CAN DRIS IMPROVE DIAGNOSIS OF NUTRIENT DEFICIENCY IN PINUS RADIATA?

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ABSTRACT

Diagnosis and Recommendation Integrated System (DRIS) norms were obtained for **Pinus radiata** D. Don using foliage chemical analysis results and site index data from published studies. The norms were then tested on fertiliser trials in which response to varied nutrition was known. DRIS proved accurate at ranking treatments in order of growth and nutritional health.

Keywords: foliage analysis; DRIS; fertiliser; mineral nutrition; **Pinus radiata.**

INTRODUCTION

Tissue analysis provides a useful measure of the elemental status of plants and is a help in fertiliser management (Will 1985). The usual way of using foliage analysis results is to compare single element concentrations to established sufficient or critical levels. One of the disadvantages of this approach is that only one element can be handled at a time and important bi-elemental interactions are missed (Sumner 1977b; Lambert 1984; Schutz & de Villiers 1986).

The Diagnosis and Recommendation Integrated System DRIS (Beaufils 1973) provides a method of handling these interactions by using ratios of foliar nutrient concentrations to calculate indices that diagnose the nutrient status of a plant (Sumner 1978; Hanson 1981; Schutz & de Villiers 1986).

The system was developed by Beaufils in the 1950s (Kim & Leech 1986) and was successfully applied to rubber trees to improve latex yield. Success was later achieved with maize (Schutz & de Villiers 1986). Since then it has been used on a wide variety of crops, e.g., sugarcane (Schutz & de Villiers 1986), wheat (Sumner 1977a), and soybeans (Hanson 1981; Beverly *et al.* 1986).

DRIS assumes that there is an optimal ratio between any two elements, departures from that optimum being associated with poorer growth. To apply the method, DRIS norms are first calculated. These are the means and variances of the ratios of pairs of elements measured in foliage from plants growing on good-quality sites. The DRIS system can then be applied to any site for which foliar nutrient concentrations are known. The DRIS norms are used to obtain an index for each nutrient relating its current foliar concentration to concentrations of other nutrients. A negative index value is taken to indicate deficiency and a positive value sufficiency or excess. The magnitude of a negative index is assumed to indicate the importance of the deficiency. A ranking of the indices is thus taken to indicate the limiting order of the corresponding elements. The sum of the absolute values of the indices, usually referred to as the total sum, is used to indicate over-all nutritional imbalance.

Databases (Letzsch 1984) and Fortran programmes (Letzsch & Sumner 1983) have been developed for many crops in order to simplify and encourage the use of DRIS as a diagnostic tool.

DRIS has not been applied in forestry on a large scale but has been tested in New South Wales, Australia, on *Pinus radiata* by Truman & Lambert (1980). They divided their plots into two groups, those with site index (height in metres at age 20) over 26 being placed in the high-yield group. These plots were used to derive DRIS norms. Truman & Lambert found that DRIS has some merit in determining the balance of nitrogen, phosphorus, and sulphur. Leech & Kim (1981) worked with *Populus deltoides* Marsh. and developed a field and a greenhouse standard for the clone D 38. Kim & Leech (1986) studied hybrid poplar clone i-45/51 in Eastern Ontario, Canada; the dbh increase through fertiliser application was tested. They found that the indices could be used for diagnosing the foliar nutrient balance. Ward *et al.* (Schutz & de Villiers 1986) applied DRIS to *Eucalyptus saligna* Sm. in Western Australia.

The objective of our work was to develop DRIS norms for *Pinus radiata* for New Zealand conditions from one set of data and test the result on independent data from fertiliser trials. It was hoped that DRIS norms could be developed successfully in order to simplify foliage tissue interpretation and diagnosis and make the large number of recommendations given in New Zealand annually (Hunter *et al.* 1985) more accurate and so save time, fertiliser, and money. The study applies only to foliage collected from the standard position in the tree crown at the standard time (Will 1985).

METHODS AND MATERIALS

Database for Compilation of DRIS Norms

From the plots sampled in a survey of site productivity by Hunter & Gibson (1984), 102 of the older permanent sample plots of *P. radiata* were selected by Hunter *et al.* (1985). They were 18–20 years of age and balanced to give clusters of plots in the forests visited. All the plots were situated in North Island forests in Rotorua, Wellington, and Auckland districts. The plots covered a range of fertility and soils, from poor sands to former farmland. Hunter *et al.* collected foliage from five to seven dominant or co-dominant trees on each plot, making a composite sample. The foliage was analysed for nitrogen, phosphorus, potassium, calcium, and magnesium. From the data collected by Hunter & Gibson (1984) site indices were calculated.

Calculation of DRIS Norms and Site Indices

The population of 102 plots was divided into two groups based on the average site index given by Hunter & Gibson (1984). Plots with a site index of 30 and above were placed in the high-yield group, the desirable population, and the others in the low-yield group.

In calculating DRIS norms the high-yield population was assumed to be under less nutritional stress than the population of low yield. This implies that some nutrient ratios should have less variation around their mean in the desirable than in the undesirable population (Jones 1981). The variance of each ratio was therefore calculated for each population and tested as to whether it was greater in the low- than the high-yield population. When it was greater, the ratio was used in the formulas for calculation of DRIS indices.

For each sub-population all possible single ratios were calculated. Prior to testing for differences between the two groups, the distributions of the ratios were tested for normality. Tests of normality are not mentioned in any reference to DRIS but are desirable since the F-test for differences in variance is sensitive to departures from normality. Several of the ratios were significantly non-normal, but this was successfully corrected by log transformation. The natural logs of the ratios were therefore used in the calculation of the DRIS norms. Apart from normalising the distribution, the log transformation has a secondary advantage: the standard method of calculating DRIS indices gives slightly different results depending on which element of a pair is the numerator, and this depends on which element is selected first. However, with the log transformation, indices are not affected by the ordering of elements (Beverley 1987).

F- and t-tests were used for testing the significance of differences between the variances and the means of the log ratios. All ratios that were shown to be significantly less variable in the high-yield population than in the low-yield one were considered important and were included in the DRIS formula. In addition, all ratios with significantly different means were included in the DRIS formula as suggested by Jones (1981).

The DRIS index for an element is a weighted mean of the deviations from the optimum values of the selected ratios of importance (Jones 1981). As an example, the index for nitrogen can be calculated as follows:

$$\text{N-index} = \frac{f(N/P) + f(N/K) + f(N/Ca) + f(N/Mg)}{4}$$

where

$f(N/P)$ = $(\log(N/P)/\log(n/p)) - 1/CV$,

$\log(N/P)$ = the natural log of the N/P ratio of the plot being considered

$\log(n/p)$ = the mean value of $\log(N/P)$ from the desirable population

CV = coefficient of variation (standard deviation/mean of log ratio) in the desirable population.

If the nutrient for which an index is to be evaluated is the numerator in the ratio, the deviation from the mean is positive and if that nutrient is the denominator the deviation is negative (Schutz & de Villiers 1986). Each important ratio is therefore used twice, for two different indices.

The coefficient of variation (the standard deviation in the desirable population divided by the mean in the desirable population) is used to scale the deviations (Schutz & de Villiers 1986), reducing the importance of a single deviation if the variation amongst the values of that ratio is large, and increasing its importance if the variation is small.

All ratios as well as means, standard deviations, coefficients of variation, and variance ratio were calculated using the Genstat program (Lawes Agricultural Trust 1980).

Testing and Verification of the DRIS Index

The DRIS norms were used to calculate DRIS indices for four fertiliser trials in different parts of New Zealand. The nutrient status of some of the trees in these trials was severely disturbed.

Trial 1 This trial is a nutrient subtractive in which various elements including nitrogen, phosphorus, and potassium were omitted from a complete fertiliser applied to *P. radiata* trees growing on a very phosphorus-deficient northern podsol. Before establishment and when the trees were 1 year old a soluble high-analysis fertiliser was applied (Table 1). There were two replicates of each treatment, with an average of 50 trees in each plot. Foliage samples were taken when the trees were 18 months old. All trees were measured for height at age 3.

TABLE 1—Cumulative amounts of fertilisers applied over 2 years in a nutrient subtractive trial in North Auckland

Treatment	Amounts of fertiliser (kg/ha)				
	N	P	K	Ca	Mg
Minus all	–	–	–	–	–
Minus N, K	–	35.2	–	44.8	40.4
Minus N, P	–	–	53.5	44.8	40.4
Minus N	–	35.2	53.5	44.8	40.4
All nutrients	169.3	35.2	53.5	44.8	40.4

Trial 2: This trial is also on a North Auckland podsol. Fertiliser was applied in 1979 when the trees were at age 4 (Table 2) and samples were collected from the cultivated part of the trial when they were aged 7 years. The site was originally deficient in phosphorus but with age became very deficient in potassium (Hunter 1984).

TABLE 2—Amounts of fertilisers applied on a cultivated podsolised sand in North Auckland

Treatment	Amounts of fertiliser (kg/ha)				
	N	P	K	Mg	Cu
No fertiliser	–	–	–	–	–
P	–	125	–	–	–
N, P	200	125	–	–	–
N, P, K, Mg, Cu	200	125	100	2.9	0.8

Trial 3: This area in southern Kaingaroa Forest was extremely deficient in magnesium (Hunter *et al.* 1986). The soil is derived from rhyolitic tephra. Fertiliser was applied at stand age 6 and samples were taken at age 11. Ground dolomite and Epsom salts were used to give 100 kg Mg/ha. Dolomite also contains some 25% calcium (Table 3).

TABLE 3—Amounts of fertilisers applied on the extremely magnesium-deficient trial in southern Kaingaroa

Treatment	Amounts of fertiliser (kg/ha)							
	N	P	K	Ca	Mg	Zn	Mn	B
No fertiliser	–	–	–	–	–	–	–	–
Mg	–	–	–	187	100	–	–	–
All nutrients	90	100	50	195	100	8	20	5

Trial 4: Nitrogen was applied to 13-year-old *P. radiata* growing on a severely nitrogen-deficient coastal sand site on the south-west coast of the North Island (Hunter & Hoy 1983). Fertiliser at the rate of 400 kg N/ha was applied in 1977 and foliage was sampled in 1981.

RESULTS AND DISCUSSION

The limitations of using site index as an indicator of yield became obvious at an early stage as some of the plots known to be on low-yield sites were not detected. This was because phosphorus had been applied at an early stage in the lifetime of the plots, increasing growth and site index, but it was not traceable in the tissue analysed many years later. Consequently, foliar phosphorus had a greater range in the high-yield group than in the low-yield group. Neither elemental phosphorus nor ratios involving phosphorus were significantly related to growth.

When the database was reduced to the 91 plots that had not received fertiliser at any stage, phosphorus as an element and some ratios involving phosphorus became significant (Table 4).

TABLE 4—Result of testing log ratios for significant differences in variances and means between the undesirable and the desirable population. Database used contained 91 plots

Ratio	Variance		Mean	
	F-ratio	Significance	T-value	Significance
N/P	1.92	*	–0.30	n.s.
N/K	2.55	**	1.12	n.s.
N/Ca	1.69	*	–5.56	**
N/Mg	2.91	**	–9.89	**
P/K	1.39	n.s.	1.32	n.s.
P/Ca	1.24	n.s.	–4.51	**
P/Mg	1.10	n.s.	–8.84	**
K/Ca	1.62	n.s.	–5.48	**
K/Mg	2.24	**	–9.34	**
Ca/Mg	1.24	n.s.	–5.82	**

Critical values

	p-level	F-ratio	t-value
*	0.05	1.66	1.99
**	0.01	2.06	2.64

Ratios with significant differences in either the means or the variances between the high-yield and the low-yield groups, were used in the DRIS formulas:

$$\text{N-index} = \frac{f(N/P) + f(N/K) + f(N/Ca) + f(N/Mg)}{4}$$

$$\text{P-index} = \frac{-f(N/P) + f(P/Ca) + f(P/Mg)}{3}$$

$$\text{K-index} = \frac{-f(N/K) + f(K/Ca) + f(K/Mg)}{3}$$

$$\text{Ca-index} = \frac{-f(N/Ca) - f(P/Ca) - f(K/Ca) + f(Ca/Mg)}{4}$$

$$\text{Mg-index} = \frac{-f(N/Mg) - f(P/Mg) - f(K/Mg) - f(Ca/Mg)}{4}$$

Indices were then calculated for the fertiliser trials described above.

Trial 1: The DRIS indices for the control showed a strong potassium deficiency and a lesser deficiency in phosphorus (Table 5). Treatment with fertilisers lacking either phosphorus or potassium did not improve the total sum very much. However, the treatment one would expect to best rectify the deficiencies, minus nitrogen (which includes both phosphorus and potassium), showed considerable improvement in the indices and in the total sum. Measurements of tree mean height taken at age 3 rank as follows:

minus N > all nutrients > minus NK > minus all > minus NP
(3.20 m) (3.15 m) (2.50 m) (1.90 m) (1.45 m)

TABLE 5—DRIS indices and total sum calculated on Trial 1

Treatment	N-index	P-index	K-index	Ca-index	Mg-index	Total sum
Minus all, control	2.41	–1.80	–4.41	1.61	0.64	10.86
Minus N,P	3.79	–1.61	–1.42	0.05	–1.57	8.45
Minus N,K	1.39	–0.92	–2.80	1.11	0.28	6.50
Minus N	1.29	–0.05	–1.11	0.01	–0.43	2.90
All nutrients	2.07	–0.75	–0.70	–0.27	–0.71	4.51

The DRIS indices and the total sum were in reasonable agreement with the height data. However, the latter suggested the phosphorus deficiency was more limiting than the potassium deficiency, in contrast to the DRIS indices for the control which ranked them in the reverse order.

Trial 2: The control showed a strong deficiency in potassium and a slight phosphorus deficiency (Table 6). Adding phosphorus alone led to a small improvement in the total sum. Application of nitrogen/phosphorus/potassium/manganese/copper, the only

TABLE 6—DRIS indices and total sum calculated on Trial 2 at 18 months and 3 years after fertiliser application

	No fertiliser		P		P, N		N, P, K, Mg, Cu	
	18 mth	3 yr	18 mth	3 yr	18 mth	3 yr	18 mth	3 yr
H-index	1.41	2.03	–0.60	–0.10	1.21	1.31	0.17	–0.18
P-index	–1.48	–0.78	2.19	1.93	0.79	1.73	0.72	1.09
K-index	–7.42	–5.99	–6.35	–4.68	–7.93	–7.76	–4.94	–6.11
Ca-index	2.58	–0.13	2.82	0.72	2.60	0.76	2.09	1.33
Mg-index	2.69	3.18	0.90	1.45	1.55	2.45	0.91	2.62
Total sum	15.58	12.11	12.86	8.88	14.08	14.01	8.83	11.33

treatment to contain potassium, considerably improved both the K-index and the total sum. When the foliar concentrations obtained 3 years after fertiliser treatment were used, the index and total sum for this treatment showed a marked deterioration (Table 7).

These results can be compared with the yield data (Table 7).

TABLE 7—Basal area 3 years and average height 4 years after fertiliser application in Trial 2. Source: Hunter (1984)

Treatment	Average height (m)	Basal area (m^2/ha)
No fertiliser	7.80	16.0
P	8.90	18.6
N, P	7.37	19.4
N, P, K, Cu, Mg	9.27	25.2
Significance	*	**

* ANOVA showed significant difference between means at 5% level
** ANOVA showed significant difference between means at 1% level

The effect of the different applications on total sum shows good agreement with height growth and reasonable agreement with basal area. The DRIS indices suggest that a greater application of potassium than that used in the fourth treatment might have produced further growth improvement.

Trial 3: This area had a strong magnesium deficiency, which was correctly identified by the magnesium index. Correction of this deficiency with magnesium fertiliser resulted in a smaller sum, and indicated that potassium was the next most-limiting element. The dolomite used contains calcium resulting in a less negative calcium index. Adding the rest of nutrients improved the total sum slightly (Table 8) as well as improving tree growth (Table 9).

TABLE 8—DRIS indices and total sum calculated on Trial 3

Treatment	N-index	P-index	K-index	Ca-index	Mg-index	Total sum
No fertiliser	3.21	1.34	0.57	–0.84	–3.80	9.76
Mg	2.04	0.33	–3.16	–0.53	0.61	6.67
All nutrients	1.93	0.65	–2.09	–0.71	–0.14	5.52

TABLE 9—Average tree height and root collar basal area in Trial 3. Source: Hunter *et al.* (1986)

Treatment	Average height (m)	Basal area (m^2/ha)
No fertiliser	4.44	24.2
Mg	5.94	32.2
All nutrients	5.68	33.4
Significance	*	*

Trial 4. Tree growth on this severely chlorotic site was extremely poor without fertiliser but showed a strong response to the 400 kg N/ha applied (Table 10). The total sum declined but remained at a high level (Table 11). The DRIS index suggests that had the trial been treated again with nitrogen, phosphorus, and potassium an even greater improvement in growth may have resulted.

TABLE 10—Effect of nitrogen fertiliser on average height and basal area in Trial 4. Source: Hunter & Hoy (1983)

Treatment	Average height (m)	Basal area (m^2/ha)
No fertiliser	9.1	22.5
N	12.7	34.7
Significance	*	**

TABLE 11—DRIS indices and total sum calculated on Trial 4

Treatment	N-index	P-index	K-index	Ca-index	Mg-index	Total sum
No fertiliser	–3.78	–2.65	–2.01	5.59	1.68	15.71
N	–1.67	–2.12	–2.64	2.20	3.04	11.66

There are some refinements required to make the system more accurate and reliable. Work should be carried out to incorporate more nutrients in the indices – for example, boron, manganese, copper, iron, and zinc. This should increase the accuracy of the system and also make it possible to give recommendations on sites with difficult micronutrient deficiencies.

The results from Trial 2 indicate that DRIS indices for volume and basal area increment may be different from those for height growth. Therefore a more sensitive measure of yield than site index needs to be found. Site index is very inflexible because the immediate response to an application of fertiliser disappears in the cumulative value that site index actually is. Basal area increment shows a quicker response to fertiliser application and is better related to the current levels of nutrients. Using basal area increment, it should be possible to analyse plots treated with fertiliser some years previously, where the yield response from the application is decreasing or where any remaining response from the application is not traceable in current tissue.

Overall, the DRIS indices derived from site index variations in older trees which had not received fertiliser proved to be encouragingly reliable when used to diagnose nutrient deficiencies and imbalances in younger trees in fertiliser trials. From this study we found no strong evidence to separate out DRIS norms by soil type. Based on the four trials studied, a DRIS total sum of less than 5 appears to indicate near-optimal nutrition, DRIS total sums between 5 and 10 appear to indicate some degree of disorder while sums of greater than 10 are associated with trees with grossly suboptimal nutrition. When applied to the database used to obtain the DRIS norms, only 13% of plots from the high-yield group had total sums greater than 5 compared with 41% of the low-yield group. The total sum thus appears to be a useful indicator of nutritional imbalance although it is theoretically possible for trees that are deficient in all elements to have a low total sum. However, it is not suggested that the DRIS system be used alone but rather that it be used to complement other conventional methods.

CONCLUSIONS

The DRIS system was employed to evaluate indices for nitrogen, phosphorus, potassium, copper, and magnesium in *Pinus radiata*. It proved to be useful for calculating the nutrient balance of fertiliser trials by showing correctly which nutrients were most limiting for growth. The system consistently showed a decreased total sum when a plot was treated with fertiliser containing the nutrient in which it was deficient. The DRIS total sum suggests that in some of the examples considered (Trials 2 and 4) the fertiliser strategy could have been improved. Trials should be commenced to test the accuracy of DRIS predictions.

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