VECTOR ANALYSIS OF FOLIAGE DATA TO STUDY COMPETITION FOR NUTRIENTS AND MOISTURE: AN AGROFORESTRY EXAMPLE

D.J. MEAD

Department of Plant Science, P.O. Box 84, Lincoln University,
Canterbury, New Zealand

and I. MANSUR

Faculty of Forestry, Bogor Agricultural University,
P.O. Box 69 Bogor, Jawa Barat, Indonesia

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ABSTRACT

Vector analysis, previously used to study nutrient status in trees, has been modified for use in competition experiments. The interpretation of changes in leaf weight, nutrient concentration, and nutrient content per leaf indicates whether moisture and/or nutrients are causing changes in growth.

An agroforestry trial with *Pinus radiata* D.Don and six ground cover treatments was studied using the new interpretation. The results indicated that, for this site/season combination, the main competition factors reducing tree growth were moisture, nitrogen, and boron. Potassium and magnesium levels were also changed but not in a manner expected to alter tree growth. There was little change in phosphorus, calcium, and micronutrients other than boron. The effect of moisture was consistent with the drought conditions experienced during the study. Lucerne proved to be the most competitive of the ground covers used in this trial.

Vector analysis gave more information on effects of competition than did foliar concentration, foliar nutrient content, or tree growth. Fascicle weight was found to be an indicator of tree vigour, but for *P. radiata* it was not as sensitive as height and diameter measurements.

Keywords: competition; agroforestry; soil moisture; foliar nutrient diagnosis; *Pinus radiata*.

INTRODUCTION

Research into agroforestry has indicated that between-species competition is an important factor limiting productivity. Competition between the tree component and the understorey component (crops/pastures) for water, nutrients, and light (Ong *et al.* 1991; Garrison & Pita 1992) may lead to a decline in crop production (Chamshama *et al.* 1992; Sharma 1992; Rao *et al.* 1991), pasture productivity (Hawke 1991; Verma 1991), and tree growth (Smail 1975). Competition for light is less important for the tree component than for the understorey (Ong *et al.* 1991). Similar competition between trees and understorey occurs in forest plantations, particularly during the establishment phase. For this paper, competition is defined as the combination of factors responsible for reduction of tree growth associated with the presence of an understorey component in the ecosystem.

Little attention has been given to finding rapid quantitative techniques for monitoring trees for possible competition effects, and in particular for determining whether the competition is for moisture, nutrients, or both.

Foliage analysis has been regarded as a reasonable tool for assessing nutrient status and fertiliser requirements in trees (Van den Driessche 1974; Mead 1984; Will 1985; Weetman & Wells 1990). Vector analysis is a comparatively new method (Weetman & Wells 1990), which can be used to examine shifts in combinations of data from foliage nutrient analyses and leaf dry weight. It has been used successfully to identify forest stands which will respond to fertiliser applications (Timmer & Morrow 1984; Weetman & Wells 1990), and also to predict growth responses of *Picea mariana* (Mill.) B.S.P. seedlings to differences in field nutrient status (Munson & Timmer 1989). The method is based on observations of significant shifts that occur in individual leaf dry weight, nutrient concentration, and nutrient content in stands treated with fertiliser as against untreated stands (Fig. 1, Table 1).

The purpose of this study was to determine whether vector analysis can be employed to measure nutrient and moisture limitations resulting from competition. Data from a silvopastoral agroforestry experiment have been used to illustrate and explore the technique.

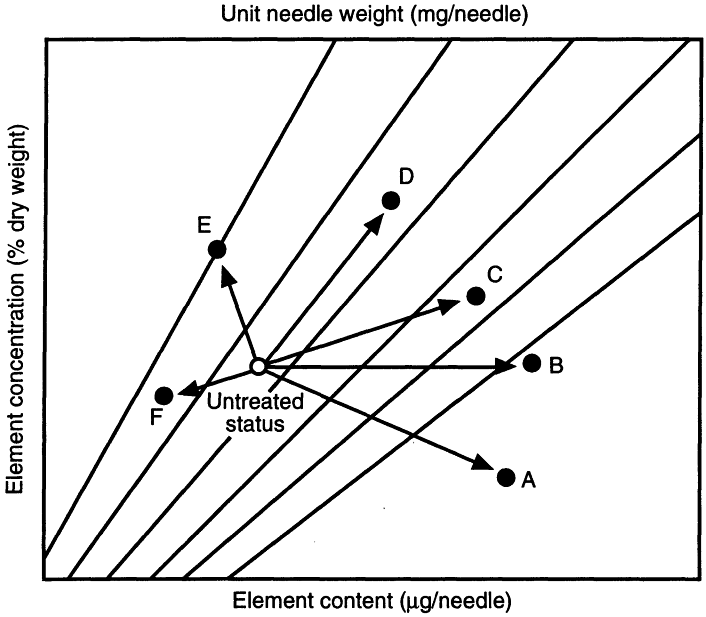

FIG. 1–Vector analysis diagram (from Munson & Timmer 1989).

TABLE 1–Interpretation of vector analysis diagram for fertiliser trials (from Munson & Timmer 1989)

Direction of shift	Response in			Changes in	
	Needle weight	Nutrient		Nutrient status	Possible diagnosis
		Conc.	Cont.		
A	+	–	+	Dilution	Non-limiting
B	+	0	+	Unchanged	Non-limiting
C	+	+	+	Deficiency	Limiting
D	0	+	+	Luxury consumption	Non-toxic
E	–	++	±	Excess	Toxic
F	–	–	–	Excess	Antagonistic

METHODS

Experimental

Details of the agroforestry experiment used to illustrate the vector analysis have been described by Mead *et al.* (1993). Briefly, the trial was located close to Lincoln University, Canterbury, New Zealand, on a Templeton silt loam soil. This soil has been described as medium- to free-draining and is derived from fine alluvial sediments (Kear *et al.* 1967). The climate of the area is temperate and subhumid with an average annual rainfall of 666 mm. For the 1991–92 growing season moisture was limiting (N. Cherry, Lincoln University, pers. comm.). That year the rainfall (July 1991 to July 1992) was only 525 mm and in 5 of those months the rainfall was less than or equal to half the long-term average. Potential open-pan evaporation greatly exceeded rainfall.

The experiment was a split-plot, randomised block design with three replications. The six main plot treatments were ground covers chosen to provide trees with a range of competition intensity. They were: bare ground (control); Maru phalaris + clovers; Wana cocksfoot + clovers; Yatsun perennial ryegrass + clovers; lucerne; and volunteer weeds. Subplot treatments within these main plots were five different genotypes of *P. radiata* (*see* Mead *et al.* 1993 for further details). Guard rows around the main plots ensured that no measured tree was within 5.6 m of a different ground cover treatment. There were 20 inner measurement trees within each subplot.

The trial was established in the winter of 1990 when trees were planted with 7-m spacing between rows and 1.4-m spacing within rows. One-third of the green foliage was buried at planting to promote high survival on this drought-prone site. Tree rows had been ripped to a depth of 60 cm prior to planting. They were strip sprayed (1 m wide) with hexazinone at 2.4 kg/ha in the spring of 1990 and again in 1991. The ground cover treatments were sown in the spring of 1990 and the control plots were kept weed-free by regular herbicide application.

Foliage and Soil Sampling

Foliage sampling of *P. radiata* was done in autumn (March) 1992. A bulk sample for each subplot was collected from 20 trees per subplot. From each tree, 10 fully grown current-growth fascicles were collected from the main spring flush of upper crown branches. Foliage samples were oven-dried at 60°C for 48 hours, weighed, and ground, and their nitrogen, phosphorus, potassium, calcium, magnesium, boron, manganese, zinc, and copper concentrations were analysed as described by Nicholson (1984).

Soil samples from 0–15 cm depth were collected from each block of the trial at the time of establishment and were analysed for pH (1:2.5 soil:water), Olsen-P, and exchangeable cations extracted with neutral molar ammonium acetate (Nicholson 1984).

Statistical Analysis

Data for fascicle dry weight, nutrient concentration, and nutrient content were analysed using the Statistical Analysis System Package (SAS Institute Inc. 1987) including analysis of variance (ANOVA) and the Dunnett Test. The Dunnett test was chosen in preference to other multiple range tests as it compares treatment means with a control, in this experiment the zero ground cover treatment. There was no statistically significant interaction ($p>0.05$) between ground cover treatment and genotypes; this indicates that all genotypes were behaving in a similar manner. Therefore, for the purposes of this paper we have used only the ground cover main-plot effects.

Vector Analysis

Unit fascicle dry weight (UFDW), nutrient (nitrogen, phosphorus, potassium, calcium, magnesium, boron, manganese, zinc, and copper) concentrations, and nutrient contents were plotted in vector analysis diagrams. The statistical significance of the changes in the three components of the vector was obtained from the Dunnett test.

The vector analysis diagram used by Munson & Timmer (1989) for the interpretation of fertiliser experiments (Fig. 1, Table 1) is not suitable for competition studies. In nutrient deficiency studies the control treatment is usually not treated with fertiliser and moisture stress is assumed to be constant throughout. In competition studies the plants (in this trial the trees) grow at various levels of competition, and such trees are likely to differ in both moisture and nutrient status.

We have developed a new interpretation of the vector shifts. The vector could be expected to move in one of eight directions, designated A to H, depending on the site, plants, and nutrients involved (Fig. 2, Table 2). Each shift would be the result of competition for the nutrient in question, or for moisture, or both. We have allowed for the possibility that nutrient status of the study plant, as indicated by nutrient concentration and nutrient content of the leaves, may remain static, decrease, or improve. These changes in nutrient status may or may not be associated with changes in growth as indicated by leaf dry weight.

In the interpretation of these shifts (Table 2) we have suggested how nutrient or moisture changes may be involved. It is conceivable, for example, that growth may improve because of better moisture status without a significant change in nutrient uptake (Shift A). In other situations vector analysis may not clearly indicate which factor is dominant. For example, a G shift could be due to nutrient competition alone or to a combination of nutrients and moisture.

RESULTS

Unit Fascicle Dry Weight and Tree Growth

Pinus radiata grown with zero ground cover had the highest unit fascicle dry weight (85 mg), while that in the lucerne treatment had the lowest (73 mg) (Table 3). This is a decrease of about 14%.

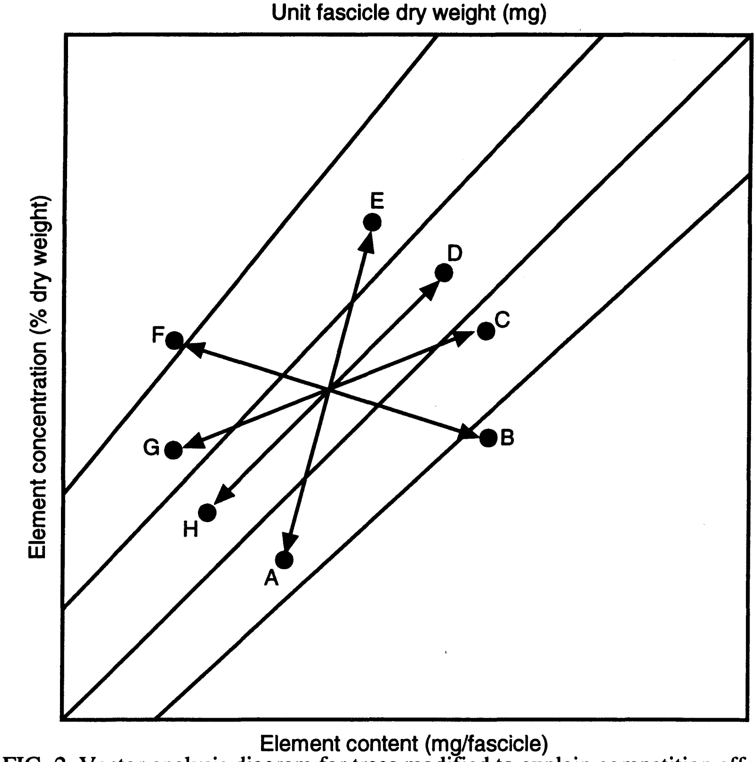

FIG. 2–Vector analysis diagram for trees modified to explain competition effects.

Height and diameter increment over the second growing season followed similar trends (Table 3) although relative differences were more pronounced. *Pinus radiata* grown with zero ground cover had the greatest height and diameter increments (100 cm and 37 mm, respectively) and the lucerne treatment gave the lowest values (71 cm and 19 mm, respectively).

Soil and Foliar Nutrient Levels

The soil showed slight acidity at pH 6.0. Soil Olsen-P level (17 µg/ml) was low for horticultural use but adequate for *P. radiata* (Jackson & Gifford 1974). Exchangeable cations were generally in the medium range averaging 0.88 me K/100 g, 7.2 me Ca/100 g, 0.83 me Mg/100 g, and 0.17 me Na/100 g.

The ground cover treatments significantly affected the nitrogen, potassium, magnesium, and boron concentrations in tree foliage, but changes in phosphorus, calcium, manganese, zinc, and copper were not significant (Tables 4 and 5).

Foliage from trees grown with zero ground cover was significantly higher in nitrogen (at 1.77%) than that from most other treatments, although only the lucerne treatment value at 1.42% would be regarded as being in the marginal range (Will 1985). It is interesting that although lucerne is a N_2-fixing legume, *P. radiata* foliar nitrogen concentration in those plots showed a reduction of about 20%.

TABLE 2–The proposed interpretation of vector analysis for trees, modified to explain understorey competition effects

Types of shift	Response in UFDW	Conc.	Cont.	Competition effects	Moisture regime
A	+	–	0/+	Growth improved. Nutrient not limiting (dilution may occur).	Moisture stress reduced.
B	+	–/0	+	Growth improved. Greater nutrient availability.	Moisture stress reduced.
C	+	+	+	Growth improved. Competition reduced all stresses or increased nutrient availability.	Moisture stress probably reduced.
D	0	+	+	No growth change. Nutrient not limited by competition and accumulation occurring.	Moisture non-limiting.
E	–	+	0/+	Growth reduced. Nutrient not limited by competition and accumulation may occur.	Moisture stress induced by competition (allelopathy or another nutrient may be possibly reducing growth).
F	–	+/0	–	Growth reduced. Nutrient uptake but not concentration reduced by moisture stress. Nutrient not limited by competition.	Moisture limiting growth.
G	–	–	–	Growth reduced. Nutrient limiting growth as well as moisture.	Moisture limiting growth as well as nutrient.
H	0	–	–	No growth change. Lower nutrient status indicates plants without competition had luxury nutrient consumption.	Moisture not limiting.

Note: UFDW = Unit fascicle dry weight
Conc. = Element concentration
Cont. = Element content

TABLE 3–Autumn unit fascicle dry weights and height and diameter increments of *P. radiata* in the second growing season, as influenced by the ground cover treatments

Competition treatments	Unit fascicle dry weight (mg)	Height increment (cm)	Diameter increment (mm)
Zero ground cover	85	100	37
Maru phalaris + clovers	78	79*	22*
Wana cocksfoot + clovers	82	92	26*
Yatsun perennial ryegrass + clovers	81	96	28*
Lucerne	73*	71*	19*
Weeds	83	96	30*

Values followed by * are significantly different from those for zero ground cover ($p = 0.05$)

TABLE 4–Foliar macronutrient concentrations and contents in *P. radiata* in the autumn of the second growing season

Competition treatments	Nutrient concentration (%)					Nutrient content (mg)				
	N	P	K	Mg	Ca	N	P	K	Mg	Ca
Zero ground cover	1.77 (100)	0.134 (100)	1.02 (100)	0.096 (100)	0.26 (100)	1.51 (100)	0.112 (100)	0.86 (100)	0.081 (100)	0.22 (100)
Maru phalaris + clovers	1.58* (89)	0.133 (99)	0.80* (79)	0.122* (127)	0.27 (104)	1.24* (82)	0.104 (93)	0.62* (73)	0.095* (117)	0.21 (95)
Wana cocksfoot + clovers	1.61* (91)	0.132 (99)	0.91* (89)	0.110* (115)	0.28 (108)	1.32* (87)	0.108 (96)	0.74* (86)	0.090 (111)	0.23 (105)
Yatsun perennial ryegrass + clovers	1.73 (98)	0.138 (102)	0.92 (90)	0.108* (113)	0.26 (100)	1.40 (93)	0.110 (98)	0.74* (86)	0.086 (106)	0.21 (95)
Lucerne	1.42* (80)	0.135 (101)	0.86* (84)	0.113* (118)	0.27 (104)	1.04* (69)	0.098 (88)	0.62* (72)	0.082 (101)	0.20 (90)
Weeds	1.67* (94)	0.123 (92)	0.90* (88)	0.102 (106)	0.28 (108)	1.39 (92)	0.102 (91)	0.74* (87)	0.084 (104)	0.23 (105)

Values followed by * are significantly different from those for zero ground cover (p=0.05)
Values in brackets are percentages relative to values for zero ground cover.

TABLE 5–Foliar micronutrient concentrations and contents of *P. radiata* in the autumn of the second growing season

Competition treatments	Nutrient concentration (ppm)				Nutrient content (μg)			
	B	Mn	Zn	Cu	B	Mn	Zn	Cu
Zero ground cover	16.6 (100)	50.0 (100)	29.7 (100)	3.80 (100)	1.41 (100)	4.20 (100)	2.49 (100)	0.32 (100)
Maru phalaris + clovers	10.7* (64)	49.8 (100)	33.1 (111)	4.06 (107)	0.81* (57)	3.85 (92)	2.53 (101)	0.32 (100)
Wana cocksfoot + clovers	11.4* (69)	48.1 (96)	30.9 (104)	3.64 (96)	0.92* (65)	3.89 (93)	2.50 (100)	0.30 (94)
Yatsun perennial ryegrass + clovers	11.6* (70)	42.1 (84)	30.8 (104)	4.07 (107)	0.92* (65)	3.34 (80)	2.43 (98)	0.33 (103)
Lucerne	10.7* (64)	61.2 (122)	33.9 (114)	4.00 (105)	0.77* (55)	4.44 (105)	2.45 (98)	0.29 (91)
Weeds	12.3* (74)	45.8 (92)	29.1 (98)	3.56 (94)	1.02* (72)	3.72 (89)	2.39 (96)	0.29 (91)

Values followed by * are significantly different from those for zero ground cover (p=0.05)
Values in brackets are percentages relative to values for zero ground cover

The foliage potassium level in all treatments was satisfactory (Will 1985). However, the changes in potassium levels were similar to those in nitrogen, the zero ground cover treatment being associated with a significantly higher level than several other treatments (Table 4). Foliar nitrogen and potassium concentrations in trees grown with Yatsun perennial ryegrass + clovers were not significantly different from those of treees grown with zero ground cover.

Trees in zero ground cover plots had the highest foliar boron concentration, i.e., 16.6 ppm, which according to Will (1985) is satisfactory. Those in all plots with ground cover had foliar boron concentrations significantly decreased to what is considered marginal (Will 1985). Lucerne and Maru phalaris + clovers gave the lowest values (10.7 ppm), some 35% lower than zero ground cover plots. Low boron concentrations in *P. radiata* foliage have frequently been associated with drought (Will 1985).

Magnesium concentrations in all except the volunteer weed treatment were significantly higher than in the zero ground cover ones (0.096%). According to Will (1985), 0.07% to 0.10% Mg represents marginal status.

Phosphorus and copper concentrations in all treatments were marginal (Will 1985). However, no treatment values were statistically different from the control ($p \leq 0.05$). In contrast to phosphorus and copper, the status of calcium, manganese, and zinc in all treatments was satisfactory (Will 1985).

Vector Analysis

From Tables 3, 4, and 5 and Fig. 3 and 4 we have summarised the vector shifts for each nutrient in each ground cover treatment (Table 6). We have described the vector as belonging to one of the eight classes, A to H. For some we have also indicated the trend (parentheses in Table 6) shown in the vector diagrams, even though one or more components of the vector was not statistically significant. For some treatments, studying the trends makes more sense than relying solely on vectors which are statistically significant. With nitrogen, for example, all treatments with ground cover show a similar pattern—a G trend. However, a G shift is only "real", based on statistical tests ($p \leq 0.05$), for the lucerne treatment. The H shifts for phalaris + clovers and cocksfoot + clovers arose because the fascicle weights were not significantly reduced. However, diameter growth was significantly lower in these treatments, indicating that competition was influencing growth.

Nitrogen

The predominant trend was towards a G shift although, as explained above, it was statistically significant only for the lucerne treatment. We would interpret this as growth being reduced due to competition for nitrogen and/or water (Table 2); only in the lucerne treatment was the nitrogen level reduced to the extent considered marginal for growth.

Potassium

The effect of competition was to reduce both foliar concentration and foliar content and this resulted in G/H shifts. The high potassium levels suggest that, although competition reduced uptake, the reduction did not affect growth. The exchangeable levels of potassium in the soil confirmed that this nutrient was unlikely to be limiting growth.

Magnesium

The general trend was towards an E shift. Here nutrient uptake was not limited by competition processes, but moisture deficit was implicated in reduced growth.

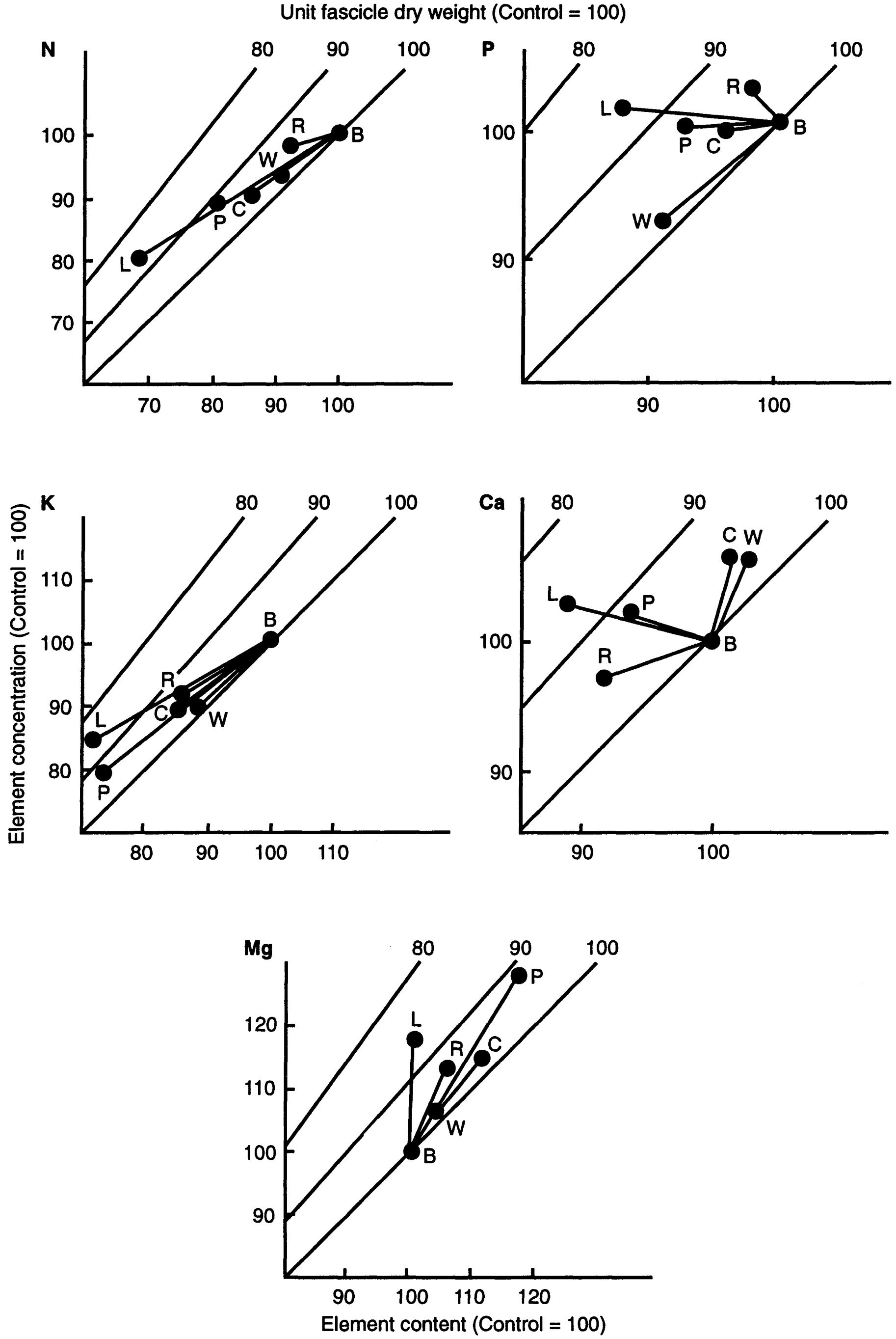

FIG. 3–The relative vector shifts for the macronutrients (N, P, K, Ca, Mg) as a result of different treatments: B = zero ground cover, P = Maru phalaris + clovers, C = Wana cocksfoot + clovers, R = Yatsun perennial ryegrass + clovers, L = lucerne, and W = weeds.

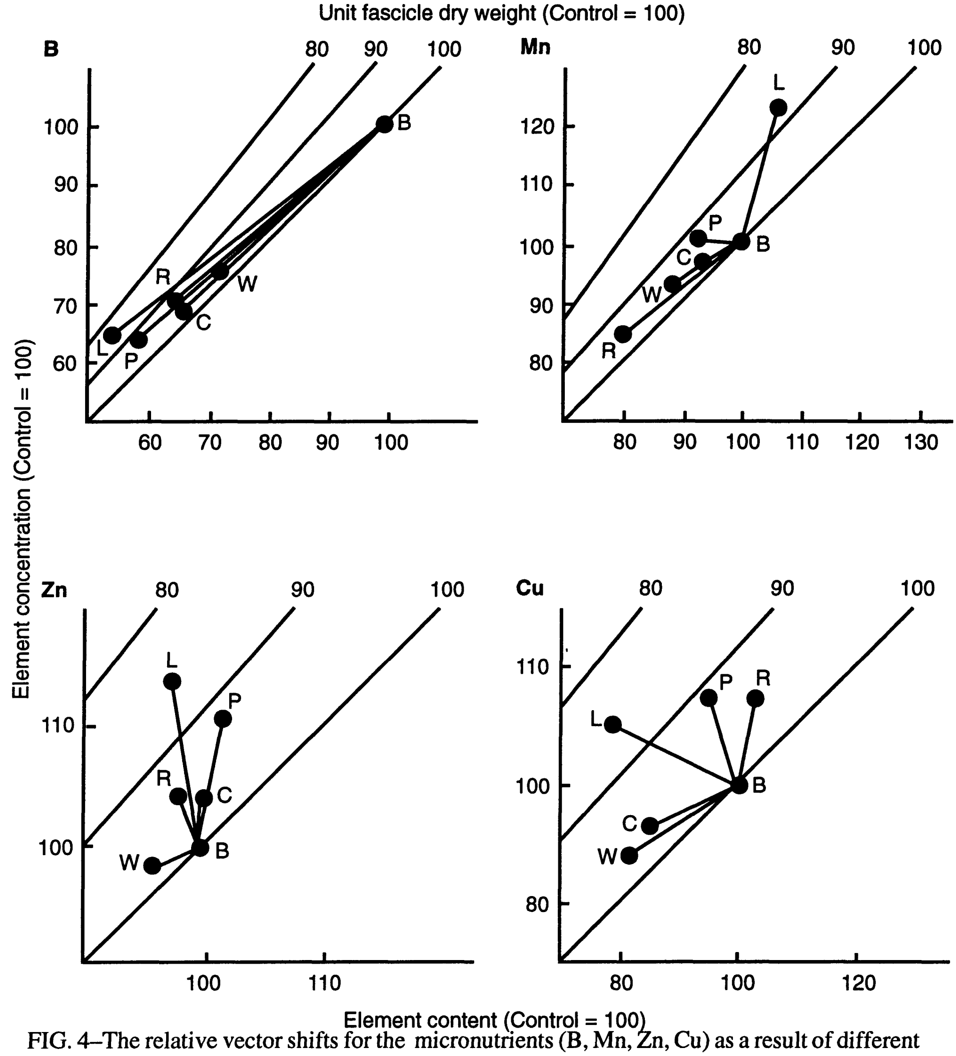

FIG. 4–The relative vector shifts for the micronutrients (B, Mn, Zn, Cu) as a result of different treatments: B = zero ground cover, P = Maru phalaris + clovers, C = Wana cocksfoot + clovers, R = Yatsun perennial ryegrass + clovers, L = lucerne, and W = weeds.

Boron

The vector analysis pattern for boron was similar to that for potassium with pronounced G/H shifts. Unlike potassium, where all levels were adequate, boron levels were sometimes marginal where ground cover was present. Foliar boron contents were also substantially reduced. Moisture stress is known to adversely affect boron nutrition in *P. radiata* (Will 1985).

Other nutrients—phosphorus, calcium, manganese, zinc, copper

All these nutrients showed non-significant changes and, apart from phosphorus and copper, were at adequate levels in the foliage. Vector shift trends were either E, F, or G:

TABLE 6–Summary of vector analysis results

Nutrient	Competition treatments				
	Maru phalaris + clovers	Wana cocksfoot + clovers	Yatsun perennial ryegrass + clovers	Lucerne	Weeds
N	H (G)	H (G)	(G)	G	(G)
P	(F)	(F)	(F)	(F)	(G)
K	H(G)	H(G)	H(G)	G	H(G)
Mg	D (E)	(E)	(E)	E	(E)
Ca	(E)	(E)	(F)	(F)	(E)
B	H (G)	H (G)	H (G)	G	H (G)
Mn	(F)	(G)	(G)	(E)	(G)
Zn	(E)	(E)	(F)	(E)	(G)
Cu	(E)	(G)	(E)	(E)	(G)

Letters in parentheses indicate a trend in the vector which is not statistically significant.

E and F vectors suggest that nutrients are not limited by competition but that moisture stress may be implicated, while G trends indicate that nutrients could be involved as well as moisture.

DISCUSSION AND CONCLUSIONS

The silvo-pastoral agroforestry trial at Lincoln University was used to study the potential of foliage vector analysis for understanding competition between trees and the understorey. The different ground cover treatments reduced tree growth to varying degrees, with the lucerne and phalaris + clovers treatments having the greatest effect. Ryegrass + clovers, cocksfoot + clovers, and volunteer weeds had a smaller effect.

Tree growth alone is not an indicator of whether soil moisture or nutrients are involved in the competition process. Foliar nutrient concentrations suggested that nitrogen and boron were reduced to marginal levels; potassium and magnesium levels in the foliage also changed but they were well above deficiency levels; phosphorus, calcium, manganese, zinc, and copper levels were unaltered. However, foliage nutrient levels cannot be used to identify moisture stress.

With vector analysis we were able to show that both moisture and nutrient stresses were involved in growth reduction. Although the vectors differed in direction, magnitude, and statistical significance, between different ground cover treatments and for different nutrients, they almost always suggested that soil moisture stress was involved. This seems reasonable, considering the drought experienced during the growing season. Nitrogen and boron stress were also implicated. Potassium uptake, as indicated by foliar concentration and content, was reduced but not to the degree that would be expected to stress the trees. Magnesium concentration, and to a lesser extent foliar magnesium content, tended to be enhanced by ground cover. Other nutrients were unaffected. In using vector analyses we found it useful to take into consideration existing knowledge about the relationships of tree growth to foliage nutrient levels and, to a lesser extent, soil analyses.

Our conclusions from vector analysis were that for this combination of site and growing season, reduced tree growth associated with understorey competition was due largely to moisture, nitrogen, and boron stress. To investigate competition processes in more depth would require other ecophysiological studies, perhaps involving experimental application of water and nutrients.

This study also examined the usefulness of fascicle dry weight as an indicator of tree vigour. *Pinus radiata* has a predetermined growth pattern but may have more than one growth cycle in a growing season (Bollmann & Sweet 1977). Care is therefore needed when collecting needle fascicles to take them from the same growth flush and crown position. However, we found that fascicle dry weight was not as sensitive an indicator of tree vigour as height and diameter increments. This may limit the sensitivity of vector analysis for *P. radiata*.

In other tree species leaf weight is apparently a more reliable indicator of vigour, possibly because the pre-determined growth habit is more strongly expressed than in *P. radiata* (Weetman & Wells 1990). In such species vector analysis should be more reliable as a method for studying competition effects.

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REFERENCES

BOLLMANN, M.P.; SWEET, G.B. 1977: Bud morphogenesis of *Pinus radiata* in New Zealand. 1: The initiation and extension of the leading shoot of one clone at two sites. *New Zealand Journal of Forestry Science 6*: 376–92.

CHAMSHAMA, S.A.O.; MONELA, G.C.; SEKIETE, K.E.A.; PERSSON, A. 1992: Suitability of the taungnya system at North Kilimanjaro Forest Plantation, Tanzania. *Agroforestry Systems 17*: 1–11.

GARRISON, M.; PITA, M. 1992: An evaluation of silvopastoral systems in pine plantations in the Central Highland of Equador. *Agroforestry Systems 18*: 1–16.

HAWKE, M.F. 1991: Pasture production and animal performance under pine agroforestry in New Zealand. Pp. 109–18 *in* Jarvis, P.G. (Ed.) "Agroforestry: Principles and Practice". Elsevier, Amsterdam.

JACKSON, D.S.; GIFFORD, H.H. 1974: Environmental variables influencing the increment of radiata pine. (1) Periodic volume increment. *New Zealand Journal of Forestry Science 4*: 3–26.

KEAR, B.S.; GIBBS, H.S.; MILLER, R.B. 1967: Soils of the downs and plains, Canterbury and North Otago, New Zealand. *New Zealand Department of Scientific and Industrial Research, Soil Bureau Bulletin 14*.

MEAD, D.J. 1984: Diagnosis of nutrient deficiencies in plantations. Pp. 259–91 *in* Bowen, G.D.; Nambiar, E.K.S. (Ed.) "Nutrition of Plantation Forests". Academic Press, London.

MEAD, D.J.; LUCAS, R.J.; MASON, E.G. 1993: Studying interaction between pastures and *Pinus radiata* in Canterbury's subhumid, temperate environment—the first two years. *New Zealand Forestry 38(1)*: 26–31.

MUNSON, A.D.; TIMMER, V.R. 1989: Site-specific growth and nutrition of planted *Picea mariana* in the Ontario Clay Belt. I: Early performance. *Canadian Journal of Forest Research 19*: 162–70.

NICHOLSON, G.M. (Comp.) 1984: Methods of soil, plant, and water analysis. *New Zealand Forest Service, FRI Bulletin No. 70.*

ONG, C.K.; CORLETT, J.E.; SINGH, R.T.; BLACK, C.R. 1991: Above and below ground interaction in agroforestry systems. Pp. 45–57 *in* Jarvis, P.G. (Ed.) " Agroforestry: Principles and Practice". Elsevier, Amsterdam.

RAO, M.R.; ONG, C.K.; PATHAK, P.; SHARMA, M.M. 1991: Productivity on annual cropping and agroforestry system on a shallow Alfisol in semi-arid India. *Agroforestry Systems 15*: 51–63.

SAS INSTITUTE INC. 1987: "SAS/SAT Guide for Personal Computers, Version 6". SAS Institute Inc., Cary, NC.

SHARMA, K.K. 1992: Wheat cultivation in association with *Acacia nilotica* (L.) Willd ex. Del. field bund plantation—a case study. *Agroforestry Systems 17*: 43–51.

SMAIL, P.W. 1975: Grass and trees: the unequal battle. *Farm Forestry 17*: 49–51.

TIMMER, V.R.; MORROW, L.D. 1984: Predicting fertilizer growth response and nutrient status of jack pine by foliar diagnosis. Pp. 335–51 *in* Stone, E.L. (Ed.) "Forest Soils and Treatment Impacts". Department of Forestry, Wildlife and Fisheries, The University of Tennessee, Tennessee.

VAN DEN DRIESSCHE, R. 1974: Prediction of mineral nutrient status of trees by foliar analysis. *Botanical Review 3*: 347–94.

VERMA, D.P.S. 1991: Evaluation of agroforestry practices in Gujarat State, India. Pp. 325–35 *in* Jarvis, P.G. (Ed.) "Agroforestry: Principles and Practice". Elsevier, Amsterdam.

WEETMAN, G.F.; WELLS, C.G. 1990: Plant analyses, an aid in fertilizing forests. Pp. 659–90 *in* "Soil Testing and Plant Analysis", 3rd ed. SSSA Book Series No. 3. Soil Science Society of America, Madison.

WILL, G.M. 1985: Nutrient deficiencies and fertiliser use in New Zealand exotic forests. *New Zealand Forest Service, FRI Bulletin No. 97.*