THE NUTRIENT CONTENT OF *PINUS RADIATA* SEEDLINGS: A SURVEY OF PLANTING STOCK FROM 17 NEW ZEALAND FOREST NURSERIES

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ABSTRACT

Representative samples of **Pinus radiata** planting stock (1/0, 1½/0 or 2/0) were collected at time of lifting from 17 nurseries throughout New Zealand. Individual sample averages for size, dry weight and nutrient content ranged widely for each age-class as a result of differences in seed source, climate, soil type and management practices. For 1/0 and 1½/0 stock, mean seedling height was 23-44 cm and 33-60 cm respectively, while average dry weight per seedling for the same two age-classes was 6.3-15.1 and 14.7-32.5. Nutrient removal by crops also ranged widely. The highest dry matter production for 1/0 crops was 7.9 t/ha at a stocking of 525 000 seedlings/ha. This crop contained (kg/ha): 76 (N), 9 (P), 49 (K), 4 (Mg), 30 (Ca), 0.08 (B), 2.9 (Mn) and 0.3 (Zn). The highest dry matter production recorded for the 1½/0 crops was 20 t/ha at a stocking of 616 000 seedlings/ha. For this crop, nutrient removal was equivalent to (kg/ha): 232 (N), 32 (P), 140 (K), 14 (Mg), 57 (Ca), 0.23 (B), 3.4 (Mn) and 1.4 (Zn).

INTRODUCTION

More than a decade has passed since a survey of nutrient content of nursery stock (Will, 1965) was last conducted in this country. In this period, various changes in nursery practice have led to a general improvement in the quality of planting stock. These changes include the wider use of graded seed, improved sowing practice (wider seedling spacing), complete weed control, and more effective conditioning regimes. During this period too, six N.Z. Forest Service (NZFS) nurseries have, for various reasons, been retired and as many have been established.

The much increased demand for planting stock in recent years has resulted in a corresponding increase in nursery production area. Over the past 10 years the area of exotic forest (state and private) planted annually in this country has quadrupled; the new area planted in state exotic forests alone has risen from 8315 ha in 1966 to 21 665 ha in 1976. Also the area restocked annually has risen; in 1966 the area was 2398 ha as compared with 7502 ha in 1976. In 1975 the total area of exotic forest (state and private) planted amounted to about 42 000 ha. In order to meet the annually increasing planting targets, several sizeable new nurseries have been established in recent years; these include Sweetwater (1967), Pakipaki (1971), Owhata (1968), Cambridge (1974), Edendale (1974), Woodend (Gressons Road Nursery, 40.5 ha; 1974) and Kaipaki

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(N.Z. Forest Products Limited, 1974). Furthermore the production area in many existing nurseries has been increased.

In view of the many changes in nurseries as well as in nursery practice, it was decided to undertake a fresh survey of stock nutrient content,

The main objectives were:

(1) To determine the average nutrient content of representative radiata pine planting stock for each nursery, so that the amounts of nutrient removed from the soil by crops can be estimated.

(2) To identify any covert nutrient deficiency which may be adversely affecting the physiological quality of seedlings and possibly productivity in a particular nursery.

(3) To examine the relative concentrations of nutrients in the foliage, stems and roots of stock of the age-classes represented.

No attempt has been made in this survey to relate nutrient status of the planting stock samples to either nursery fertiliser or conditioning regimes* as the necessary information was not readily available. However considerable variation in both fertiliser practice and frequency of wrenching and root pruning does exist among nurseries and there is little doubt that both factors would have had a major bearing on the nutrient status of seedlings at the time they were lifted.

METHODS

Sampling Procedure

At normal time of lifting at least one representative, composite sample of planting stock for each age-class raised was collected in each nursery. More than one sample per age-class was collected only where markedly different areas were known to exist in a particular nursery, e.g., differing soil types or past crop histories. Nursery locations and other details are given in Fig. 1 and Table 1.

Criteria laid down for sampling were as follows:

(1) Each sample to consist of 25 average-sized seedlings collected from an area selected as broadly representative of either the nursery as a whole, or of a specified area of the nursery.

(2) Seedlings to be taken one a bed from 25 beds, with care being taken to avoid bed ends or marginal beds.

(3) Seedling roots to be trimmed in accordance with the normal nursery practice; trimmings to be collected in a clean plastic bag and to accompany the seedling sample.

(4) All samples to be despatched without delay in clean plastic bags and to be accompanied by a completed questionnaire giving full details of the crop sampled.

Laboratory Processing of Samples

After the height and collar diameter of each seedling had been determined, they were divided into shoots and roots. The shoots were then washed with distilled water to remove any dust or soil contamination which may have occured before or during transit. The process was kept as brief as possible to minimise any leaching of nutrients. Initially, shoots of 1/0 seedlings were not separated into foliage and stems. After the first five 1/0 samples had been processed however, it was decided to divide all subsequent

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* Undercutting, wrenching and root pruning commonly result in a decline in the nutrient (particularly nitrogen) status of seedlings.

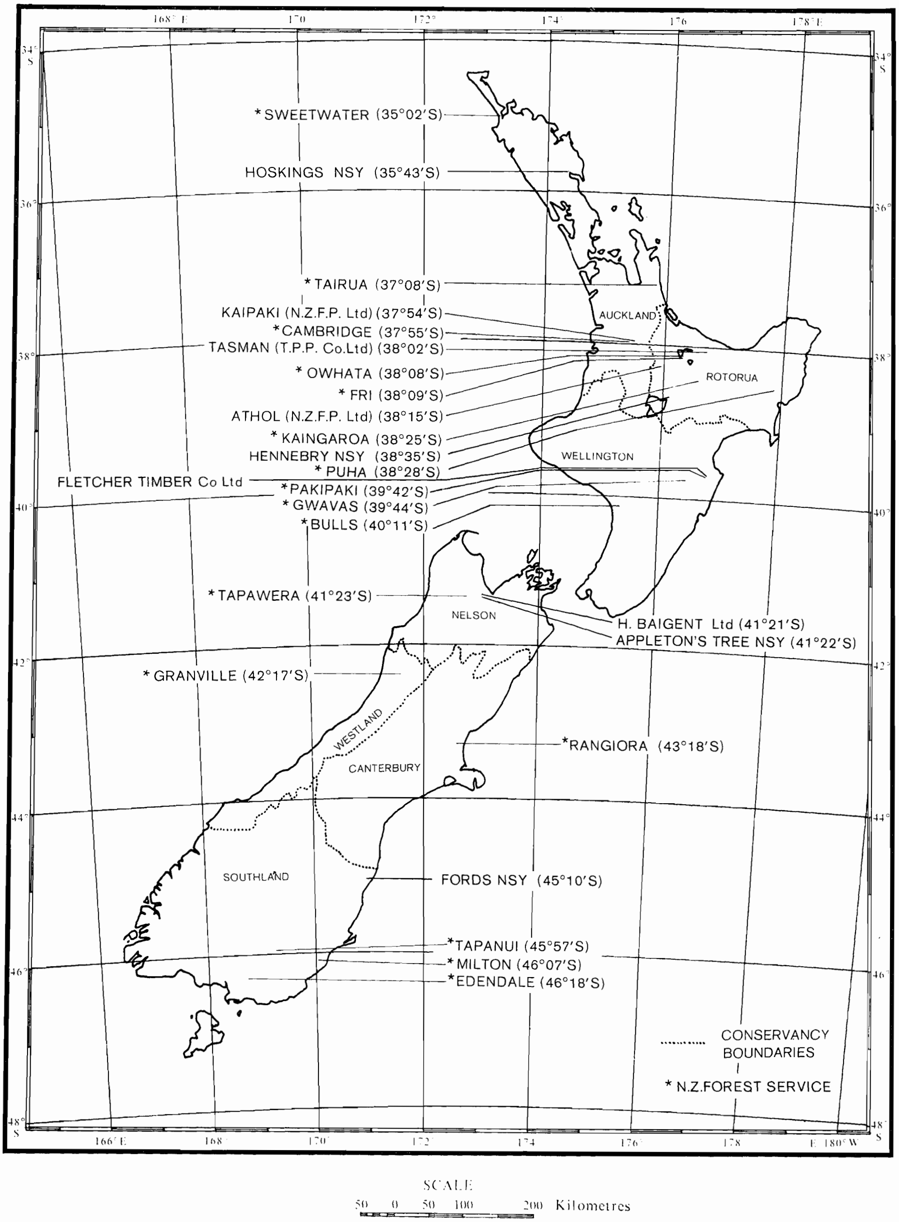

FIG. 1—Locations of major forest nurseries in New Zealand.

samples of this age-class so that a comparison could be made of foliar and shoot nutrient concentrations. All shoots of the other two age-classes were separated into foliage and stems. Roots were thoroughly washed in tap water; the clean roots were given a final brief rinse under a stream of distilled water.

TABLE 1—Alphabetical list of nurseries represented in the survey showing number and age-class of seedling samples submitted

Nursery		Total area (ha)	Production area (1975)	No. of samples received		
				1/0	1½/0	2/0
Athol (Kinleith)	NZFP Ltd	55.4	36	4	—	—
Bulls	NZFS	48	21	2	1	—
Cambridge	NZFS	103.5	37.6	—	6	—
FRI	NZFS	10.1	4	1	1	—
*Granville	NZFS	12.1	8.5	—	2	—
Gwavas	NZFS	6	6	1	—	1
Kaingaroa	NZFS	55.9	47	—	—	3
Kaipaki	NZFP Ltd	60.7	24.2	1	—	—
*Milton	NZFS	38	27	1	1	1
Owhata	NZFS	44	40	—	1	—
Paki Paki	NZFS	50.2	9	1	1	—
Puha	NZFS	50.6	25	1	—	—
*Rangiora	NZFS	36	27	1	1	1
Sweetwater	NZFS	45.7	30	1	1	—
Tairua	NZFS	13.1	10.9	1	—	—
*Tapawera	NZFS	22.7	17	2	—	1
Te Teko (Tasman)	TPP Co. Ltd	24.3	17	1	—	—
Total				18	15	7

* South Island nurseries.

Stems and roots were chopped by secateurs into small pieces to facilitate drying and grinding.

The various seedling components were placed on aluminium foil trays and oven-dried at 70°C for seven days. After dry weights had been recorded, the samples were ground in a stainless steel Wiley mill to pass a 1 mm round-hole sieve, and subsamples retained for chemical analysis.

Elements Determined

Determinations of N, P, K, Mg, Ca, Na, B, Mn, and Zn were carried out on all shoot, foliage, stem and root samples; similar analyses were performed on root trimming samples where sufficient material was available. In addition, all above-ground seedling components were analysed for ash, Al and Fe. Even after careful washing, root systems tend to occlude small amounts of soil with concentrations of Al and Fe which are several hundredfold greater than those in plant tissues. For this reason no determination of Al and Fe were made in either roots or root trimmings.

With the exception of Milton, Rangiora and Sweetwater Nurseries, all nurseries included in the survey are located in parts of the country declared infected with

Dothistroma pini. Routine control measures taken against this needle blight fungus in nurseries situated within infected regions consist of spray programmes using aqueous suspensions of a copper compound. Copper analyses were only performed on samples from nurseries in which copper sprays were not applied, and where consequently copper values represent intrinsic tissue concentrations. (Although the questionnaires completed for Tapawera and Te Teko Nurseries indicated that no copper sprays had been used, off-scale readings were obtained when the samples were examined, indicating copper contamination from some source.).

Methods of Analysis

After a semimicro-Kjeldahl digestion of a sample with a selenium catalyst, nitrogen was determined colorimetrically using an automated indophenol-blue method.

For all other elements, samples —1 g for Cu and B, and 2.5 g for the remainder — were first charred on a hot-plate, and then ashed for 4 hours at 480°C in a muffle furnace.

For B and Cu, the ash was dampened with 1 ml of water and dissolved in 4 ml of 2N HCl. A crystal of hydroxylamine hydrochloride was added to facilitate dissolution of manganese oxides. Boron was determined in an aliquot of this solution using an automated colorimetric procedure based on the carmine-H_2SO_4 method. Copper was determined by atomic absorption spectrophotometry.

For P and the remaining cations, the ashed sample was taken up in 5 ml of 5N HCl and digested on a boiling water bath for 5 minutes. The resultant solution was filtered and quantitatively transferred to a 50 ml volumetric flask. Phosphorus was determined colorimetrically in an aliquot of this solution by the vanado-molybdate yellow method, using an automated procedure. Cations, except Al, were determined by atomic absorption spectrophotometry using an air-acetylene flame. Strontium chloride was used as a "releasing agent" to suppress interference from other ion species when determining Ca and Mg. Aluminium was determined by flame emission spectroscopy using a nitrous oxide-acetylene flame.

All analyses were carried out in duplicate. The maximum acceptable difference from the mean of the duplicate analyses were:— 5% for N, P, K, Mg, Ca, Mn, Zn, in needles and stems and for N, and P in roots; 10% for Al, B, Cu, and Fe in needles and stems, and Zn, B, and Ca in roots; and 8% for K, Mg, Ca, and Mn, in roots.

RESULTS AND DISCUSSION

Limitations

Firstly, judgment of what is average or representative tends to be subjective in the absence of statistically adequate crop measurements and may vary considerably according to the experience and bias of the person who does the sampling. Secondly, as it was necessary to limit the number of survey samples to manageable proportions, a limitation of one composite sample per crop had to be set. Consequently, it is not possible to estimate statistical error due to sampling. Lastly, appreciable year-to-year or crop-to-crop differences may well occur at any one nursery site as a consequence of variations in climate, seed source, crop age or soil management practices.

Despite these limitations, the survey provided quantitative data for nutrient removal by *P. radiata* seedling crops which can be usefully related to a wide range of nursery conditions. This paper summarises results which are available in full, in unpublished form (Knight, 1976a), on request from the editor.

General Crop Data and Details of Stock Size

Full particulars of sowing and lifting dates, seed sources or lot, average height and collar diameter (based on composite sample received), have been given by Knight (1976a) for each crop sampled, as also are dimensions of the bed modules, number of drills, details of seedling spacing and the corresponding theoretical density of seedlings per square metre for each nursery surveyed. Ranges for samples by age-class, of crop age (days), average seedling height, average root collar diameter and height/collar diameter are given in Table 2.

The final size of stock attained in any nursery is decided by the interaction of genetic, environmental and cultural factors. The wide ranges recorded in the survey (Tables 2 and 3) therefore are a reflection of the various differences in seed source, seedling density, climate, soil type, crop age and cultural treatments which existed from nursery to nursery. However, it was not the intention of this survey to make comparisons of stock size and quality from nurseries throughout the country.

Dry Weight

The data are summarised in Table 3. In the 1½/0 class, the lowest shoot/root ratio was for Sweetwater stock, which besides having well-developed fibrous root systems had

TABLE 2—Means and ranges of crop-ages and stock size* by age-class

Age-class	Crop-age (days)	Mean Ht (cm)	Root collar diameter (CD) (cm)	Ht/CD range	Ht/CD class mean
1/0	210 -306 (262)	23-44 (34)	0.45-0.68 (.59)	50-68	58
1½/0	(396+)[a]-577 (485)	33-60 (49)	0.65-1.11 (.86)	50-69	59[b]
2/0	547 -638 (600)	32-52 (45)	0.70-1.00 (.78)	59-71	59[c]

* based on crop samples received (usually 25 seedlings each)
a Exact sowing date not recorded on questionnaire
b Excluding a single topped sample
c Including all topped samples

TABLE 3—Means and ranges of crop dry weight values (grams) by age-class

Age-class	Entire seedling	Shoots*	Roots	Shoot/root ratio range	Shoot/root ratio (mean)
1/0	6.3-15.1 (9.9)	5.1-12.2 (8.3)	1.0-2.9 (1.7)	2.5-7.8	(5.0)
1½/0†‡	14.7-32.5 (23.3)	11.9-28.1 (17.7)	2.5-5.8 (3.7)	3.2-7.4	(5.3)
2/0‡	13.2-25.9 (18.2)	10.4-20.0 (14.7)	2.5-5.9 (3.5)	3.4-5.3	(4.3)

* i.e. all above ground growth
† Excluding K deficient sample ex Granville
‡ Including topped samples

also been topped to *c.* 35 cm. At the other extreme the highest shoot/root ratio was recorded for the Cambridge samples which had only received a restricted wrenching programme as a compromise intended to achieve "the greatest good for the greatest number" (P. F. Lawrence (O.C. Cambridge Nursery), pers. comm.). However, as a general rule "top heavy" seedlings with excessively high shoot/root ratios tend to be at a disadvantage when planted out as they are more susceptible to drought, frost damage, and to toppling.

From the data presented in Table 4 it will be seen that the crop mean dry weight was positively and significantly correlated with both mean seedling height and root collar diameter for the 1/0 and 1½/0 survey samples, but not for the 2/0 samples. Data for the 2/0 category were very limited however, relating to only five untopped samples. The significant correlations found require caution in interpretation as each crop sample consisted only of 25 subjectively-selected seedlings of about "average" size; the correlations may not therefore be applicable as far as the whole crop is concerned.

TABLE 4—Coefficients for linear regression equation Y = a + bx predicting mean dry weight per seedling (g) from mean seedling height (H, cm), and mean collar diameter (D, cm) for a given crop area and based on survey data for each age-class

Seedling age-class	Independent Variable x	Intercept a	Regression Coefficient b	Standard Error SEb	Explained Variance r^2
1/0	H	1.232	0.257	± 0.081	0.386 **
	D	— 2.285	20.690	± 6.072	0.420 **
1½/0†	H	— 2.861	0.534	± 0.141	0.545 **
	D	— 14.600	44.523	± 4.157	0.905 ***
2/0‡	H	— 18.096	0.738	± 0.534	0.389 NS
	D	4.231	18.022	± 25.180	0.146 NS

† Excluding data for Sweetwater sample which had been topped
‡ Five pairs of data only after excluding measurements for topped samples
*** Significant at 0.1% level
** Significant at 1% level
NS Not significant

Elemental Analyses

The range of values recorded for each plant component analysed is shown by age-class in Table 5 for macronutrients and Table 6 for micronutrients and aluminium.

Generally, the foliar concentration ranges recorded for the nursery stock samples are closely comparable to the range of values which both the literature and experience have shown can be encountered in current-year foliage of forest-grown radiata pine trees of various ages. This is in accord with the observations made by Smith (1962) that the mineral composition of foliage is relatively unaffected by the age of the entire plant.

Two other elements — sodium and aluminium — were determined in the plant

TABLE 5 - Summary of macronutrient and sodium concentration means and ranges (%) recorded for survey sample components

Stock	Ash	N	P	K	Ca	Mg	Na
Shoots							
1/0	1.56-3.84 (2.81)	0.91-1.56 (1.29)	.105-.168 (.138)	0.43-1.04 (.84)	.22-.52 (.51)	.050-.113 (.075)	.019-.170 (.052)
Foliage							
1/0	2.24-4.36 (3.27)	1.10-1.90 (1.50)	.124-.188 (.155)	0.47-1.08 (.85)	.26-.62 (.40)	.056-.085 (.072)	.020-.083 (.053)
1½/0	2.24-4.44 (3.46)	0.99-1.94 (1.52)	.099-.199 (.161)	0.31-0.99 (.76)	.23-.83 (.47)	.066-.117 (.081)	.021-.084 (.043)
2/0	2.85-4.12 (3.13)	1.09-1.27 (1.17)	.147-.182 (.165)	0.42-0.90 (.74)	.28-.61 (.44)	.058-.096 (.076)	.016-.069 (.036)
Stems							
1/0	0.80-2.88 (2.01)	0.53-1.10 (.72)	.065-.133 (.101)	0.34-0.92 (.70)	.11-.26 (.19)	.039-.070 (.055)	.015-.067 (.037)
1½/0	1.16-2.76 (1.89)	0.31-0.74 (.60)	.052-.166 (.091)	0.28-0.73 (.51)	.10-.36 (.20)	.049-.076 (.058)	.014-.082 (.036)
2/0	1.16-2.32 (1.70)	0.40-0.53 (.46)	.088-.153 (.104)	0.32-0.63 (.53)	.15-.26 (.19)	.049-.070 (.060)	.009-.040 (.024)
Roots							
1/0	nd	0.54-1.09 (.82)	.078-.146 (.109)	0.12-0.70 (.39)	.10-.36 (.19)	.034-.121 (.064)	.033-.145 (.088)
1½/0	"	0.55-0.84 (.72)	.075-.131 (.103)	0.17-0.49 (.31)	.11-.42 (.25)	.049-.092 (.065)	.035-.100 (.066)
2/0	"	0.44-0.74 (.58)	.087-.123 (.108)	0.19-0.41 (.28)	.14-.25 (.20)	.049-.071 (.060)	.021-.092 (.056)
Root trimmings							
1/0	nd	0.79-1.44 (1.20)	.111-.204 (.152)	0.60-0.86 (.73)	.19-.50 (.31)	.066-.129 (.087)	.036-.358 (.130)
1½/0	"	0.62-1.32 (1.05)	.104-.181 (.144)	0.22-0.71 (.49)	.18-.77 (.41)	.066-.115 (.084)	.062-.159 (.105)
2/0	"	0.61-0.88 (.80)	.081-.150 (.131)	0.32-0.59 (.47)	.20-.40 (.29)	.055-.102 (.074)	.035-.095 (.067)

Underlined levels fall inside deficiency range for P. radiata foliage   nd - not determined

TABLE 6 - Summary of micronutrient and aluminium concentration means and ranges (ppm) recorded for survey samples

Stock	Al	B	Cu	Fe	Mn	Zn
Shoots						
1/0	224- 927 (401)	5.8-17.9 (12.5)	5.8-24.0‡	76-409 (201)	28-388 (162)	16- 71 (47)
Foliage						
1/0	228-1033 (497)	7.8-21.3 (13.6)	--	104.483 (261)	32-487 (176)	36- 72 (51)
1½/0	203-1063 (547)	10.7-20.0 (16.7)	3.6-4.6+	97-499 (241)	19-276 (189)	20- 82 (50)
2/0	413-1222 (751)	12.0-21.6 (15.9)	4.4-5.3+	106-495 (211)	173-480 (276)	43- 66 (52)
Stems						
1/0	199- 665 (316)	7.7-12.7 (10.0)	--	73-230 (153)	18-178 (90)	27- 62 (42)
1½/0	163- 758 (301)	7.3-13.1 (9.9)	5.1-6.0+	41-230 (153)	18-178 (90)	18- 65 (40)
2/0	165- 504 (320)	7.2-10.2 (9.2)	4.6-5.0+	68-204 (125)	59-230 (121)	30- 51 (41)
Roots						
1/0	*	5.0-12.1 (9.0)	--	*	34-277 (132)	17- 87 (47)
1½/0	*	7.0-15.4 (9.9)	5.6-8.6+	*	25-299 (124)	14-100 (41)
2/0	*	6.9- 8.7 (7.8)	6.6-6.8+	*	54-200 (90)	24- 43 (33)
Root trimmings						
1/0	*	9.3-19.1 (15.9)	--	*	29-276 (119)	21- 96 (47)
1½/0	*	8.0-18.9 (12.4)	4.2-7.0+	*	27-466 (198)	14- 89 (39)
2/0	*	8.8- 8.9+	(6.9)	*	50-192 (97)	26-106 (42)

\+ 2 samples only; (6.9) single value; -- Copper sprays used;

* Not determined as inevitable contamination from soil would make results for these elements of doubtful value

‡ Three samples only; upper limit relates to a crop which received a single copper spray application approx. 4 months before lifting (Cuprox 11.2 kg/ha).

samples in addition to the range of essential elements. Interest in sodium was primarily in relation to possible accumulation in toxic concentrations, such as can result from oceanic, spray-generated aerosols in coastal situations or from upward movement of saline ground water. Aluminium is not generally considered essential for plant growth, but is very abundant in soil minerals. Under strongly acid conditions the concentration of soluble Al^{3+} in the soil may be so high as to be deleterious to plant health. According to Russell (1973), a high Al^{3+} concentration is the most common cause of failure of agricultural crops on acid soils.

The interpretation of foliar analyses is usually based on a comparison of foliar data with values which have been found to be critical for normal healthy growth. The actual value for a given nutrient element can be defined as the minimum concentration at which near maximum growth is obtained. It is important to note that plants may have their vitality lowered by incipient nutrient deficiencies, without the appearance of any overt symptoms. Thus, susceptibility to disease, drought and frost injury is often increased by inadequate nutrition (Kramer and Kozlowski, 1963; Baule and Fricker, 1970). Conversely, what could be regarded as "luxury consumption" for growth in the nursery might, in fact, be important for enhanced growth or, in some circumstances, for survival of out-planted seedlings (Krueger, 1967).

A tentative assessment of nutrient status of each survey sample was made by considering the foliar levels in relation to the critical values tabulated by Knight (1977a). Table 7 shows by age class, the proportion of survey samples which were rated satisfactory with respect to the individual nutrients determined. As can be seen from the results of this assessment, by far the commonest nutritional shortcoming in stock was that of inadequate or marginal N status. The next most common failing was that of inadequate or marginal P status. Fewer instances were recorded where Mg status was questionable. Deficient or marginal K levels were relatively uncommon.

Although individual levels of the macronutrients N, P, K, and Mg were, in several instances, low enough to be rated marginal or unsatisfactory, they were not generally so low as to cause acute, visual deficiency symptoms. Nevertheless, in these instances, the levels recorded were low enough to adversely affect both growth and physiological quality of the seedlings.

For the most part, the micronutrient status of the samples was satisfactory. The few instances where foliar levels were well below average, generally occurred in stock

TABLE 7—A synopsis of survey samples by age class showing the actual number and proportion of nursery stock samples which rate "satisfactory" in nutrient status with respect to individual nutrients

Age class	N.R.	T.S.	Number of samples rated "satisfactory"								
			N	P	K	Ca	Mg	B	Fe	Mn	Zn
1/0	13	18	9	13	17	18	15	16	16	17	17
			(50)	(72)	(94)	(100)	(83)	(89)	(89)	(94)	(94)
1½/0	9	10*	3	8	8	10	10	10	9	9	9
			(30)	(80)	(80)	(100)	(100)	(100)	(90)	(90)	(90)
2/0	5	7	4	7	6	7	7	7	7	7	7
			(57)	(100)	(86)	(100)	(100)	(100)	(100)	(100)	(100)

N.R., number of nurseries represented; T.S., total number of samples examined.

* The six samples from Cambridge were treated as a single sample to avoid an unduly weighted result.

raised on atypical nursery soils, e.g., acid peat (Sweetwater) or calcareous pumice loam (Pakipaki), where corrective measures are already well in hand. The relatively low boron levels recorded in stock raised in two different pumice soils (Tairua and Te Teko nurseries) point to the desirability of supplementary boron in these nurseries. Although there was no evidence that the relatively low boron supply had caused any visible damage to the seedlings, there is a danger that the physiological quality, in particular frost hardiness, of the seedlings could be adversely affected.

The various incipient deficiencies or "hidden hunger" which the survey has revealed, point to the need for constant vigilance in the matter of nursery fertility maintenance. Surveys of this type can help the nursery manager by drawing attention to nutritional shortcomings which are not detectable by eye, but which nonetheless may seriously affect survival and early performance following planting.

Certain features of the foliar data for the samples are of interest in relation to particular nurseries. For example, the Pakipaki samples show a general tendency to be well above average in foliar calcium, but relatively low in foliar aluminium and manganese. The high foliar calcium level is associated with a very high soil exchangeable Ca concentration, while the low foliar Al and Mn, and for 1½/0 stock, Zn levels, are a reflection of the reduced availability of these elements to the seedlings as a consequence of the calcareous nature of the soil (Knight, 1977b). Recent trials with acidulants (sulphur and sulphuric acid) have resulted in a marked improvement in the growth of seedlings in calcareous areas of this nursery.

The levels of foliar iron found in the FRI nursery stock were among the lowest recorded in the survey; this is of interest, as it has been found (A. E. Summers, pers. comm.) that a chlorosis which occasionally affects the younger foliage of seedlings in some parts of the nursery can usually be corrected by foliar applications of iron sulphate. The chlorosis tends to appear in the spring during the cold wet periods of weather. The treatment which has usually proven effective has been a spray application of 5% w/v solution of iron sulphate at a rate of about 465 litres/ha. One to two repeat applications made at 7- to 10-day intervals have generally been necessary to restore good colour.

Sweetwater Nursery is located only some 3 km inland from Ninety Mile Beach and is unusual in that it was established on a deep sandy peat deposit (McKinnon and Nicholson, 1974). Although generally the nursery has proven very successful, the peat soil is very low in plant-available copper and zinc (Knight, 1975, 1976b). Two distinctive growth disorders which occurred in various parts of the nursery were found to result from a deficiency of these nutrients. The disorders were successfully treated by means of foliar sprays supplying copper or zinc as appropriate. It should be noted that even though the block sampled for 1/0 seedlings had received a basal application of zinc sulphate at about 28 kg/ha, the seedling tops contained only 16 ppm zinc. Despite the relatively low levels of zinc recorded in their tissues, the stock appeared perfectly healthy. The relatively high concentrations of sodium present in the tops and roots of both 1/0 and 1½/0 planting stock from this nursery probably resulted from appreciable amounts of salt reaching the nursery in aerosol form from the nearby coast.

Although the 1½/0 seedlings from Block B2 Granville Nursery were exactly the same age as those from Block A2, the former yielded roughly half of the dry weight of the latter. It should be noted that the foliar K concentration of the "B2" seedlings was critically low (0.33%), and it appears likely that the supply of K had become limiting to growth. Both Fe and Mn had accumulated in the foliage of this sample — presumably as a consequence of retarded growth.

Aluminium concentrations in the foliage and stems of seedlings appear to be very variable (see Table 6). The 1/0 sample from Kaipaki, and one of the Cambridge 1½/0 samples were well above average in both foliar and stem Al concentration. Both samples were also above average in foliar N and Fe. This suggests a possible synergistic relationship for these nutrients. The relatively high levels of Al recorded in these samples do not appear to have been harmful to the seedlings.

Although the 1/0 stock from Te Teko Nursery (on Otakiri sandy loam) was healthy in appearance its shoot concentration of 6 ppm boron was the lowest recorded for this age-class and amounted to less than half the average of 13 ppm recorded for 1/0 survey samples. Boron does not seem to be mobile in the foliage of plants, and unlike the more mobile nutrients such as K and Mg, that taken up early in the season is not translocated to the growing points later on. Thus foliar concentrations of this element represent the net accumulation over the entire period of growth of the needles. Irreparable damage to apical meristems can occur if the supply is interrupted even for a relatively short period, irrespective of the foliar concentration. According to Russell (1973) B deficiency most commonly occurs on acid, light-textured soils low in organic matter, and is often most pronounced in dry summers. It can usually be corrected by applying low rates of B fertiliser to the soil or by means of foliar sprays.

Comparison of Foliar and Shoot Analyses for 1/0 Stock

It is often more convenient to analyse the entire above-ground parts (referred to hereafter as shoots) when dealing with 1/0 nursery crops. This speeds up processing, particularly when large numbers of samples are involved, and also provides a greater bulk of dry matter for analysis where the sample received is smaller than might be desired. Most yearling seedlings have not become very woody, and it has generally been assumed that the nutrient concentrations of their shoots will not differ appreciably from those in their foliage. The survey samples provided an opportunity to check this. Table 8 shows highly significant correlations between concentrations of foliage and shoot components for 13 of the 1/0 survey samples. The explained variance falls in the range 96-99% for 10 of the 11 elements determined. For Mg, the value is slightly lower (91%). As might be anticipated, the foliar concentrations are almost invariably slightly greater than the corresponding shoot values — usually by a factor of *c.* 1.1 to 1.2. Allowance for this disparity should be made therefore, wherever shoot concentrations are being compared with critical values which were originally established for foliage.

Nutrient Removal in Planting Stock

Summaries of estimated nutrient removal per thousand stock based on the average seedling contents are given by age-class in Table 9.

Nutrient removal per unit area proved more difficult to assess than anticipated. This was because details of actual stock output were not forthcoming for some nurseries and for others were seasonally atypical, with actual production per unit cropped area in some instances appreciably less than normal or potential output.

TABLE 8—Linear regression and correlation coefficients for 1/0 seedling foliar concentration (Y) on whole shoot concentration (X) for a range of elements

Foliar concentration Y	Intercept a	Regression coefficient b	Standard error SEb (±)	Explained variance r^2
N	0.191	1.029	.033	.988***
P	0.013	1.034	.052	.972***
K	0.055	0.987	.064	.956***
(K)	0.051	0.998	.053	.972***
Mg	0.009	0.940	.089	.910***
Ca	0.000	1.192	.044	.986***
Na	0.000	1.093	.063	.964***
(Na)	0.000	1.113	.054	.976***
Al	—7.194	1.140	.031	.992***
B	—2.213	1.265	.056	.978***
(B)	—2.018	1.255	.054	.982***
Fe	—6.782	1.169	.031	.992***
Mn	—9.471	1.233	.029	.994***
Zn	—0.719	1.072	.058	.968***

Data for elements shown in brackets are based on 12 pairs of data, i.e., after rejection of a single anomalous pair.
*** Significant at 0.1%.

As dimensions of seed beds and tractor paths, as well as actual number of drills and nominal seedling spacing differ appreciably amongst New Zealand forest nurseries (see Knight, 1976a) the number of seedlings produced per ha varies considerably. Other factors such as cull rate and disease sometimes accentuate these differences. The limited data available indicate that the number of seedlings produced ranges from about 280 000 to 750 000 useable plants per ha of cropland depending on the particular nursery bed module and seedling spacing in use.

An attempt has been made to provide estimates of the quantities of nutrients removed by crops of each age-class wherever the approximate stock output per hectare of crop-land was known. The tentative estimates for *P. radiata* seedling crops sampled in the 1976 survey are presented in Table 10. The maximum and minimum values recorded for nutrient removed per hectare for each age-class illustrate the considerable variability which exists among the nurseries.

Where specific chemical analyses are not available and a rough estimate of nutrient removal is required for a particular open-grown New Zealand crop of *P. radiata* seedlings, this can be obtained by assuming (on the basis of data obtained in the 1976

TABLE 9 - Means and ranges by age-class of nutrient* content per thousand stock

Crop age-class	Dry matter	N	P	K	Mg	Ca	B	Mn	Zn
	kg	Weight per thousand seedlings							
1/0	6-15 (10)	56-174 (120)	7-22 (13)	36-102 (75)	4-14 (7)	16- 57 (28)	0.1-0.2 (.1)	0.3-5.5 (1.5)	0.2-0.8 (.5)
1½/0	15-32 (24)	129-441 (278)	16-52 (32)	83-246 (151)	12-22 (17)	40-138 (81)	0.2-0.4 (.3)	1.0-7.1 (3.9)	0.5-2.3 (1.1)
2/0	13-26 (18)	110-210 (150)	18-32 (24)	85-129 (103)	9-17 (12)	34- 92 (56)	0.2-0.3 (.2)	2.0-7.0 (3.4)	0.5-1.1 (.8)

* 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 ranges from 0.05-0.10 g/1000 seedlings.

Contents of other elements also given as g/1000 seedlings.

TABLE 10 - Nutrient* removal per hectare - means and ranges by age-classes

Crop age-class	Dry matter	N	P	K	Mg	Ca	B	Mn	Zn
	t/ha	kg/ha							
1/0	1.8- 7.9 (4.3)	21- 84 (52)	3- 9 (5.5)	10- 52 (33)	1- 7 (3)	5-30 (14)	0.02-0.11 (.06)	0.1-2.9 (.8)	0.1-0.4 (.2)
1½/0	6.1-20.0 (9.6)	54-232 (100)	5-32 (12)	25-140 (54)	4-14 (6)	18-57 (31)	0.09-0.23 (.12)	0.1-3.4 (1.4)	0.1-1.4 (.5)
2/0	5.3- 9.6 (7.2)	44- 74 (60)	7-13 (10)	30- 56 (41)	3- 6 (5)	12-36 (23)	0.06-0.11 (.09)	0.8-2.4 (1.4)	0.2-0.4 (.3)

* A single value of 0.04 kg/ha Cu was recorded for each of the age-classes.

survey) that the crop removes the quantities given in Table 11 per kg of dry matter produced. The appropriate modal value from Table 11 (k), the mean dry weight per seedling for the crop in grams (x) and the number of thousand stock produced per hectare (y) can be entered in the following equation to obtain the net dry weight of nutrient removed per ha (w):

$$w = k.x.y/1000$$

If the average dry weight per seedling is not known for a crop, this could be crudely estimated from mean height or collar diameter by means of the simple regression equations given in Table 4. Clearly the use of predicted seedling weight is liable to compound the error in the final estimate of weight of nutrient removed, particularly where the effect of density is ignored. Nonetheless, such an estimate may be helpful as a rough guide to the amount of nutrient removed per hectare by a particular crop where more precise data are lacking.

TABLE 11—Modal values (g) for nutrient removal per kg of dry matter produced by open-grown **P. radiata** crops under New Zealand conditions

Age class	Grams of element per kg of dry matter[1]							
	N	P	K	Mg	Ca[2]	B	Cu	Zn
1/0	14.5	1.45	8	0.8	2.5	0.013	0.006	0.05
1½/0	13.0	1.38	7	0.7	3.4	0.014	0.005	0.04

[1] assuming adequate but not unduly high supply of all essential nutrients
[2] applicable for non-calcareous soils only

The figures for crop removal which have been given in this report should on no account be regarded as providing a close guide as to the amount of nutrients which need to be applied after each crop to ensure continued productivity. Supplemental fertilisers should be applied at rates sufficient to replace, not only the nutrients removed when the crop is lifted, but also the nutrient quantities which are lost or cease to be available from one season to the next as a result of volatilisation, immobilisation, and leaching. Thus 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. 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. Thus it is sound practice to check the soil nutrient status at regular intervals, e.g., once a growing season and preferably after lifting, by means of standard soil tests.

CONCLUSIONS

Substantial quantities of nutrients are taken off-site each time a crop of *Pinus radiata* seedlings is lifted, and the stock dispatched for planting. The actual amount of nutrients taken off-site varies considerably from nursery to nursery, being dependent on the composition and dry weight of the planting stock produced.

It is important that the extent of nutrient depletion of nursery soils by continuous cropping be recognised by all responsible for nursery management, in order that effective measures may be taken to ensure a satisfactory level of nutrition for continued productivity. Advantage should be taken of existing soil testing facilities to regularly check soil nutrient status. The result of the soil tests can then be used as a basis for selecting types and rates of fertilisers which will economically and satisfactorily maintain an adequate balanced nutrient supply for the crop to be grown. If a particular crop fails to grow satisfactorily and nutritional causes are suspected, early consideration should be given to having a sample of the crop analysed. Plant analysis* will in many instances provide a clear indication as to which, if any, nutrient is limiting to growth, so that appropriate and prompt remedial action can be taken.

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* Although rapid plant analysis would provide an effective means of checking plant nutrient status during the growing season, FRI is not at present able to provide this service, other than when a crop is clearly in jeopardy.