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VECTOR ANALYSIS OF RADIATA PINE FOLIAGE FROM A NITROGEN AND PHOSPHORUS TRIAL

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EXECUTIVE SUMMARY

Chemical determination of the nutrients in pine foliage is used to monitor the nutritional health of forests and to drive fertiliser programmes. Customarily the concentration of a nutrient is used as the indicator. However there are often needle weight changes following fertilisation, which complicate analysis. In this paper a graphical vector analysis technique which combines needle weight and needle nutrient concentrations is tested with radiata pine needles from a nitrogen and phosphorus fertiliser trial. The objectives of the study were to see whether the technique is useful in a species with a less determinate growth pattern than the species on which the technique was developed and whether the technique would apply as well in situations where two or more nutrients affect growth. Our conclusions are that the technique appears to work well for radiata pine but that interpretation needs to be modified to distinguish between the nutrient that is applied and other nutrients that are affected by the application. Moreover it is important to know whether the applied nutrient has changed needle weight, since that also affects interpretation. Interpretation of situations in which one nutrient concentration is diluted by the application of a second nutrient as fertiliser, is still enhanced by knowledge of the critical level.

VECTOR ANALYSIS OF RADIATA PINE FOLIAGE FROM A NITROGEN AND PHOSPHORUS FERTILISER TRIAL.

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Abstract

Chemical determination of the nutrients in pine foliage is used to monitor the nutritional health of forests and to drive fertiliser programmes. Customarily the concentration of a nutrient is used as the indicator. However there are often needle weight changes following fertilisation, which complicate analysis. In this paper a graphical vector analysis technique which combines needle weight and needle nutrient concentrations is tested with radiata pine needles from a nitrogen and phosphorus fertiliser trial. The objectives of the study were to see whether the technique is useful in a species with a less determinate growth pattern than the species on which the technique was developed and whether the technique would apply as well in situations where two or more nutrients affect growth. Our conclusions are that the technique appears to work well for radiata pine but that interpretation needs to be modified to distinguish between the nutrient that is applied and other nutrients that are affected by the application. Moreover it is important to know whether the applied nutrient has changed needle weight, since that also affects interpretation. Interpretation of situations in which one nutrient concentration is diluted by the application of a second nutrient as fertiliser, is still enhanced by knowledge of the critical level.

Introduction.

It is customary to assess the nutritional health of trees and the effects of applied fertiliser by chemically analyzing foliage to determine it's nutrient contents (Will 1985). The results of such analysis are presented as concentrations of nutrients. Workers have attempted to identify the "critical" concentration below which growth is markedly reduced (Bates 1971). Fertiliser programs are driven by these critical concentrations. There are many biomass studies however which show that canopy mass is affected by fertiliser treatment (Brix, 1981; Miller and Miller 1976 , Hunter et al 1986) and that canopy mass can vary greatly between sites of different fertility (Hunter et al 1987). If the canopy mass increases as a result of treatment then studying nutrient concentrations alone ignores part of the response. Weetman (1989) has pointed out that a special case occurs in determinate tree species in the initial stages of response. Such species have set the number of new leaves or needles at the end of the preceding season and in response to a fertiliser treatment can only increase the size of the pre-determined number of leaves. Timmer and Morrow (1984) present the results from 10 studies in which changes in needle weight were correlated with growth. Weetman (1989), Timmer and Stone (1978) have developed a graphical technique using the weight, the nutrient content and the nutrient concentration of needles collected from fertiliser treatments within 6 months of fertiliser application to assess the success of the fertiliser application in increasing tree growth. In the interests of clarity, the key figure is reproduced here (figure 1).

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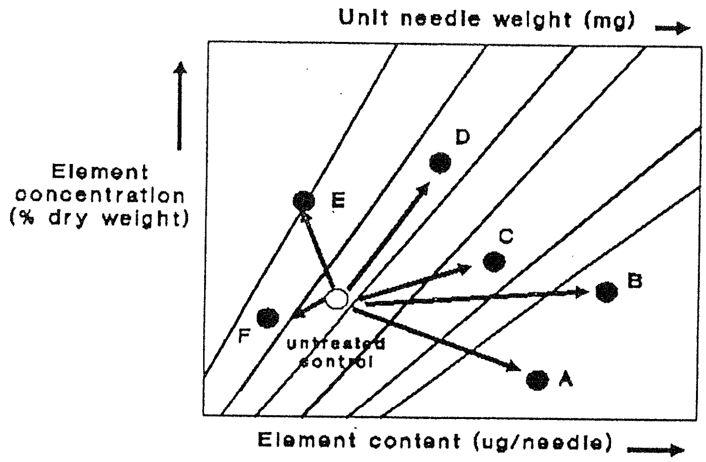

Direction of shift	Response in: Needle weight	Nutrient Conc	Nutrient Content	Interpretation	Possible Diagnosis
A	+	-	+	Dilution	Non-limiting
B	+	O	+	Sufficiency	Non-limiting
C	+	+	+	Deficiency	Limiting
D	O	+	+	Luxury consumpt.	Non-toxic
E	-	++	±	Excess	Toxic
F	-	-	-	Excess	Antagonistic

Figure 1: The Vector Analysis technique as given in Weetman (1989).

Weetman et al (1988) have related the volume growth three years after fertilising to the indications derived from the graphical analysis and reported that the graphical analysis was a reliable indicator.

We had collected needles from young radiata pine trees in a suite of 5 central composite fertiliser trials with nitrogen (N) and phosphorus (P), 6 months after fertiliser was applied. The trees have been measured for volume four years after fertiliser application. Using these data we decided to study:-

1. Whether the technique was applicable to radiata pine, a species which is only semi-determinate in it's growth. That is to say it produces multiple growth flushes during the year.
2. Whether the technique was readily applicable to situations in which responses to two fertiliser elements occurred.

Methods:

Five fertiliser trials were established in 1983 in 4/5 year old radiata pine. The location and environmental details about the 5 sites are shown in Table 1.

Table 1 Location and climatic characteristics of the five sites

Location	Latitude (°S)	Average annual temp(°C)	Yearly rainfall (mm)	Yearly sunshine (hours)	Tree age (years)
Parengarenga	34.6	15.5	1448	2091	4
Maromaku	35.6	13.1	1905	1902	4
Kaingaroa	38.7	9.3	1704	1896	5
Nelson	41.2	11.8	1372	2341	5
Nemona	42.6	11.0	2488	1769	4

Fertiliser was applied in spring 1983 using the rates of nitrogen and phosphorus given in table 2. Phosphorus was applied as food grade mono-calcium phosphate, and nitrogen as urea. Foliage samples were collected in February/ March 1984 from the standard position in the crown; needles in their first year from secondary branchlets in the upper crown. Many hundreds of complete fascicles were collected from each treatment. A sub-sample of fifty fascicles was randomly extracted from each foliage sample and put to one side for determination of weight after drying. Needle fascicles were rejected unless they contained three needles; radiata pine is somewhat variable in this respect. The fascicles were also rejected if they had insect damage. The remaining fascicles were prepared by the methods given in Nicholson (1984) for chemical determination of N, P and potassium (K) concentrations.

Table 2 Fertiliser rates used

Treatment	Nitrogen kg/ha	Phosphorus kg/ha
1	80	40
2	80	120
3	240	40
4	240	120
5	0	75
6	400	75
7	150	0
8	150	200
9	150	75

The trees in each fertiliser plot were measured for height and diameter at the time of fertilising. They were remeasured annually thereafter but only the response four years after will be presented here. Tree volume was calculated by logarithmic volume equations. Volume response over four years was calculated by subtracting the volume in the unfertilised plots from that in treated plots.

The significance of the volume responses, the needle weight changes, and the nutrient concentrations was established by analysis of variance using GENSTAT and the ANVAR structure described in Hunter et al (1987).

Results and Discussion

The five trials gave contrasting volume responses to applied fertiliser. The Kaingaroa site did not respond at all; Nelson responded positively to P alone, positively to N and P but negatively to N alone; Parengarenga responded to both N and P; Maromaku responded to NP; Nemona responded to N and P. The other workers who have used this technique have been dealing with sites that were predominantly N responsive. Weetman et al (1988) reported on 15 trials, nine of which responded to N alone, and two to P alone. No stands responded to K alone or to P in combination with N. Timmer and Morrow's (1984) trials responded only to N although P and K were included. Thus their discussions of the effects of changes in needle weight and nutrient concentration have tended to centre on the effect of nitrogen on the trees and on other elements.

There were needle weight changes in 3 out of the 5 trials following fertilisation (Table 3a). Nitrogen increased needle weight in proportion to the amount of N applied, with an average weight increae of 20%. However P did not increase needle weight either by itself or in interaction with N. Other workers seem to have had similar experiences. Timmer and Stone (1978) reported that needle weight was increased by 25 - 33% by N fertiliser. Neither P, K, P+K, nor lime alone significantly affected needle weight. Weetman and Fournier (1982) reported a 20% increase in needle weight to N fertiliser, with an extra 8% to N and P together over N alone but no gain to NK over N. This is an important finding for the use of the graphical method proposed by Weetman and by Timmer. It means that any treatment including N is likely to have an increase in needle weight and hence highly likely to cause an increase in the **content** of other nutrients, even if their respective **concentrations** reduce. On the other hand a treatment containing P has a neutral effect on needle weight and on the content of other nutrients.

Table 3a Effect of N and P fertiliser on needle weight

Trial	Significance		
	Linear	Quadratic	Comment
Parengarenga	*	NS	Increased by N
Maromaku	*	NS	Increased by N
Kaingaroa	*	NS	Increased by N
Nelson	NS	NS	-
Nemona	NS	NS	-

NS = not significant

* = significant at $p \leq 0.05$

** = significant at $p \leq 0.01$

Table 3b Effect of N and P fertiliser on N concentration in needles

Trial	Significance Linear	Quadratic	Comment
Parengarenga	**	**	Increased by N; decreased by P
Maromaku	**	NS	Increased by N; decreased by P
Kaingaroa	**	**	Increased by N
Nelson	**	NS	Increased by N
Nemona	**	NS	Increased by N

Table 3c Effect of N and P fertiliser on P concentration in needles

Trial	Significance Linear	Quadratic	Comment
Parengarenga	**	**	Increased by P; decreased by N
Maromaku	**	*	Increased by P
Kaingaroa	**	NS	Increased by P; decreased by N
Nelson	**	NS	Increased by P
Nemona	**	NS	Increased by P

Table 3d Effect of N and P fertiliser on N content in needles

Trial	Significance Linear	Quadratic	Comment
Parengarenga	**	NS	Increased by N
Maromaku	**	NS	Increased by N
Kaingaroa	**	NS	Increased by N
Nelson	**	NS	Increased by N
Nemona	**	NS	Increased by N

Table 3e Effect of N and P fertiliser on P content in needles

Trial	Significance		Comment
	Linear	Quadratic	
Parengarenga	*	NS	Increased by P
Maromaku	**	NS	Increased by P
Kaingaroa	NS	NS	-
Nelson	**	NS	Increased by P
Nemona	**	NS	Increased by P

There were significant relationships between needle weight and four year volume

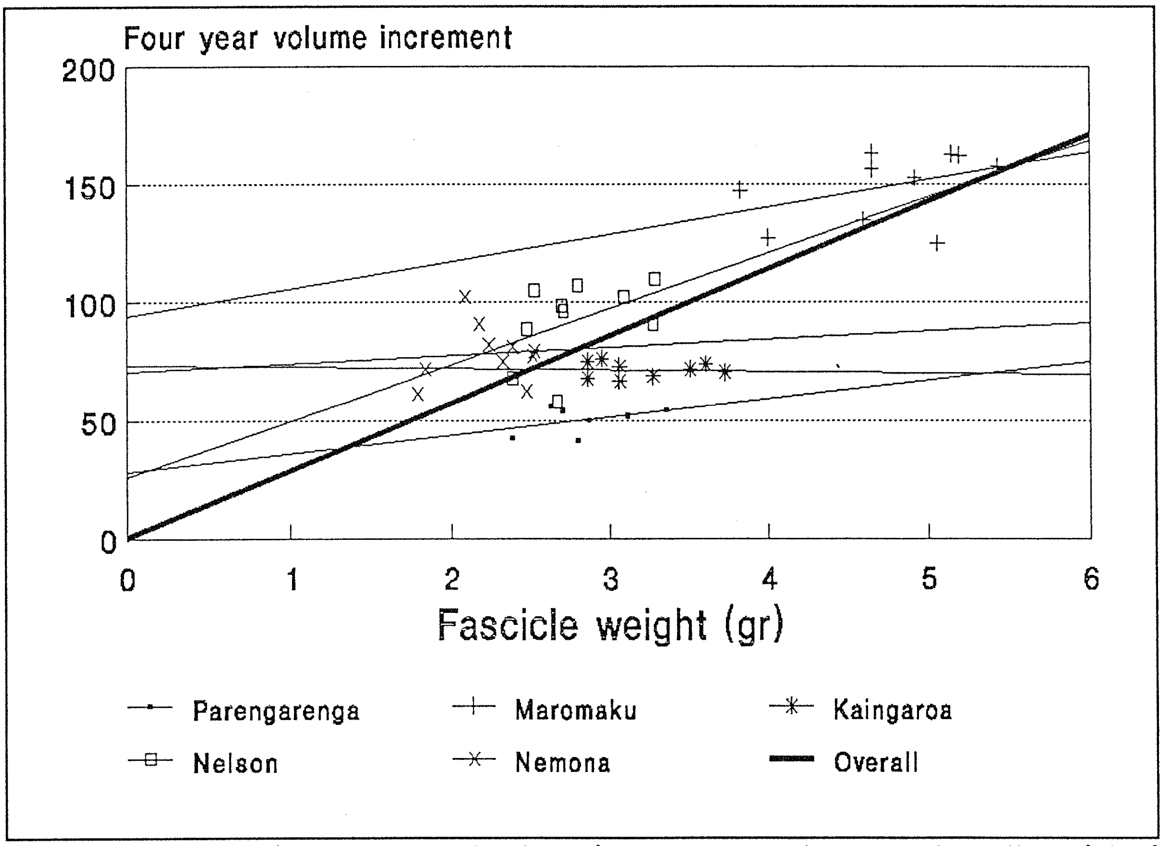

Figure 2: Relationship between total volume increment over 4 years and needle weight 6 months after fertilising for all sites and treatments.

increment between sites, but only weakly significant relationships within only two of the sites (figure 2). Timmer and Morrow (1984) document similar findings from 10 other studies. It is potentially of some practical significance however, that volume increment in a stand can be approximately predicted from the average needle weight. Needle weight could become an important indicator of stand productivity.

Both nitrogen and phosphorus had strongly significant effects on foliar concentration and content (table 3 b-e). Generally each applied nutrient increased both the concentration and content of that nutrient in the foliage, although at Parengarenga, Kaingaroa and at Maromaku the elements sometimes negatively interact.

Table 4: Revised interpretation of vector analysis.

Direction of shift	Applied nutrient	Secondary nutrients With needle weight increase	Secondary nutrients without
A	unlikely	dilution (possibly depressing)	dilution (probably depressing)
B-C-D	normal (use and storage)	synergism (strong response)	synergism (increased response)
D-E	Poisoning (by uptake)	Not possible	Luxury uptake
E-F	Poisoning (by root death)	unlikely	antagonism

There was a very wide range of results to emerge from the graphical analysis of concentration, content and needle weight, and no clear relationship to fertiliser volume response. In order to advance interpretation we found it necessary to dismantle and reconstruct Figure 1, discriminating between the applied nutrient and the other nutrients. We present our classification and it's interpretation in Table 4. We reasoned that, in the case of the applied nutrient, there was little change in the interpretation except in the case of an A-shift and an F-shift . We reasoned that "dilution" was unlikely to be the cause of an A-shift in the applied nutrient, although it could be the cause of such a shift in the non-applied nutrients. We felt it was unlikely that an applied nutrient would show an A-shift; reasoning that only if the species responded by greatly increasing it's needle weight at the expense of its nutrient concentration would such a shift be possible. It has been speculated that this technique would work on non-determinate species such as eucalypts. From our limited experience it seems A-shifts of this nature might occur in such species. We felt that the term "antagonism" was more appropriate to non-applied nutrients and the term "poisoning" might be better applied to F-shifts in the applied nutrient.

In the case of the non-applied nutrients we felt a substantial change in interpretation was justified. An A-shift indicates deficiency but we felt that a C-shift, where the content and concentration of nutrient B had increased when nutrient A was added, indicated a highly desirable **synergism** between two elements. An E-shift, implying an increase in the concentration of element B where presumably, element A had reduced needle weight, merely indicated luxury uptake. It concerns us that when an applied nutrient, such as nitrogen, causes a strong increase in needle weight shifts D through F become unlikely. Indeed an E-shift is mathematically impossible. On the other hand, where an element such as phosphorus, brings about a response without changes in needle weight, shifts D through

F become possible.

Table 5: Interpretation of combined shifts in two elements

Classification	Description	Four Year Volume reponse m^3/ha
D_n	N diluted; P deficient (A/C shift)	13.1
D_p	P diluted; N deficient	5.3
S	Both deficient (C/C shift)	21.3
A_n	Antagonistic to N (F/C shift)	6.6
A_p	Antagonistic to P	-6.8

We reclassified our results as shown in Table 5 and averaged the fertiliser response for each new classification. We found that this classification gave much greater explanation of volume increment. However anomalies remained. Where P was diluted by applications of N, there was a positive response to fertiliser twice and a negative response three times. In their early descriptions of their technique Timmer and Stone (1978) stressed the inadequacy of the concentration alone approach and they were right to do so. However the two approaches are in fact complimentary. There is generally a large pool of information about "critical" values. Our data shows that dilution per se does not matter but dilution when the concentration is already deficient or becomes so following dilution, does matter. The criticism can easily be countered by entering the known critical concentration as a line on the graph. A-shifts that move below the line are likely to be associated with growth reductions. A-shifts that terminate above the line are likely to have no growth consequences.

Conclusions.

We set ourselves the task of utilising the vector analysis technique in radiata pine to see whether it was suitable for use in a species that is slightly less deterministic in growth than the species on which the technique was developed. We found that it did work just as well. We also set ourselves the task of using the technique in a trial series where responses to two elements occurred to see if it worked in such a situation. We found it desirable to separate the interpretation into the "applied" nutrient and "secondary" nutrients, i.e. to distinguish between the fertiliser nutrient causing the change and those nutrients merely affected by it. We also found it desirable to re-introduce the concept of the "critical level" when interpreting the likely consequences of concentration dilution.

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