kauri forest has been followed by gum digging and erosion. Podzolised soils in the same districts are also P deficient. In the South Island the more weathered and leached soils derived from Moutere gravels (Mapua and Rosedale hill soils) and granite (Kaiteriteri hill soils) in the Nelson district (Chittenden *et al.,* 1966) are moderately P deficient: pakihi and related soils in Westland are moderately to severely deficient (Ballard, 1978; Mead and Gadgil, 1978).

In agriculture almost all New Zealand soils are P responsive so it can be expected that P deficiency will be found in forests on other soils. Foliage analysis surveys have already pointed out possibly responsive stands.

Potassium Deficiency

Seedlings

This deficiency has not been recognised in any nursery to date.

Adult trees

Needle tip chlorosis and some necrosis under extreme deficiency particularly of current foliage in the late summer and winter. In younger trees the whole crown may be affected but in older trees chlorosis is more pronounced in the lower crown (Will, unpubl.).

Occurrence — see Fig. 2

In Europe, North America, and Australia K deficiency occurs in numbers of coniferous forests, and in at least some parts of Europe is the major deficiency affecting pines. In New Zealand K deficiency is restricted to a few soils of very limited area. Near Nelson there are small areas of soils developed on ultra-basic serpentine type parent material (Chittenden *et al.,* 1966). On these soils *P. radiata* is affected by K deficiency through the very high Mg/K ratio in the soil. K deficiency has also been seen in small experimental plantings on pakihi type soils in Westland.

Magnesium Deficiency

Seedlings

Tip chlorosis of primary and secondary needles. Chlorosis changes from yellow to deep gold with increasing deficiency (Will, 1961a).

Adult trees

Needle tip chlorosis (golden yellow) of previous year's foliage — most marked in late spring (follows maximum withdrawal of Mg into current year's foliage) and in upper third of tree crown (Fig. 5). Chlorosis of all needles of the same age on a branch is characteristically very regular.

Occurrence — see Fig. 2

Severe Mg deficiency occurred in some pumice soil nurseries growing their first crop of trees (Will, 1961a); it occurs and needs regular correction in all pumice soil nurseries and those on other soils that have been extensively used for raising trees e.g., Totara Flat nursery in Westland.

In plantations on pumice soils Mg deficiency has been regularly seen in young crops — particularly after pruning (which reduces the pool of Mg within the tree crown) and in a dry spring (which reduces nutrient uptake from the top soil) (Will, 1966). As tree roots reach buried soils, with higher Mg contents, deficiency symptoms are rarely seen.

Mg deficiency has also been observed in a mild form in the South Island in forests on Moutere gravel soils (Appleton and Slow, 1966).

Note: Care must be taken to distinguish between Mg (and K) deficiency and attacks by needle-cast fungi — see later.

Calcium Deficiency

Seedlings

Unknown in New Zealand but described by Purnell (1958) for seedlings grown in water culture.

Adult trees

In some forests where P deficiency is severe, it is thought likely that the resin flow on stems and around buds and the dieback of leaders is due to an associated Ca deficiency; foliage levels of Ca are certainly low. Humphreys (1964) suggested that dieback caused by Ca deficiency occurs on some soils in New South Wales.

Occurrence — see Fig. 2

In Riverhead and Tairua Forests on strongly weathered, leached and eroded clays, Ca deficiency is very probably present but because superphosphate has always been used to correct the P deficiency, the individual roles of P and Ca have not been determined.

Boron Deficiency

Seedlings

Never observed in nurseries, but on severely deficient planting sites the death of terminal buds can occur within a year.

Adult trees

Bud death and in more severe cases shoot dieback which usually affects terminal shoots first but in severe cases can affect most shoots on a tree producing a hedging effect. Dead shoots of 25 cm or more in length are often twisted into an "inverted hockey stick" shape. Symptoms usually appear in midsummer and are enhanced by drought. The pith below the point of dieback is often affected by necrotic spots (Fig. 6) but it is not known whether this is a distinctive symptom (Stone and Will, 1965b).

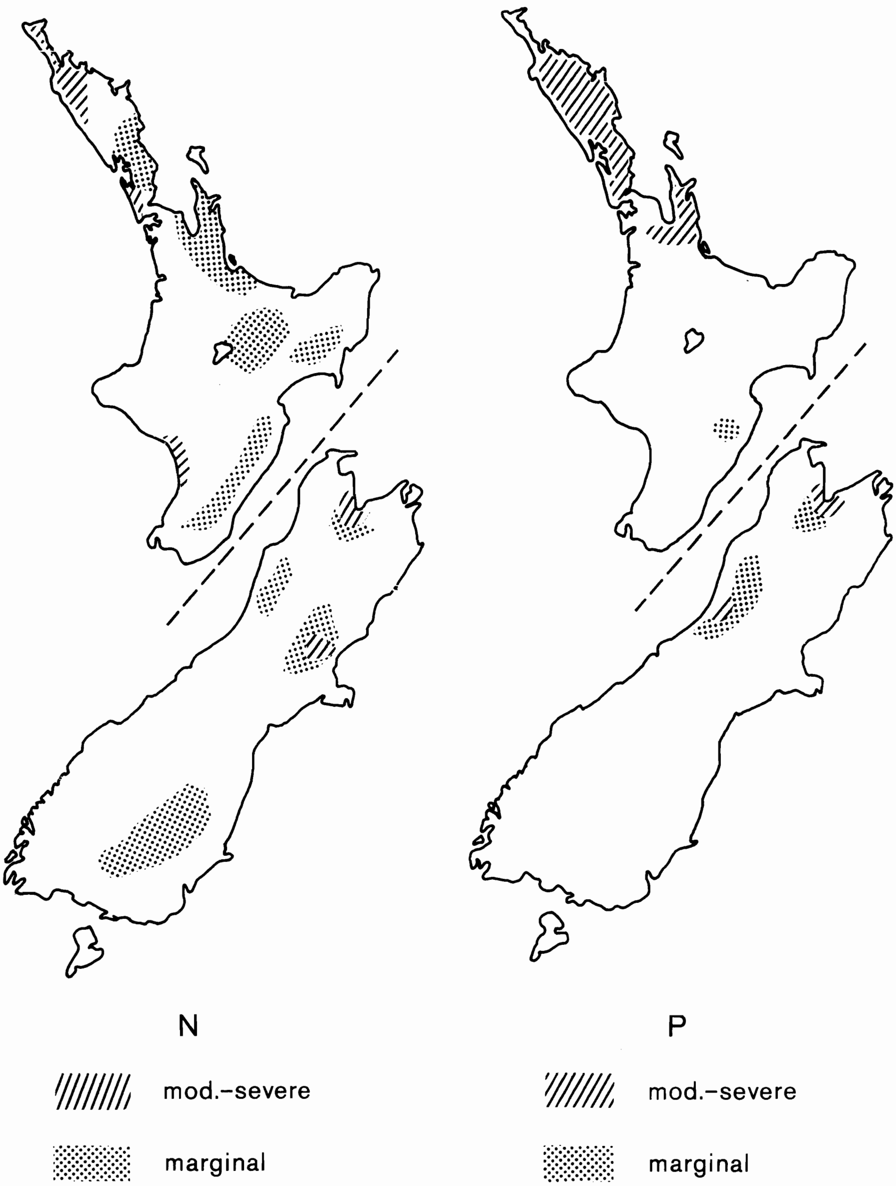

FIG. 1—Occurrence of nitrogen and phosphorus deficiencies in **Pinus radiata** forests in New Zealand.

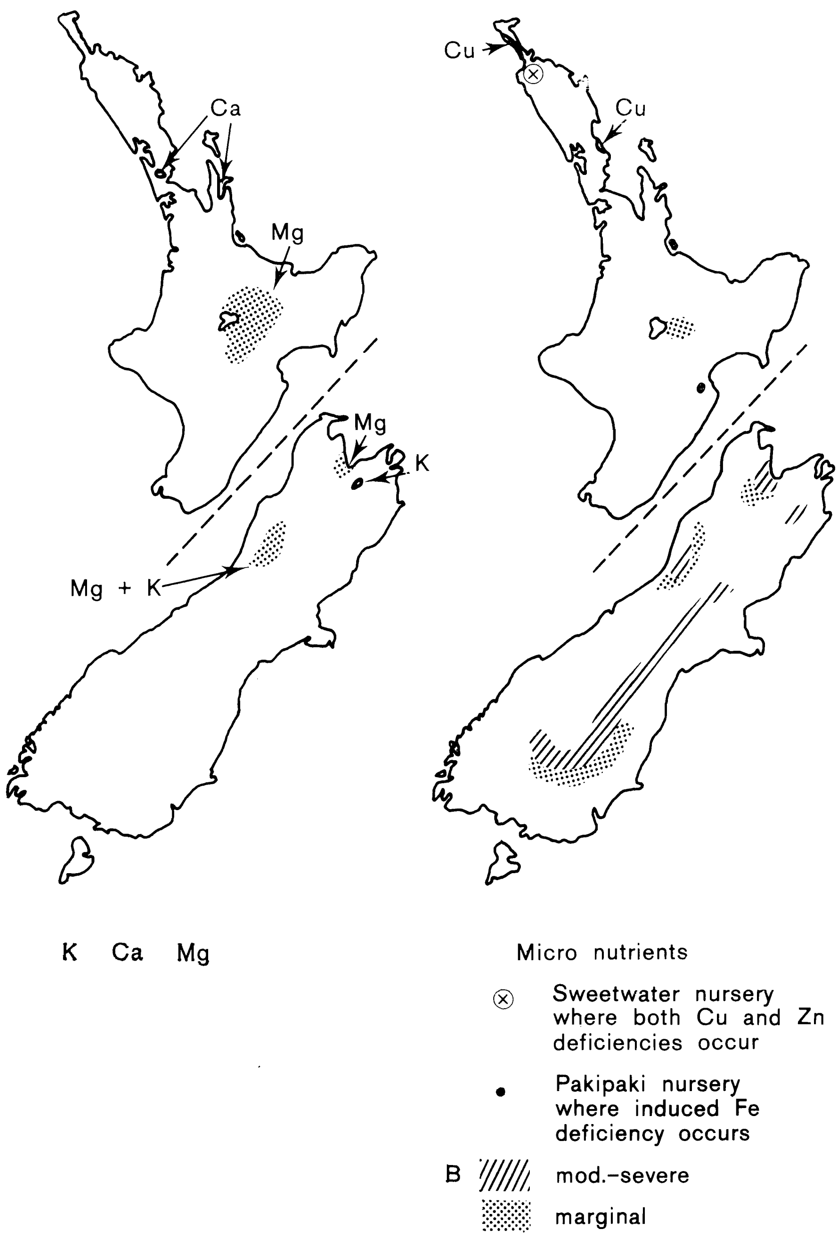

FIG. 2—Occurrence of potassium, calcium, magnesium and micronutrient deficiencies in **Pinus radiata** forests in New Zealand.

FIG. 3 (left)—Group of N deficient trees on sand blow-out area, Woodhill Forest.
FIG. 4 (right)—Phosphorus deficiency symptoms on young tree, Riverhead Forest.

FIG. 5 (left)—Magnesium deficiency symptoms in recently thinned and pruned stand, Kaingaroa Forest.
FIG. 6 (right)—Longitudinal section of boron deficient shoot.

Occurrence — see Fig. 2

Marginal B deficiency occurs on some shallow and coarse pumice soils in the centre of the North Island. In the South Island B deficiency is often severe and is more scattered occurring on a wide range of soils — in Nelson (Moutere gravel and granite parent material), in the low rainfall belt east of the Southern Alps in Marlborough, Canterbury, and Otago (soils, often alluvial, formed from parent materials low in B, e.g., metamorphic rocks) and in Westland (on dredge tailings; Will, 1971b).

Copper Deficiency

Seedlings

Drooping foliage (primary needles) with needle tip necrosis (Knight, 1975).

Adult trees

Twisting of branches and, in severe cases, tree leaders. Branches not severely twisted have a horizontal growth habit (Will, 1972).

Occurrence — see Fig. 2

In seedlings Cu deficiency has been found only on the peat soils of Sweetwater nursery. In adult trees symptoms are also restricted to small areas of raw coastal sands in Mangawhai and Aupouri Forests. However marginal levels of Cu in foliage have been recorded elsewhere.

Zinc Deficiency

Seedlings

Restricted growth or death of terminal shoot followed by the development of a rosette of secondary buds (Knight, 1976).

Adult trees

Not known in New Zealand but is common in parts of Australia. For a description of symptoms — see Stoate (1950).

Occurrence — see Fig. 2

The occurrence of Zn deficiency has been restricted to small parts of Sweetwater nursery.

Iron Deficiency

Seedlings

In cases of slight deficiency the terminal primary needles have a yellowish-white colour which is usually ephemeral and only seen in seedlings less than 10-15 cm in height; there is no obvious effect on growth. In the case of more severe Fe deficiency however, all needles are stunted and chlorotic and height growth is substantially reduced (Knight, 1977).

Adult trees

Not known in New Zealand.

Occurrence — see Fig. 2

Slight Fe deficiency occurs sporadically in seedlings in several nurseries and usually disappears without treatment. The soil conditions that cause its appearance are not known but its scattered nature and recovery without treatment suggest an association with changes in the N status of the soil. Knight (1977) has recently shown that one case of severe deficiency is due to the almost complete unavailability of Fe in soil with a high pH.

Fused-needle Symptoms

In the early period of investigation into severe P deficiency on clay soils in Riverhead Forest (Weston, 1956) it was thought that "fused needle" was a symptom specific to P deficiency. However it has since become apparent that the cause of "fused needle" is not a simple one. It does not occur on Westland's pakihi soils which are very low in P (Mead, pers. comm.); but it does occur in association with severe B deficiency in the Nelson district (Stone and Will, 1965b), and with a Cu deficiency in Mangawhai Forest (Will, 1972). Mead (pers. comm.) has suggested that it is a symptom of Ca deficiency but a full understanding of the cause(s) has yet to be reached. It is also induced by some weedicide sprays (Preest, pers. comm.), and it seems likely that "fused needle" can be a result of several nutrient deficiencies or imbalances. A low level of occurrence (one tree per several hectares) is common in the most vigorous of stands and this, together with the appearance of a growing percentage of affected trees as the severity of some deficiencies increases, suggests a wide range in genetic susceptibility.

Deficiency-like Symptoms Produced by Other Causes

1. Animal or fungal damage to stem bark or roots can induce N deficiency and its symptoms in the tree crown.
2. Some dieback caused by *Diplodia pinea* can have an appearance similar to B deficiency (see Chou, 1976).
3. In a nursery in which radiata pine has not been grown previously, seedlings usually develop slowly and may show signs of P deficiency. This is due to lack of mycorrhizal infection which in most cases is corrected by natural infection within a year. Soil sterilants when applied at high rates, have reduced mycorrhizal populations to the point where seedling growth has been subdued and deficiency symptoms produced (Will, unpubl.).
4. Incompatibility in grafts produces symptoms that at some stages may be confused with N or Mg deficiencies.
5. Needle-cast fungi such as *Lophodermium* and *Naemacyclus* produce needle chlorosis superficially very similar to Mg deficiency. However it should be noted that the nutrient deficiency characteristically produces a chlorosis which uniformly affects all needles in a fascicle and usually all needles of the same age on a shoot. The chlorosis also lessens in intensity uniformly from the needle tip towards the base. In contrast chlorosis caused by needle-cast fungal attack is almost always less uniform with chlorotic bands separated by greener tissue present on at least some needles (Stahl, 1966).

Foliage Analyses

While visual symptoms give a reasonably good indication as to whether a nutrient deficiency is present and what deficiency it is, there may often be grounds for some uncertainty because of a lack of complete specificity of some of the symptoms. Before corrective measures (usually fertiliser applications) are undertaken on trial or management scales, confirmation of deficiencies should be made by foliage analyses. Foliar analysis has the added advantage that incipient deficiencies, which produce no overt symptoms but restrict growth, can be detected. This is of importance to management who are concerned with taking corrective measures before any appreciable growth reduction occurs.

Second only to field fertiliser trials, foliage analysis (combined with an assessment of any visual symptoms present) is the most positive means of identifying a deficiency. Low, marginal, and satisfactory foliage nutrient concentrations for growth of radiata pine are given in Table 1. When foliage samples are taken from seedlings or adult trees, composite samples should be taken to even out genetic differences, and with adult trees sampling in mid- to late summer is recommended as during this period concentration fluctuations with time are the least and resolution between nutrient conditions is greatest (Mead and Will, 1976).

In the case of a slight to moderate deficiency of one nutrient, foliage analysis will give a good indication of the supply of other nutrients and which one(s) may limit growth once the primary deficiency has been corrected. In the case of a severe deficiency however, the concentration of other nutrients may be abnormally high or low due to accumulation in slow growing tissues or interruption of nutrient transport by the severe primary deficiency.

TABLE 1—Foliage analysis values used to indicate the nutrient status of **P. radiata**

Nutrient	Low less than:	Marginal	Satisfactory more than:	Confidence rating
		%		
N	1.2	1.2-1.5	1.5	**
P	0.12	0.12-0.14	0.14	***
K	0.30	0.30-0.50	0.50	*
Ca	0.10	0.10	0.10	*
Mg	0.07	0.07-0.10	0.10	**
		ppm		
B	8	8-12	12	**
Cu	2	2-4	4	**
Zn	10	10-20	20	*
Mn	10	10-20?	20?	*

*** Good prediction of responsive sites in both the low and marginal range.
** Good prediction of responsive sites in the low range but not in the marginal range.
* Insufficient information and experience to confidently predict a response even in the low range (values based mainly on overseas experience).

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