FERTILISER PRACTICE IN NEW ZEALAND FOREST NURSERIES

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ABSTRACT

Commercial fertilisers provide a convenient and effective means of maintaining a satisfactory level of balanced nutrition in nurseries provided they are used with proper regard to timing and in quantities which have some relation to the actual requirements. For many years their regular use has been regarded as an accepted part of nursery husbandry. In New Zealand Forest Service nurseries, as well as some private forest nurseries, assessment of requirements is made largely on the basis of standardised agricultural soil tests. Soil sampling methods and interpretation of soil test results are outlined. Prescriptions based on soil test ratings have generally helped to maintain satisfactory growth in successive crops, while preventing cumulative excesses which could also adversely affect nursery stock.

Fertilisers are commonly applied during bed preparation (especially P, K and secondary nutrients (Ca, Mg, S) as low-cost simple agricultural fertilisers), as well as later during the period when seedlings are making rapid growth (light maintenance side- or topdressings of granulated multinutrient fertilisers or nitrogenous fertilisers according to soil requirements).

In the event of poor growth or malnutrition symptoms affecting a crop, visual diagnosis, aided where necessary by foliar analysis, is used to resolve the cause so that prompt remedial action can be taken, e.g., by foliar spray. Descriptions of diagnostic symptoms and "critical" foliar nutrient levels for radiata pine seedlings are given.

INTRODUCTION

At the present time in New Zealand, coniferous seedlings for exotic afforestation are raised almost entirely from seed as open grown row crops in permanent nurseries. In most New Zealand Forest Service (NZFS) nurseries as well as the larger private nurseries, size-graded seed is mechanically sown in a number of parallel drills (6-12) in beds ranging from about 91 to 185 cm in width. Because the spacing and number of drills as well as bed and alley width differ considerably between nurseries, the actual seedling production per hectare also varies appreciably, ranging from about 250 000 to 750 000. Species other than *Pinus radiata* make up only a minor proportion of the total stock produced by NZFS nurseries (see Fig. 1a) and the same is true of private nurseries (Chavasse, 1974).

As can be seen in Fig. 1b, nearly two-thirds of the *P. radiata* stock produced by

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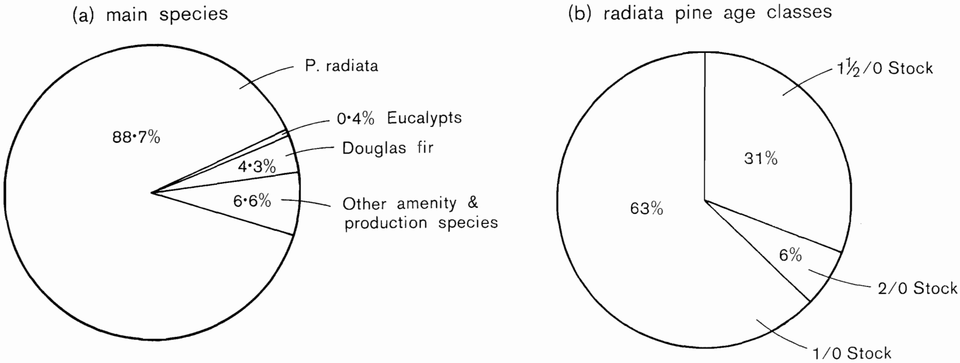

FIG. 1—Production data for 1975 for N.Z.F.S. nurseries. Relative proportions of (a) main species grown, and (b) three age-classes of radiata pine. Based on data supplied by P. Berg.

the NZFS in 1975 was grown as 1/0, a little under a third as 1½/0 and the balance as 2/0 stock. Eucalypts are generally raised as 1/0 crops while the slower-growing Douglas fir is usually grown as a 2/0 crop.

At a conservative estimate, the total forest nursery production area (i.e., NZFS and private combined) in 1975 amounted to about 540 ha. The actual area of individual nurseries varies considerably, ranging in the NZFS from about 6 ha (Gwavas) to 103 ha (Cambridge). The two more recently acquired nursery areas (Cambridge and Edendale (95.2 ha)) and recently negotiated leases at Sweetwater, represent a continuation of the move towards larger centralised nurseries which began in the late 1950s.

It is generally recognised that the production of bare-rooted stock can be best accomplished with the minimum of cultural problems on light freely-draining soils. Such soils warm up more rapidly than heavy soils, can be cultivated soon after heavy rain, make weed control easier, and cause less root damage at lifting. These advantages generally outweigh the inherently low natural fertility of most soils of this type. Consequently (and especially in recent years) a high proportion of forest nurseries have deliberately been established on soils where constant vigilance in the control of soil fertility is essential and where heavy reliance is placed on commercial fertilisers. Thus the observation made by Wakeley (1954) in his excellent monograph on raising Southern pines that "the simplest means of adding known amounts of mineral nutrients to nursery soils, and often the only economical way of correcting serious nutrient deficiencies is by applying inorganic fertilisers" is equally applicable and appropriate to present day forest nursery practice in this country.

Successful planting, i.e., good survival and early growth, depend in large measure on the physiological quality of the stock produced, and this in turn is greatly influenced by the standard of nursery nutrition provided. Commercial fertilisers play a key role in all well-run permanent forest nurseries, providing a convenient, effective means of ensuring a balanced supply of nutrients for successive tree seedling crops.

Forest nurseries in New Zealand tend to be highly individual with respect to soil fertility maintenance practices. This is understandable as soil type and texture, climatic conditions, size of production area, seedling density, and length of growing season vary appreciably from nursery to nursery. To illustrate the sort of extremes encountered, Sweetwater nursery in the far north is located close to sea-level on a sandy peat soil near latitude 35°S, while Edendale nursery is located at about 45 m above sea level, on a silt loam, close to latitude 46°S. Granville nursery in Westland has an annual rainfall expectation of over 1900 mm, while Rangiora nursery in Canterbury can expect little over 600 mm. Kaingaroa nursery is situated 583 m above sea level on a rhyolitic pumice sandy loam, while Tasman nursery, only 30 km away at Te Teko is situated 8 m above sea level on a basaltic sandy loam.

In any one nursery, there are a good many options as to how much, how often, and in what form fertiliser should be applied. No single set of recommendations is ever likely to fit all circumstances. In the matter of amount and timing of applications of nitrogenous fertilisers particularly, informed local judgment is essential. In each nursery, the final decision as to the most appropriate means of maintaining soil fertility must take into account the conditions peculiar to that nursery; it should be based on all the available information, including soil nutrient status (as indicated by soil tests), soil characteristics (e.g., texture and nutrient retention capacity), previous land use, annual rainfall expectation, length of growing season, crop specification, effectiveness of past fertiliser prescriptions and availability of resources (e.g., equipment and fertilisers).

The importance of physiological quality to survival and early field performance of seedlings has long been recognised, though the role which sound balanced nutrition plays in its attainment is apparently not always fully appreciated by those responsible for seedling production. In some instances, the vigorous wrenching schedules used to harden seedlings are carried out at the expense of seedling nutrient status. However, it must be admitted that a question mark still hangs over precisely what constitutes optimal nutrient balance in relation to the ability of stock to withstand environmental stresses such as drought and frost. Indeed as Wakely (1954) has remarked, "the final proof of the effectiveness of any nursery treatment over and above its cost and its visible effect, is the relative performance of the stock when planted out."

The purpose of this paper is to provide a convenient source of information relating to present-day use of commercial fertilisers in New Zealand forest nurseries.

METHODS USED FOR ASSESSING FERTILISER REQUIREMENTS

Aldhous (1972) has stated that the regulation of a balanced supply of nutrients is one of the nursery manager's most important duties. Although much can be achieved in this respect simply by good judgment and careful observation based on experience, some indication of the actual nutrient status of the soil and crop, based on chemical soil tests and plant analysis, can greatly assist the nursery manager in planning a sound and economical fertiliser schedule. Despite the various limitations of chemical soil testing and plant analysis (*see* Walsh and Beaton, 1973), both techniques provide useful means of recognising any impending deficiency or nutrient imbalance which needs correction.

Planning fertilisation by waiting until deficiency symptoms appear is not sound practice as the loss of vigour and tone attendant on inadequate nutrition may increase the susceptibility of plants to disease and insect attack and adversely affect the quality of planting stock produced. However there is some justification for gauging the need for supplementary nitrogen on the basis of crop growth and appearance as a rapid response to this highly mobile growth-stimulating nutrient can usually be readily obtained.

(1) *Soil Testing*

Soil tests have the unique advantage over plant analysis in that they can be made prior to seedbed formation when it is easiest to apply the heavier rates of fertiliser sometimes needed to correct shortages of essential nutrients, they provide a useful guide for soil fertility management and, where suitable records are maintained (*see* Wojahn and Iyer, 1974), enable the nursery manager to recognise particular trends in soil fertility level over an extended period.

(a) *Sample collection*

The validity of any soil test is entirely dependent on whether the sample is truly representative of the area sampled (a kilogram of soil represents only about one part in a million for a hectare of nursery soil at a depth of 10 cm). It is customary to bulk spot samples collected from each reasonably uniform area to provide a single, composite sample for analysis. The actual details of collecting spot samples for bulking will vary with each sampling area; as a general guide, at least 15 cores should be collected for areas up to about 5 hectares in size; uniform areas larger than this are preferably subdivided into smaller sampling areas.

Routine nursery soil sampling is normally done in autumn-winter so that fertiliser recommendations can be made before spring sowing. One composite soil sample is taken from each area which has a similar soil and uniform management history (usually one sample per nursery block). Each composite sample is made up of 20 or more samples taken to a depth of 10 cm and collected at random; these are reduced to about 500 ml in volume by quartering after thorough mixing.

(b) *Laboratory testing*

A nursery soil can be regarded as both rooting medium and storehouse for water and nutrients. Its capacity to retain nutrients and water and provide a suitable rooting substrate for tree seedling crops is governed by certain fundamental physical and chemical properties which can be measured rapidly and simply by various well-established laboratory procedures. Evaluation of pre-sowing fertiliser requirements for NZFS nurseries is normally made on the basis of standard Ministry of Agriculture and Fisheries (MAF, Research Division) advisory soil tests for pH, phosphate, calcium, potassium, and magnesium. Some account of the laboratory procedures used can be found in Mountier *et al.* 1966; it should be noted however that the Truog P procedure which he gives and which was used for many years was recently superseded by a modification of the bicarbonate method described by Olsen *et al.* (1954).

(c) *Evaluation of test results*

(i) *Cations and phosphate*

Although chemical extraction techniques can give a reasonable indication of the level of readily available, i.e., exchangeable cations, and mobile or more labile forms of phosphate, the mild extractants used do not remove less-soluble or non-exchangeable nutrient forms which may nevertheless be utilised by tree seedlings. For this reason, low test ratings do not necessarily imply that seedlings will "starve" without appropriate fertiliser additions, whereas consistently high ratings generally indicate that the supply of exchangeable cations and readily-available phosphate are such that no fertiliser application is needed prior to sowing. In most instances even where ratings are high, maintenance side-dressings of a complete fertiliser during the growing season are usually desirable to replace nutrients immobilised in the crop, lost by leaching or fixed in unavailable form. In interpreting the soil test results then it is generally assumed that nursery soils analysing low in P, K, Mg, and Ca by agricultural test standards are likely to need these nutrients where rapid growth is sought.

The arbitrary criteria shown in Table 1 have been used, with reasonable success, for evaluating the fertiliser requirements of NZFS nurseries.

TABLE 1—Summary of arbitrary criteria generally used for interpreting Ministry of Agriculture and Fisheries soil quick-test ratings in relation to forest nursery soils used for production of **P. radiata** planting stock

Soil exchangeable/ readily available nutrient status	Test rating arbitrary units*			
	Ca	K	Mg	Olsen P
Satisfactory/high (S/H)	4	8	7	31
Satisfactory (S)	3	7	6	21-30
Marginal (S/L)	2	4-6	4-5	11-20
Low (L)	1	3	3	10

* Ca 1 unit = 125 ppm in soil (0.6 me/100 g)
K 1 unit = 200 ppm in soil (0.05 me/100 g)
Mg 1 unit = 5 ppm in soil (0.04 me/100 g)
P (½ hr Olsen) 1 unit = 1 ppm in soil (0.1 me/100 g)

Interpretation of test results is somewhat flexible in practice as the final fertiliser recommendations generally take some account of previous test results, the local rainfall distribution, soil type and texture, and any information on the effectiveness of past fertiliser prescriptions. Also particular attention is paid to the balance of nutrients as indicated by the test results. If P and K, or K and Mg for example, are seriously out of balance, the crop is liable to be affected by a physiological or "induced" deficiency. In this event, some redress of balance may be desirable even where individual test ratings appear adequate. Thus for example a ratio of exchangeable K : Mg in excess of 2 : 1 is likely to need some redress to avoid interference with Mg uptake (i.e., K test units $\times$ 0.05: Mg test units $\times$ 0.04 should be $\leq$ 2 : 1).

However, assuming that nutrient levels are reasonably well-balanced, the ratings shown as satisfactory are taken as an indication that pre-sowing applications of fertiliser are not needed. Ratings of "satisfactory/high" indicate that not only are pre-sowing applications of fertiliser unnecessary but also undesirable. Low ratings are generally taken as an indication that fairly heavy fertiliser dressings are needed (see Table 3), while marginal ratings signify that lighter rates should suffice to provide the necessary boost.

Suggested target levels at which labile P and exchangeable cations might, on the basis of the advisory soil tests, be maintained in *P. radiata* nurseries are given in Table 2. The ease with which these target levels can be maintained will depend very greatly on the colloid content of the particular nursery soil. Thus fine-textured soils which have a large mineral colloid fraction, and soils rich in humus, will have a much greater nutrient retention capacity than humus-depleted, coarse-textured soils. For crop produc-

TABLE 2—Target levels for bicarbonate soluble P and exchangeable cations (based on MAF advisory soil tests) in nursery soils to be used for **P. radiata** seedling crops

Nutrient index	ppm	Test units
bicarbonate soluble P (Olsen)	30	30
exchangeable Mg	30	6
exchangeable K	100-140*	5-7
exchangeable Ca	250	2

* depends to some extent on the rate of K release from soil minerals; longer established nurseries may need to aim at the higher end of this range.

TABLE 3—Guide to rates of common agricultural fertilisers which can be incorporated in the plough layer during seedbed preparation to raise soil status of readily available nutrients to a satisfactory level

Nutrient required	Fertiliser	Soil status Low (L)	Marginal (SL)
P (Ca, S)	Superphosphate (0-10-0)	500-1000	250-500
K	Muriate of potash (0-0-50)	250-375	125-250
Mg (Ca)	*Dolomite (10-13%)	500-750	375-500
Mg (S)	Kieserite (17% Mg)	250-400	125-250

* Some quick acting magnesium source (e.g., Epsom salts) may also be needed in maintenance side dressings.

Notes:

1. Nitrogen: In most nurseries it is preferable to apply 2-4 supplements during the growing season rather than a single large basal application. On lighter soils a large application of soluble N fertiliser made in advance of sowing is likely to be leached from the rooting zone before the seedings can benefit from it.
2. Selected variants of superphosphate can sometimes be used to advantage as multi-nutrient sources to meet the need for particular nutrient combinations.
3. Sulphate of potash may be preferable to the muriate in certain circumstances (see text).
4. A basic form of Mg such as dolomite or calcined magnesite is preferred where soil pH is relatively low (e.g., 4.5-5.5); where the soil pH is higher (e.g., 5.5-6.5) a neutral salt such as Epsom salts or Kieserite is more suitable.
5. As sulphur and/or calcium are normally supplied as secondary constituents of several commonly used "straight" and compound fertilisers specific additions are seldom necessary. However, where necessary, gypsum ($CaSO_4.2H_2O$; 22% Ca, 19% S) can be applied without affecting soil pH (this same compound accounts for about 50% by weight of ordinary superphosphate).

tion on the latter category of soils greater dependence must be placed on fertiliser side-dressings to the growing crop unless some marked improvement in humus content can be achieved through organic matter amendments.

(ii) *Nitrogen:*

At present there is no universally accepted and reliable laboratory method for assessing how much nitrogen will become available in the course of the growing season. Because of the wide range of soil and climatic conditions which are encountered in the various forest nurseries, and the rapid fluctuations in mineral N which commonly occur, it is doubtful whether a single simple laboratory test could provide a relative index of seasonal nitrogen availability. Total nitrogen, although usually correlated with soil organic matter (*c.* 5% N), is not a particularly reliable guide as it gives no indication of the rate at which the nitrogen is mineralised. Nevertheless it can be safely assumed that soils rating very low in terms of total N ($\leq$ 0.1%) will contribute very little N to the growing crop and that consequently an appreciable supplement of soluble applied N will be needed. Wilde and Krause (1959) estimate that, in nursery soils with uninhibited activity of ammonifying and nitrate-forming micro-organisms, the annual release of available nitrogen fluctuates between 1 and 2 percent of the total N. According to Cooke (1972), N mineralised from organic matter rarely provides more than one-fifth to two-thirds of the crop requirement on continuously cropped land. In this regard, Allison (1973) has aptly commented that the soil organic matter constitutes a nitrogen reservoir that is never completely empty and yet seldom full enough to provide enough of the element to permit maximum growth of most common crops.

(iii) *Soil reaction (pH)*

Although *Pinus radiata* seedlings appear to be tolerant of a wide range of pH (Will, 1969; Giulimondi, 1972) the range which probably represents the best compromise for a nursery soil from a nutritional and pathological standpoint is about 5.0 to 6.0. According to Bowen (1969), the best mycorrhiza production generally occurs in the pH range 4.5-5.5. Unduly high pH values in nursery soils tend to promote "damping off" fungi (Van den Driessche, 1969a). Liming of nursery soils is usually unnecessary and undesirable unless the soil test rating indicates less than 1 milliequivalent percent (2 soil test units) of exchangeable calcium, and then dolomite is generally to be preferred to lime as it also constitutes a slow-acting source of magnesium.

Problems such as lime chlorosis, resulting from reduced iron mobility, can arise where pH is in the slightly to moderately alkaline range. At the other extreme, strongly-acid soils generally have a low capacity to retain nutrient ions such as K^+ and NH_4^+ as the exchange complex tends to be saturated with Al^{3+} and H^+ ions; consequently leaching losses are liable to be commensurately larger. Most weeds are less vigorous on a very acid soil.

In most instances selective use of acidic, basic or neutral fertilisers as appropriate (*see* Ignatieff and Page, 1960: Table 8) will suffice to maintain soil pH in the desired range.

Where a large adjustment to pH is deemed necessary or desirable, this can be achieved by the thorough and even incorporation of appropriate amounts of slow-acting amendments which will either raise or lower the pH to the required value. Rules of thumb as to the approximate amounts of such amendments needed to produce a given change have been described by Armson and Sadreika (1974):

— to lower pH of a non-calcareous soil with a pH value 6, about 110 kg/ha of sulphur will be needed for each 0.1 unit reduction.

—to raise the pH of a soil in the range 4.5-5.5 by about 0.1 unit will usually require about 110-170 kg/ha dolomite, the lower rate will usually suffice on lighter soils low in organic matter.

Both of these amendments are slow-acting and take several months to take full effect. The actual amount of amendment required to raise or lower the soil pH by a given amount will depend on soil texture and organic matter content. Many light soils are weakly buffered and require less neutralising material than would be necessary to achieve the same adjustment on fine-textured soils and those high in organic matter content. Charts or tables setting out appropriate rates for soils of particular textures and pH values are given by Stoeckeler and Arneman (1960, p. 162), Ignatieff and Page (1960, p. 140), Aldhous (1972, p. 16), and Williams and Hanks (1976, p. 5).

2. *Foliar Analysis*

The fact that the concentrations of nutrients in the foliage of crops tend to reflect the availability of nutrients in the soil, has resulted in foliar analysis becoming an important and widely-used diagnostic tool in plant nutrition studies. The interpretation of foliar analysis is usually based on a comparison of foliar data with values which have been found to be marginal for normal healthy growth. The critical value for a given nutrient element can be defined as the minimum concentration at which near maximum growth is obtained. Generally, the foliar concentration ranges recorded for *P. radiata* nursery stock (Knight, 1977b) are broadly comparable to the range of values which the published literature and experience have shown can be encountered in current-year foliage of forest-grown trees of the same species at various ages. For convenience it is common practice in New Zealand to analyse the whole shoot rather than just the foliage of crops being raised for 1/0 planting stock. However foliar critical levels can still be used, as a recent study by Knight (1977b) has shown the foliar concentrations of most elements to be higher than those in the whole shoot by a fairly constant factor of *c.* 1.1-1.2.

(a) Pinus radiata *stock*

A list of provisional "critical" foliar values used for evaluating the nutrient status of radiata pine nursery crops in New Zealand is presented in Table 4. It cannot be stressed too strongly that the balance between nutrients is often at least as important as the absolute concentration of individual nutrients, so that the values shown are intended only as a generalised guide and may under certain conditions be inapplicable. Also, as progress is made in our knowledge and understanding of the nutrition of *Pinus radiata* it is possible that some of the provisional values given in Table 4 will require adjustment. In the interim they serve to represent the approximate levels at which transition from slight deficiency to bare sufficiency commonly occurs. The values therefore correspond to marginal, *not* optimal levels of nutrition. Foliar nutrient concentration ranges of macronutrients associated with maximum growth have been determined for different pine species by various investigators (e.g., Mitchell, 1939; Fowells and Krauss, 1959;

TABLE 4—Provisional critical foliar nutrient levels used as guidelines for evaluating the nutrient status of radiata pine nursery crops in New Zealand

Nutrient		Approximate lower end of sufficiency range
Nitrogen	N	1.4-1.6%
Phosphorus	P	0.12-0.14%
Potassium	K	c. 0.35%
Magnesium	Mg	0.06-0.08%
Calcium	Ca	c. 0.10%
Sulphur	S	0-80 ppm SO_4-S c. 0.12% total S
Boron	B	c. 8 ppm
Copper	Cu	2-3 ppm
Iron	Fe	25-40 ppm
Manganese	Mn	5-14 ppm
Zinc	Zn	5-10 ppm

Will, 1961a; Ingestad, 1960; 1962; Swan, 1972b, c, d) under artificial carefully controlled nutrient conditions. Usually, the sole criterion for these optima has been seedling dry weight production under the particular experimental conditions employed. Under nursery conditions, maximum dry matter production may often be desirable during the earlier part of the growing season, though later on, the emphasis is more on development of satisfactory physiological condition and quality. Consequently foliar concentrations which may be optimal as regards dry matter production are not necessarily the most appropriate in terms of physiological quality. Much remains to be learnt as to exactly what levels or nutrient ratios are optimal in relation to the ability to withstand environmental stresses such as drought and frost (*see* section on nutrient balance). Foliar N levels exceeding about 1.7-1.8% appear undesirable. Quotients of about 10 for N/P and 0.6 for K/N seem both normal and acceptable in healthy 1/0 *P. radiata stock.*

(b) *Douglas fir stock*

Krueger (1967) has given foliar data for 14 elements in both forest and nursery-grown Douglas fir in the Pacific Northwest of the U.S.A. Ratings given by Van den Driessche (1969b) (on the basis of a literature review and nursery experiments) for end of season nutrient levels in 1/0 Douglas fir (*Pseudotsuga menziessii*) are shown in Table 5.

TABLE 5—Ratings for foliar nutrient levels in 1/0 Douglas fir (data drawn from Van den Driessche, 1969b)

	N	P	K	Ca	Mg	B	Cu	Fe	Mn	Zn
Adequate	c. 2.0	c. 0.40	c. 1.2	c. 0.20	c. 0.12	9-39	5.1-7.7	—	390-1294	17-63
Low	<1.5	<0.25	<0.6	—	—	5	—	39-51	—	—
Very Low	<1.0	<0.17	<0.4	—	—	—	2.4-5.1	—	—	—

— no data given. Low — possibly limiting growth; very low — probably limiting growth

(c) *Other species*

Aldhous (1972; p. 38) gives ranges of expected values (i.e., the lower and upper limits to be expected in normal crops) for end of season analysis of foliage from 1-year-old seedlings of several coniferous species (viz. Scots pine, Corsican pine, lodgepole pine, Sitka spruce, Norway spruce, Douglas fir, Western hemlock).

Similar data are given by Armson and Sadreika (1974) for conifers grown in Ontario nurseries (white pine, red pine, jack pine, Scots pine, white spruce, black spruce and Norway spruce). Ingestad (1960; 1962) and Swan (1970; 1971; 1972a, b, c, d) have investigated the nutritional requirements of seedlings of a range of pine and spruce species, and provide guidelines for evaluating nutrient status from foliar nutrient levels for each species studied.

Benzian and Smith (1973) have examined nutrient concentrations in healthy seedlings of Sitka spruce, Norway spruce, Western hemlock and Noble fir grown in British nurseries, and have compared these data with other published data from various sources.

Will (1964) lists provisional deficiency threshold concentrations of N, P, K, and Mg in the foliage of four *Eucalyptus* species as determined by means of nursery fertiliser trials. White and Carter (1968) include a comparison of the various published deficiency thresholds for *Populus* spp.

3. *Diagnosis of Mineral Deficiencies by Visual Symptoms*

Seedling appearance (i.e., vigour, evenness of growth, foliage colour, length of needles and any morphological peculiarities) can often give a useful indication as to which, if any, nutrient is in short supply in a particular nursery crop. Certain visual symptoms or combinations of symptoms tend to be specific to particular nutrient disorders. However, it sometimes happens that although growth is markedly depressed as a result of nutrient stress, the particular deficiency may not be so acute as to induce distinctive visual symptoms.

It is beyond the scope of this paper to more than briefly allude to the various symptoms associated with specific nutritional disorders in forest nursery crops. A list of references to nutritional studies or papers in which the visual symptoms associated with specific mineral deficiencies are documented for radiata pine, Douglas fir, *Eucalyptus* spp. and *Populus* spp. is given in Table 6.

Abnormal appearance of nursery seedlings often results from causes other than nutrient deficiency or imbalance. Careful examination of affected seedlings can generally eliminate many potential non-nutritional causes. For example, spotting, blotching or banding of pine needles is more likely to be caused by fungal infection than by nutrient deficiency. Perusal of recent nursery records may point to chemical damage (e.g., by fertilisers or biocides), or climatic damage by frost, drought, wind abrasion, water-logging, or insect attack.

In new nursery areas, extremely patchy beds with uneven sized seedlings are likely to be caused by lack of uniform mycorrhizal inoculation rather than by outright nutrient deficiency. Absence of any mycorrhizae on the root systems of stunted seedlings will generally confirm this.

In New Zealand forest nurseries, probably the commonest deficiency is that of

TABLE 6—Sources, including mineral nutrition studies, for descriptions of specific nutrient deficiencies in selected nursery species (**P. radiata**, **Eucalyptus** spp, Douglas fir, Poplar spp.)

Species	Nutrient(s) studied	Reference
Pinus radiata	N,K,Ca,Mg	*Purnell, 1958
" "	N,P,K,Mg(Ca),Fe(S)	Will, 1961a
" "	N,P,K,Ca,Mg,Fe	*Truman, 1972
" "	Ca	*Flinn, 1975
" "	Mg	Will, 1961b
" "	Ca,B	Snowdon, 1972
" "	B	Ludbrook, 1940
" "	B,Cu,Mn,Mo	Smith, 1943
" "	Zn	Smith and Bayliss, 1942
" "	B,Mn,Mo	*Marcos de Lanuza, 1966
" "	Cu,Zn	*Knight, 1975; 1976
" "	Fe,Cu,Zn	Marcos de Lanuza, 1968
Eucalyptus gomocephalia	N,Mg,Fe (salt injury)	Karschon, 1963
" **botryoides**	N,P,K,Mg,Ca	*Will, 1961c
" **saligna**	"	"
" **pilularis**	"	"
" **hybrid**	N,P,K,Ca,Mg,S	Kaul **et al.**, 1966a
" "	"	" " 1966b
" **grandis**	"	" " 1968
" **citriodora**	"	" " 1970a
" **globulus**	"	" " 1970b
" **pilularis**	N,P,K,Mg,Ca,S,Fe	*Truman and Turner, 1972
" **globulus**	N,P,K,Ca,Mg	*Marcos de Lanuza and Marzo Munoz-Cobo, 1968; 1969
" spp.	B	Savory, 1962
" **grandis**	"	" "
" **saligna**	"	" "
Pseudotsuga menziesii	K,Mg	Gessel **et al.**, 1951
" "	N,P,K,Mg	*van Goor, 1970

* Description includes colour plates

NITROGEN. For radiata pine and Douglas fir, seedling colour provides a sensitive index of nitrogen status, with a healthy green colour generally indicating an adequate supply. With diminishing supply, foliar colour passes from a uniform normal light green (Munsell colour notation 7.5 GY 5/6) to a fairly uniform yellow green (2.5 GY 7/6) and growth rate becomes increasingly depressed. An oversupply of N results in a dark green heavily branched, soft plant.

Acute deficiencies of *PHOSPHORUS* or *POTASSIUM* such as result in the distinctive visual symptoms described in the literature do not appear to have been recorded in nursery stock under New Zealand conditions. Depressed growth resulting from inadequate supply of one or other of these nutrients does undoubtedly occur from time to time. A mild deficiency of potassium may even pass unrecognised as only a general reduction in growth results. A more acute deficiency results in yellowing of the tips of older needles with some necrosis. The characteristic golden yellow needle-tip chlorosis caused by *MAGNESIUM* deficiency (Will, 1961b) seems to have been particularly prevalent on pumice soils. Putative physiological *IRON* deficiency has also been encountered in certain pumice soil nurseries. Characteristically the apical tuft is affected first becoming a yellowish-green colour. *SULPHUR* deficiencies have not been recorded in New Zealand nurseries and are unlikely to occur where fertilisers containing sulphate are routinely used. Yellowing of the young foliage and stunted growth are characteristic of a sulphur deficiency.

As yet, there is no documented instance of a deficiency of either *CALCIUM* or *BORON* affecting nursery stock. A deficiency of the former is unlikely wherever superphosphate or dolomite limestone are regularly applied. A recent survey of nursery stock (Knight, 1977b) showed that foliar B levels in 1/0 *P. radiata* stock from at least two nurseries were well below average and that some improvement in B supply was desirable. Both Ca and B deficiencies generally result in damage to the apical meristems of seedlings. The earliest symptoms in radiata pine seedlings grown in both B- and Ca-free cultures (other than retarded growth) is the appearance of resin droplets on the apical needles or bud (Snowdon, 1972).

On the strongly acid peat soil of Sweetwater nursery, distinctive micronutrient disorders have been recorded in radiata pine seedling crops on two separate occasions (Knight, 1975, 1976). The earlier disorder, found to be caused by *COPPER* deficiency, was characterised by the wilted appearance of the apical tufts and by needle-tip necrosis. The later disorder which was diagnosed as *ZINC* deficiency, was characterised by a high incidence of retarded bud formation or, in severely affected plants, necrosis of the apical portion of the plant; some yellow or bronzing of the foliage was also evident. Both deficiencies resulted in a marked reduction in growth.

ESTIMATES OF NUTRIENT DEPLETION BY *PINUS RADIATA* SEEDLING CROPS

1. *Nutrient Content of* P. radiata *Planting Stock*

Van den Driessche and Wareing (1966), in a comparison of the productivity of various conifer species, viz. radiata pine, larch, Douglas fir, Scots pine, lodgepole pine, Corsican pine and Sitka spruce under carefully controlled conditions, concluded that *P. radiata* was remarkable in having produced the greatest dry weight at all nutrient levels, and in having a better yield at the lowest nutrient level than any other of the conifers represented. Because of the former invaluable attribute, radiata pine seedling crops impose a substantial nutrient drain on nursery soils.

A survey of radiata pine planting stock from 17 forest nurseries was recently undertaken (Knight, 1978) to determine the nutrient content of apparently normal, healthy seedlings grown under a range of New Zealand conditions. An indication of the ranges of dry weight and nutrient content per thousand seedlings recorded for three age classes is given in Table 7.

The limited data available indicate that the number of seedlings produced may range from about 250 000 to 750 000 useable plants per ha of cropland depending on the particular nursery bed module and seedling spacing in use. For this reason it would be unwise to offer any generalisation as to the quantity of nutrients removed per ha of productive area.

TABLE 7—Range by age-class of nutrient* content per thousand seedlings

Crop age-class	Dry matter ($kg/10^3$seedlings)	N	P	K	Mg	Ca	B	Mn	Zn
		Nutrient content ($g/10^3$ seedlings)							
1/0									
max:	15	174	22	102	14	57	0.2	5.5	0.8
min:	6	56	7	36	4	16	0.1	0.3	0.2
1½/0									
max:	32	441	52	246	22	138	0.4	7.1	2.3
min:	15	129	16	83	12	40	0.2	1.0	0.5
2/0									
max:	26	210	32	129	17	92	0.3	7.0	1.1
min:	13	110	18	85	9	34	0.2	2.0	0.5

* Few samples were examined for Cu as fungicidal copper sprays are routinely used in most of the nurseries represented. For the few samples examined, copper content ranged from 0.05-0.10 g/1000 seedlings.

(2) *Crop Nutrient Removal in Relation to Fertiliser Practice*

The amount of fertiliser that should be applied for maximum productivity is almost invariably more than the amount of nutrient removed by the crop produced. This is because only a proportion of the added nutrient may actually be taken up by the crop; the balance may become either immobilised in the soil (especially P), lost to the atmosphere (mainly N) or leached beyond the rooting zone (especially the more mobile anions e.g., NO^-_3 and $SO_4{}^{2+}$). Fried and Broeshart (1967) sum up the relationship between nutrient removal and fertiliser application as follows: "In the case of N and to some extent K, the quantities removed {by crops}, together with some consideration of the losses or natural additions, can give some indication of the quantity to be applied as fertiliser. For Mg there is less of a relationship, and for P very little".

The efficiency of fertiliser utilisation is seldom known with certainty for individual forest nursery soils. Leaching losses may vary appreciably from year to year, depending on land use, rainfall seasonal distribution, and the particular fertiliser regime which is in operation. As a broad indication of the sort of recovery rates to be expected, the figures given by May (1958) for southern pine nurseries established on acid sandy loam soils in the U.S.A. are of interest. He suggests that recoveries are of the order of 60 percent of applied N and K, and in the range 15 to 30 percent for phosphorus. Under New Zealand conditions total applications of nitrogen and potassium may need to be some 2-3 times greater than actual crop removal, while the amount of P may need to be tenfold or more.

COMMERCIAL FERTILISER USAGE

In New Zealand, most nutrient supplements are at present applied in solid form, though occasionally foliar applications of aqueous solutions of materials such as urea, magnesium sulphate or soluble micronutrients salts are made to growing crops to prevent or alleviate a particular nutrient deficiency. Although several nurseries have sprinkler irrigation systems, none have made use of them for applying fertiliser in the irrigation water. As yet, use has not been made of concentrated liquid fertilisers or fertiliser suspensions for direct soil application in New Zealand nurseries. Use of such materials in the future will depend on availability of suitable formulations as well as on-site application costs. Reasons given (Cooke, 1967) for the increasing popularity of such materials for arable crops in the U.S.A. (and other countries where they are manufactured) include their cheapness and suitability for bulk handling and spreading; they can be applied more uniformly and accurately than solids. Fertiliser suspensions have one important advantage over liquid fertilisers in that they can be formulated with a high percentage of potassium.

1. *Pre-sowing Dressings*

Where soil tests indicate the need for large amounts of one or more nutrients to supplement the existing soil supply, the appropriate amounts of "straight"* fertiliser (*see Table 3*) are generally broadcast over the land and worked (generally by discing) into the main crop rooting zone prior to seedbed formation.

(a) *Nitrogen*

On light soils low in organic matter and mineral colloids, highly soluble nitrogen fertilisers should not be applied before sowing as it is probable that the greater part of any nitrogen applied at this stage will be lost by leaching before the plants have developed sufficiently to benefit from it. On fine-textured soils however, a light dressing of ammonium sulphate can sometimes be applied to good effect as the ammonium is held by the clay and humus fractions for a time until converted to the more easily leached nitrate form. In most instances however, highly soluble nitrate and ammonium salts are best applied as side-dressings during crop growth.

An organic fertiliser once favoured in nurseries as a convenient means of applying pre-sowing dressings of nitrogen in water-insoluble form was blood and bone (6-7-0). As it is water-insoluble, relatively heavy rates of this material can be incorporated in the rooting zone without risk of salt injury, though excessively heavy rates can increase the activity of damping-off organisms and should therefore be avoided. There seems to be little factual basis for the supposition that this material provides a slow but steady supply of N over an extended period. Experiments conducted overseas with similar materials (Rubins and Bear, 1942; Clark *et al.*, 1951) suggest that this is largely a fallacy, and that where conditions favour rapid decomposition most of the total nitrogen is mineralised during the first 3 weeks or so after incorporation. Because of its high cost per unit N, often irregular supply and the trend towards use of side-dressings to supply the growing crop's N requirements, there is now little use of blood

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* This arbitrary designation is used here, and subsequently, to refer to those widely-used agricultural fertilisers (such as urea, ammonium sulphate, superphosphate and muriate of potassium) which individually supply only one of the primary plant nutrients at relatively low unit cost. It is also taken to indicate N-free superphosphate variants such as potassic "super", serpentine "super", etc., as well as important nursery sources of magnesium such as dolomite and Epsom salts.

and bone in New Zealand nurseries. In a few nurseries it is still used at about 100 kg/ha with other fertilisers in the pre-sowing dressing.

Although a number of imported synthetic slow-release nitrogen carriers are commercially available in New Zealand, their high cost per unit nutrient has tended to preclude their general use in forest nurseries. The main advantages which such materials offer over ordinary soluble N sources are reduced application costs (since repeated applications are unnecessary), freedom from salt injury, and slow, steady release of soluble N over an extended period. However, there is some risk that supply may lag behind demand in some seasons with nitrogen starvation as a consequence. The main types which are at present commercially available in New Zealand are listed and discussed by Knight (1977).

In some nurseries where eucalypt species are grown there has been a move towards slow-release fertilisers. Because of the small seed size of *Eucalyptus* species and consequently the small nutrient reserves contained therein, it has been found beneficial in the FRI experimental nursery (A. E. Summers, pers. comm.) to incorporate basal dressings of slow-release fertilisers such as magnesium ammonium phosphate (MagAmp*, 7-17-5+12 Mg), and IBDU* (32-0-0) in the seed bed. In this way near-optimal growth is assured in the early stage of development without risk of damage to the very small seedlings. Later in the season maintenance side-dressings of less expensive soluble fertilisers are given to boost growth. Rates which have been found effective are 500 kg/ha IBDU* and 250 kg/ha of MagAmp*. In Athol Nursery (New Zealand Forest Products Ltd) a basal dressing of 400 kg/ha IBDU* plus 125 kg/ha Complesal Supra* (12-5-14+1.2 Mg) has also given good results.

(b) *Phosphorus*

In many nurseries broadcast applications of phosphorus are made in the form of ordinary granulated superphosphate (10% P; on average about 85% of the total P is water-soluble), or where it is desired to include nutrients such as K, Mg or B in the same dressing, the appropriate variant may be used. The rate at which superphosphate is applied generally ranges from about 250 to 1000 kg/ha depending on the soil type and soil test result. It is generally worked into the soil to a depth of at least 10 cm to ensure that it is readily accessible throughout the main zone of root development. On coarse-textured acid soils predisposed to exhaustive leaching, a reverted form of superphosphate is sometimes applied.

(c) *Potassium*

In New Zealand the most widely used potassic fertilisers are the sulphate (40% K) and the chloride (muriate) (50% K) salts of potassium. Both forms are readily water-soluble, and are generally used at rates of 125-375 kg/ha according to soil test value and soil type. The sulphate which also contains 18% S in water-soluble form is roughly three times as expensive as the muriate per unit K.

As both salts supply K in identical form, the main factors which have to be considered in selecting one or other form are firstly the cost per unit K, and secondly the effect of the accompanying ion. In most instances the cheaper muriate is the logical

* Brand names

choice. However, where there is any risk of excessive chloride accumulation in tree stocks (as for example in nurseries located in more exposed coastal situations, or where the ground-water tends to be locally high in chlorides e.g., Pakipaki nursery), the sulphate form is used. It should be noted that, as heavy dressings of potassic fertilisers to soils low in Mg may induce magnesium deficiency in the crop, care should be taken to avoid any such imbalance.

(d) *Calcium and magnesium*

The approximate calcium contents of superphosphate and its principal variants are given in Knight (1977) as well as a list of fertiliser sources of magnesium and their Mg concentrations. Levels of soil calcium and magnesium can conveniently be increased in acid soils by applying finely ground dolomitic limestone (usually about 22% Ca, 10-13% Mg) during land preparation. This slow-acting material is applied at rates of from about 375 to 750 kg/ha depending on soil pH and soil test ratings for Ca and Mg.

The use of dolomitic limestone is always preferable to calcitic limestone on acid nursery soils low in Mg, since the latter amendment may result in an unfavourable Ca/Mg ratio, possibly increasing Mg deficiency. As the rate of solution of dolomitic limestone is much slower than for calcitic limestone (at pH 7 or higher dolomitic limestone becomes nearly insoluble) there is far less danger of over-liming (Ignatieff and Page, 1960). Where some increase in both pH and Mg level is sought without any increase in soil Ca level, calcined magnesite (MgO, 48-55% Mg) can be used. This relatively cheap, imported material is quick-acting in moist, acid soils, and weight for weight is usually a little more than twice as effective as dolomitic limestone in raising soil pH.

Where no change in pH is sought, magnesium can be applied in the form of Kieserite ($MgSO_4.H_20$, 17% Mg) or Epsom salts ($MgSO_4.7H_2O$, 9.6% Mg). To furnish about 40 kg/ha of Mg would require about 250 kg/ha of the former or 400 kg/ha of the latter. Epsom salts dissolve rapidly in water, whereas Kieserite has a much slower rate of solution. Serpentine superphosphate (5-6% Mg of which about 40% is water-soluble) can be used to supplement Mg without affecting soil pH where additional P is also required.

(e) *Sulphur*

On the assumption that a 1/0 radiata pine crop requires approximately the same amount of S as P, it can be estimated that a crop of half a million tree seedlings per ha will require between 4 and 9 kg/ha of S, the actual amount depending on dry matter produced. The incidental applications of sulphate sulphur in superphosphate (10-12% S) or in soluble sulphate sources such as ammonium sulphate (24% S), Kieserite (23% S), Epsom salts (13% S), sulphate of potash (18% S) etc., together with sulphate released by mineralisation of organic matter, generally ensure that the demand is adequately met. As a general safeguard on light soils, the amount of sulphur applied in various forms should amount at least to one-fifteenth the total amount of N applied and, as for N supplements, soluble sources preferably should be applied to growing crops in several small applications.

Elemental sulphur, which in the soil is oxidised by microbial action to sulphuric acid, can be used as an amendment for drastically lowering soil pH. It is also used commercially to coat urea prills to slow down the rate of solution of this readily soluble nitrogen source. One such slow-release product marketed in New Zealand, "Gold-N" (32% N) (used as a pre-sowing dressing for *Eucalyptus* seedling crops in certain nurseries), contains about 30% by weight of elemental sulphur as a coating. Where this product is used, care should be taken to counteract its acidifying action with a material such as dolomitic limestone.

(f) *Micronutrients*

Micronutrient supplements have seldom proven necessary in most New Zealand nurseries.

In districts where a needle blight caused by the fungus *Dothistroma pini* is prevalent, monthly spraying with an aqueous suspension of cuprous oxide is normally carried out. The actual amount of copper applied varies from nursery to nursery, though nominally it amounts to about 2.2 kg/ha per treatment so that a deficiency of this micronutrient can be ruled out in these areas. In the few isolated instances where deficiencies have been recorded, e.g., on peat soil at Sweetwater, applications of dilute aqueous solutions of soluble salts, or suspensions of insoluble compounds to either the soil or crop have generally proved both convenient and effective (Knight, 1975; 1976).

2. *Fertiliser Applications to the Growing Crop*

As nurseries are often located on coarse-textured soils of low cation exchange capacity and poor nutrient reserves, repeated applications of readily soluble fertilisers containing the mobile elements N and K are commonly necessary during the more active growth period to ensure adequate nutrient supply. In most nurseries two or more light maintenance dressings are applied at appropriate intervals, either as topdressings, i.e., broadcast applications of granulated fertiliser, or as side-dressings drilled between the seedling rows, to supplement the soil nutrient supply and to make good any overall decrease in nutrient availability resulting from crop removals, fixation, leaching or other causes.

Side-dressing with accurate placement between the seedling drills is generally preferable to broadcast topdressing as the latter method can result in uneven application, as well as damage to the plants through lodgement of granules in the seedling tops. The apical buds of pine seedlings are particularly susceptible to fertiliser damage. Where equipment is not available for side-dressing, and topdressing has to be resorted to, precautions such as only topdressing when seedling foliage is dry, and using suitable means (e.g., towing weighted scrim behind the spreader) to shake loose any granules which may have lodged in the seedling tops, help to reduce the risk of damage.

The type of fertilisers used for application to the growing crop are normally quick-acting, water-soluble materials — mostly either nitrogenous fertilisers (e.g., prilled urea) or granulated multi-nutrient fertilisers, though occasionally straight fertilisers such as magnesium or potassium sulphate are used where necessary.

Although *P. radiata* seedlings can utilise either nitrate-N or ammonium-N, it has been reported (McFee and Stone, 1968) that they exhibit greater growth and N uptake with an ammonium source and that this superiority is independent of pH effect. For Douglas fir seedlings, it has been reported (Radwan *et al., 1971)* that seedling growth was essentially the same with calcium nitrate and urea and that both fertilisers were superior to ammonium sulphate.

(a) *Straight nitrogenous fertilisers*

In New Zealand nurseries, the straight nitrogenous fertilisers which are most commonly used are urea and ammonium sulphate. Although ammonium nitrate is often referred to in overseas literature dealing with nursery soil management, it is not generally imported because of its potentially explosive properties and fire risk under certain conditions. However, it does occur in safe form in certain imported European formulations e.g., as a component of granulated nitrophosphate fertilisers ("Complesal", "Nitrophoska" and "Rustica"), in granulated carbonate of lime-coated granular formulations e.g., "Calnitro" (26% N), calcium ammonium nitrate (20 or 26% N) and in dolomite-coated granular formulations e.g., "Nitro Magnesia" (20% N, 5% Mg).

Urea is not generally used on soils with pH of 6.0 or greater because of the risk of volatilisation (Tisdale and Nelson, 1975). Where applied to the soil as a solid side dressing, split applications using low rates (50-100 kg/ha urea) are generally preferred to high rates because of the risk of volatilisation, as well as of injury to the crop from the temporary high concentration of ammonia produced during rapid hydrolysis.

Ammonium sulphate (21% N) is presently slightly more expensive than urea per unit N, but has the advantage of supplying 24% of its weight as readily available sulphur. It is less hygroscopic than most other synthetic nitrogen fertilisers (*see* Ignatieff and Page, 1960; p.76) and, by virtue of this, is convenient to handle, store and mix with other materials. As the ammonium ion (NH_4^+) is retained by the soil colloids, this fertiliser, in common with other ammonium sources, initially provides a less-mobile form of N than nitrate sources. Ammonium sulphate is usually applied at 100 to 250 kg/ha when used as a side-dressing.

The use of ammonium or ammonium-forming fertilisers over an extended period of several years tends to lower soil pH. While an acid reaction is generally beneficial to most coniferous seedlings, an excessively low pH (e.g., lower than about 4.8), is undesirable as it can lead to toxic levels of soluble aluminium and manganese in the soil as well as accelerated leaching. However the soil pH is easily and economically raised by an appropriate application of dolomite if it becomes too low.

Although side-dressing rates vary somewhat depending on local conditions, particular crop, and stage of development of seedlings, usual rates for straight nitrogenous fertilisers generally lie in the range 40-100 kg/ha N per application. The lower rate is more suitable in most instances. Where supplementary potassium in straight fertiliser form is considered necessary, this is applied as sulphate of potash at a rate of about 125 kg/ha (i.e., 50 kg/ha K). Similarly supplementary magnesium is applied as magnesium sulphate — either as Epsom salts at 125 kg/ha (12 kg/ha Mg), or Kieserite at the same fertiliser rate (equivalent to about 23 kg/ha Mg).

(b) *Granulated compound fertilisers*

To reduce transport and labour costs and eliminate storage problems associated with nursery fertiliser mixtures, it has been found convenient in many nurseries to make use of commercially available compound* fertilisers. By applying light side-

* A compound fertiliser (or in American usage a "mixed" fertiliser) is defined (Anon, 1967) as containing at least two and usually three primary nutrients in definite predetermined percentages. Where such a fertiliser contains all three primary nutrients (NPK) it is often referred to as a complete fertiliser.

dressings of suitably balanced granulated multinutrient fertiliser at appropriate intervals during the growing season, a well-balanced nutrient supply can be ensured on even the least fertile of nursery soils provided adequate moisture is also available.

Although compound fertilisers are generally appreciably more costly per unit nutrient than straight fertilisers, this is offset to some extent by the convenience and the saving in application costs and time which result when all needed nutrients are supplied in balanced quantities in a single dressing. Granulated fertilisers are generally easier to handle, store and spread uniformly than mixtures prepared from powdered straight fertilisers; although more expensive to manufacture, they are generally cheaper to transport and apply than the bulkier low analysis mixtures. Also they are rather less liable than certain straight fertilisers (e.g., superphosphate and ammonium phosphate) to result in accelerated leaching losses of nutrients such as K and Mg through displacement of the ions from the soil exchange complex by Ca^{2+} and NH_4^+ ions respectively.

The list of brand names and grades offered commercially is somewhat bewildering at first sight, but many can be eliminated as being unsuitable for general use in forest nurseries on grounds of nutrient proportions, cost, or both. The types of granulated complete compound fertilisers which are generally available in New Zealand are listed by Knight (1977). He also discusses in detail the selection and use of appropriate grades in nurseries.

(1) *Magnesium supplements*

Where a complete fertiliser used for side-dressing does not supply either magnesium or sulphate it is sometimes necessary to supplement it with a separate soluble material such as Epsom salts ($MgSO_4.7H_2O$; 9.6% Mg, 13% S) or Kieserite ($MgSO_4.H_20$; 17% Mg, 23% S) to ensure adequate supply of readily available Mg and S during the period of peak growth. The former rapid-acting compound can be applied either as a side-dressing (*c.* 125 kg/ha) or as a foliar application (see next section). Kieserite is only slowly soluble and is therefore not suitable for foliar application.

3. *Foliar Application of Nutrients*

It is well known that plant nutrients can be rapidly absorbed through the foliage of plants, and that this method of fertilising can in many instances be used to swiftly alleviate specific nutrient deficiencies, or to improve the nutrient status of a particular crop more rapidly than is usual by soil applications. The chief advantages of the method of application are uniformity of coverage, ease and speed of treatment, rapidity of absorption and utilisation, and freedom from soil fixation problems. The main limitation is that only very weak nutrient solutions can be safely used if foliar scorch is to be avoided; consequently foliar applications are usually reserved for occasions when it is desirable either to elicit a rapid improvement in growth rate and vigour, or to correct a specific deficiency or imbalance which may have developed. Such a need can arise from a variety of factors including shortage of available nutrients in the soil, root impairment due to mechanised conditioning practices, or unfavourable climate conditions.

Concentrations of between 1 and 5% w/v are suitable for most compounds supplying macronutrients and 0.1 to 1.0% for most of those supplying micronutrients (see Table 8). Responses from spray treatments commonly require a period of 1-2 weeks to become plainly visible in the foliage, though sometimes repeat applications at 2-3 week intervals may be necessary to produce the desired effect. Over-dosages can result in severe scorching and should always be avoided.

The relatively high application cost per unit of plant nutrient when applied in this way can sometimes be reduced by combining foliar fertilisation with other routine spray operations. Chemical compatibility is a prerequisite to any such combined operation and should not be taken for granted.

Although very useful for boosting or maintaining vigorous growth during dry periods or when the normal root functions have been disrupted by routine mechanised undercutting, lateral root pruning and wrenching operations (*see* van Dorsser and Rook, 1972), foliar nutrient sprays cannot normally take the place of soil applied fertiliser dressing and must be considered as supplemental.

Table 8 gives concentrations for single salt chemical solutions which have been found both safe and effective in practice. Certain nutrients do not feature in the table as there has been no precedent for their use in New Zealand nurseries to date.

Urea is the most suitable nitrogenous fertiliser for foliar application (Eberhardt and Pritchett, 1971). It is absorbed by the foliage within a few hours of spraying, commonly with recoveries of about 70% (Russell, 1973). According to Franke (1967), the high permeability of leaves to urea also favours absorption of ions applied together with urea; the rate of penetration of urea exceeds that of ions by 10- to 20-fold and its rate of entry is independent of concentration. The strength of solution that can be safely tolerated by *P. radiata* seedlings depends on the stage of growth as well as climatic conditions. In general foliar applications are best avoided where there is a prospect of unseasonably cold weather. Cumulatively, the small doses of N which can be safely applied, can make a large difference to the N status of a seedling crop.

Concentrated (high analysis) fluid fertilisers other than urea solutions (e.g., 'Liquid N20') are not readily available in New Zealand at the present time. Thus ammonium polyphosphate solutions (e.g., 11-16-0), although suitable in many respects for foliar application (after dilution), are not used. The concentrated urea solutions which are commercially available have a solution strength of about 48.8% w/v urea and therefore require about 10-fold dilution to give a 5% w/v solution of urea suitable for foliar application.

In New Zealand forest nurseries, the nutrients most commonly applied in foliar sprays are nitrogen, magnesium and iron. Apart from occasional instances of physiological iron deficiency in nursery crops, acute micronutrient deficiencies (Cu and Zn) have so far only been recorded in peat soil in Sweetwater nursery. Very few nurseries currently make use of balanced foliar sprays that supply all primary nutrients; even fewer (possibly none) use a spray which supplies both macro- and micronutrients. Application of a balanced foliar spray (containing at least the primary and secondary nutrients), however, avoids risk of imbalance in nutrition and therefore merits consideration. An appropriate solution can either be made up from a few simple basic ingredients, or from solid or liquid commercial concentrates designed for foliar application after dilution.

To prepare a 100 litre spray solution of formulation (% w/v) 1.5 : 0.1 : 1 : 0.2 (Mg): 0.3 (S) would require 3.26 kg urea, 204 ml phosphoric acid (SG 1.75), 2.0 kg muriate of potash and 2.0 kg of Epsom salts.

At present there is no sound experimental basis for recommending the use of spreaders, stickers or spreader-stickers in conjunction with foliar sprays in the nursery. Radiata pine seedlings are liable to be damaged by the solution strengths given for urea in Table 8 if a wetting agent is included (van Dorsser, pers. comm.); however the relative efficiency of foliar absorption with and without such an agent has not been compared.

TABLE 8—Fertiliser solutions used as foliar sprays on radiata pine seedlings in N.Z. nurseries(1)

Element	Chemical Source	Formula	Content (%) of: element	sulphur	Solution[1]	Nutrient applied[2]
			%	%	% w/v (compound)	kg/ha (element)
N	urea[3]	NH_2CONH_2	46	0	5 2	11.5 4.5
Mg	Epsom salts[4]	$MgSO_4.7H_2O$	10	13	5	2.5
Fe	Ferrous (Iron) sulphate[4]	$FeSO_4.7H_2O$	20	11.5	5	5.0
B	Borax	$Na_2B_4O_7.10H_2O$	11.3	—	0.2-0.5	0.11-0.28
	Solubor	$Na_2B_8O_{13}.4H_2O$	20.5	—	0.2-0.5	0.20-0.51
Cu	Copper sulphate[4,5]	$CuSO_4.7H_2O$	25	12	0.5	0.62
Mn	Manganous sulphate[4]	$MnSO_4.4H_2O$	24	14	1	2.4
Zn	Zinc sulphate[4]	$ZnSO_4.7H_2O$	23	11	1	2.3

(1) Safe concentration (%) w/v) of single salt solution. Where combinations of two or more compounds are included in the same spray solution the concentration of each should be substantially reduced; e.g. to supply N, Mg and Fe together, compound concentrations of 2% w/v each would be more appropriate.

(2) Rate as kg/ha for element concerned when solution applied at standard rate of 500 litre/ha.

(3) The strength of solution that can be safely tolerated depends on stage of growth and climate factors. If frosts are likely concentration should not normally exceed 2% w/v. For eucalypt species, the strength should not exceed 0.5% w/v (equivalent to 1.15 kg/ha N) even when frost free conditions obtain.

(4) Magnesium, iron, copper, manganese and zinc can alternatively be supplied in chelated form; a loosely bonded state which reduces both toxicity and tendency to form insoluble compounds. Generally a concentration of 0.05% w/v compound applied in 500 litres will be suitable. EDTA chelates contain (Cu) 9.8, Mn 9.8, (Mg) 6, (Zn) 14 and (Fe) 14% element while EDDHAFe supplies (Fe) 6%.

(5) Scorching can be avoided by adding 1.25 kg of sodium carbonate for each kilogram of copper sulphate in the spray solution. Alternatively copper oxychloride (50% Cu) or cuprous oxide (also 50% Cu) can be applied e.g. at 0.5% w/v compound as for routine **Dothistroma** prophyllaxis.

FERTILISATION IN RELATION TO PHYSIOLOGICAL QUALITY

There are two important objectives in applying fertilisers in forest nurseries: the first to economically ensure that a vigorous even crop of the desired or specified morphological grade of stock can be regularly produced, and the second to confer on the stock the maximum potential for survival and rapid early growth by ensuring that at lifting the seedlings are nutrient full and nutritionally well balanced.

The second objective can pose more problems than the first as the most appropriate nutrient balance for optimum physiological quality under particular conditions has not been established and, in any case, there is not, for New Zealand's forest nurseries, currently any provision for routinely monitoring crop nutrient status during the growing season. This means that the onus falls largely upon the nursery manager to decide how to produce stock of an acceptable physiological quality. It is hardly surprising therefore that morphologically similar stock from different nurseries sometimes perform very differently on the same planting site. Long ago Wakeley (1954) drew attention to the fact that morphological grade does not give a reliable indication of physiological quality. More recently, a study (Rook *et al.,* 1977) with radiata pine seedlings under carefully controlled conditions has shown that, even with every care at planting, survival immediately after transplanting can be poor despite a healthy, well-conditioned appearance in stock.

Although the literature generally confirms the importance of balanced mineral nutrition in the nursery for survival and rapid early growth, the impact of particular nutrient treatments has tended, under different sets of conditions, to yield conflicting results. This possibly derives from failure in many instances to take into account actual plant composition and, more especially, the balance between nutrients. Also there is evidence (Menzies, 1976) that seedlings are physiologically hardier in July/August than in May irrespective of conditioning methods or nutrient supply; thus studies in which nutrition is confounded with time of season are likely to yield conflicting results. Many instances have been recorded where correction of a specific deficiency or imbalance has resulted in greater resistance to frost damage in conifers (e.g., Atterson, 1967; Baule and Fricker, 1971) and in eucalypts (Cooling, 1967; Summers (FRI nursery), pers. comm). Recently however, it has been shown by Timmis (1974), working with Douglas fir seedlings, that balance between nutrients (in particular N and K) can be an important factor in cold hardiness.

Also there is considerable evidence that nutritional status has an important bearing on drought resistance. The ability of planting stock to withstand drought following outplanting depends to a large extent on (1) the rapidity of root expansion and (2) on the capacity of the seedling to reduce water loss and tolerate a water deficit (Brix and van den Driessche, 1974).

The capacity for rapid root expansion following outplanting seems dependent in part at least on a suitably high N status in stock (Switzer and Nelson, 1967). However, the role of N nutrition in relation to conditioning of radiata pine seedlings needs further detailed study as there is no doubt that, under some conditions, late season applications of N fertiliser to stock can adversely affect survival. The maintenance of a satisfactory water economy in conifer seedlings hinges, at least in part, on potassium status (Zech *et al.,* 1969; Christersson, 1973; Bradbury and Malcolm, 1977).

Until such time as criteria for optimum nutritional balance in relation to physiological balance are established, the nurseryman must continue to rely on his own judgment in striking a suitable balance between adequate and excess nutrition. This means taking every care to avoid gross imbalance, particularly between N and other nutrients. An increase in the supply of a limiting nutrient (and N is the most commonly limiting nutrient in nurseries) not uncommonly results in a decrease in the concentration of other non-limiting elements (dilution effect). Thus there is an ever present risk that late season applications of N alone can adversely affect the nutrient balance within the plant. The approach advocated by Brix and van den Driessche (1974) for container seedlings, viz. that the fertiliser regime should be adjusted throughout the growing season to meet the changing requirement for optimum nutrition seems worthy of consideration in relation to open grown seedling crops. In this way, emphasis can be placed on rapid growth initially with proportionately more N supplied, and physiological quality later in the season with proportionately more K.

Nearly 2 decades ago, Stoeckeler and Arnemann (1960) drew attention to (1) the need to correlate drought resistance and frost hardiness with the balance of nutrients in plant tissue or other physiological criteria and (2) the importance of carrying nursery nutritional trials into the field to evaluate the effects of nursery treatments. Their assessment of research needs in relation to nursery fertility seem no less apposite today. Indeed, as actual value of seedling crops and the quantity of stocks produced have both greatly escalated in recent years, the need for research along these lines seems all the more urgent.

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