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DEVELOPMENT OF SOIL TESTS FOR PREDICTING FOLIAR MG CONCENTRATIONS IN *P. RADIATA*

By

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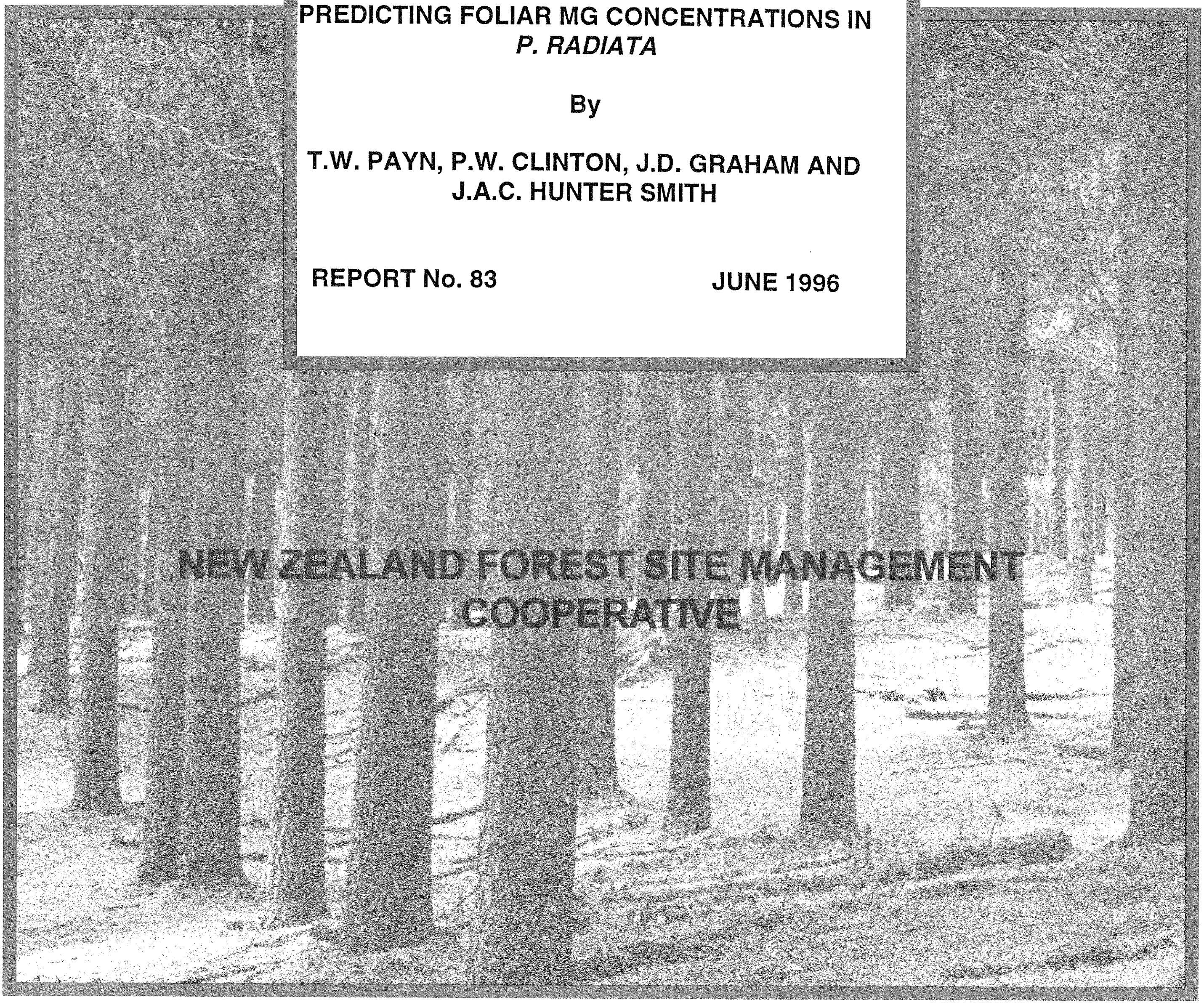

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Development of soil tests for predicting foliar Mg and B concentrations in *P. radiata*

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ABSTRACT

Soil and foliage samples were taken from four year old *Pinus radiata* in 75 temporary sample plots in the Central North Island, Canterbury, Nelson, and Otago regions. Management history and environmental data was recorded for each plot. Soils were analysed for Bray 2 and Acid Extractable Mg and $CaCl_2$ extractable boron. Foliar chemistry was analysed on one and two year old needles.

Relationships between soil and foliage concentrations were weak for magnesium, with the best relationships with the two year old foliage. Stand management had an impact on foliage Mg concentrations. Plots with a history of site disturbance (ripping, V-blading etc) had significantly lower foliar Mg concentrations. There was no apparent change in foliar Mg concentrations with successive rotations, increasing percentage weed cover caused a slight increase in foliar Mg concentration due to a decrease in needle mass.

The concentration above which none of the sampled stands had values below 0.07% was 0.75 meq/100g for Bray Mg in one and two year old foliage and 5 and 9 meq/100g for acid extractable Mg. These levels are defined as critical levels. As the models were weak, a decision tree was constructed incorporating the soil tests into a more general approach.

The relationship between soil and foliar B was poor. No critical levels for soil B could be defined and it was suggested that further work concentrate on soil texture and moisture supply characteristics of sites.

INTRODUCTION

The effect of magnesium and boron supply on the nutrition of radiata pine in New Zealand has been of increasing concern in recent years. Deficiency symptoms have been widely reported with magnesium deficiency reported to varying degrees in all regions except Northland and possibly the south west of the North Island, and boron deficiency occurring in the Central North Island, Canterbury, Marlborough, Nelson, Otago and Westland regions (Hunter et al 1992, Will 1985).

Magnesium deficiency is typified by a golden yellow chlorosis mainly in older foliage and in the upper part of the crown. The deficiency can develop into a more severe condition as trees age, with loss of older needles and twig death in the upper mid-crown. This condition is known as Upper Mid-Crown Yellowing (Beets *et al* 1993), and is exacerbated by high foliar K concentrations. The condition can be treated with magnesium fertiliser but the response is slow causing a number of years of volume growth to be lost (Hunter *et al* 1986). This slow response has been attributed to a need to rebuild foliage and root mass (Payn *et al* 1995) In the case of Boron, shoot growth is adversely affected by die back resulting in bushy trees with little height growth in the early years after planting (Will 1985), stem form can be poor

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and the value of the lower logs much reduced. For both elements therefore, prevention rather than treatment of the deficiency is preferred.

In managing these nutrients it is necessary to be able to identify sites where radiata pine is at risk of deficiency. Deficient sites can be identified using foliage analysis once the crop is established, however such screening is normally done at age 3 or 4, by which time both Mg and B symptoms will be strongly expressed on deficient sites. Other approaches such as mapping probability of deficiency in an area from historical data (Hunter *et al* 1991) have been attempted, but were at too broad a scale to be useful at the compartment or stand level. A third approach is to develop a soil test based on the development of a relationship between soil and foliar concentrations of the elements, and this approach is the focus of this paper.

Research has been done on the relationship between soil Mg concentrations and foliar Mg concentrations in *P. radiata*. The study of Ballard *et al* (1971) yielded no significant correlation between Ammonium Acetate extractable Mg and foliar Mg in a study of 128 pairs of soil and foliage samples, they suggested other extraction methods be tried. A negative correlation between foliar Mg and exchangeable K and Cation Exchange Capacity suggested the Mg status in the tree might not be able to be evaluated independently of the soil K status. Examination of the data showed that only 5% of the 128 sites had marginal or low foliar magnesium concentrations, so it is possible that there would have been a relationship if more samples with low or marginal levels had been included. Turner and Lambert (1987) working in New South Wales found no relationship between soil exchangeable Mg and foliar concentrations. Their study, like Ballard's, had no foliar concentrations below a sufficient level.

In contrast, Adams (1973) investigated critical soil Mg levels by studying a 5 hectare block near Reefton in the South Island of New Zealand. He found a correlation between visual deficiency symptoms and foliar Mg concentration. Foliar concentrations of his samples were all below the level of sufficiency of 0.1% suggested by Will (1985). Significant correlations were found between total, HCl, and HNO_3 extractable soil Mg and foliar Mg concentrations. Critical levels of 1400 mg/kg, 500-600 mg/kg and 300 mg/kg soil Mg were calculated respectively as corresponding to the critical level of 0.07% Mg in the foliage.

Ballard (1978) evaluated the usefulness of the Bray extractant for predicting foliar Mg concentrations again using the 128 samples from his 1971 study. No significant correlations were found over the whole data set, but significant relationships were found within the Yellow Brown Pumice and Southern Yellow Brown Earths, these being the soils where foliar concentrations were generally low. However he concluded that the Bray extractant could not be used satisfactorily at that stage for predicting sites where radiata pine would be Mg deficient. Using a considerably larger database Hunter (1991, unpublished Ph.D thesis) evaluated the relationships between soil and foliage data available on the New Zealand Forest Research Institute nutritional database, but also found no relationship between soil exchangeable Mg and foliar Mg concentrations. He concluded that the older needle classes which show deficiency symptoms more strongly might be preferred samples for identification of deficiency and the development of such relationships.

No research has been done on the relationship between soil B concentrations and *P. radiata* foliage B concentrations, although work has been done in New Zealand on comparative tests of extraction methods, and the relation to boron uptake by radishes (Adams *et al.* 1991). They concluded that hot $CaCl_2$ extractable B was the most analytically convenient measure.

Given the increasing emphasis on Mg and B nutrition in New Zealand forestry, and the increase in the application of both B and Mg fertilisers to forests, a further appraisal of the possibilities of developing a soil test was warranted. Such tests would allow identification of sites likely to be deficient, and increase the efficiency of fertiliser application by ensuring fertiliser was applied to the correct site before growth was lost due to deficiency. Initially an evaluation of straightforward analytical techniques was planned, to be followed up at a later date with development of new analytical methods if necessary. The aim for both Mg and B was to select sites with a greater proportion of the foliar concentrations in the marginal to deficient range, as this may give more precise tests, and also to include other factors such as needle age and environmental and management factors in the analysis, as these factors are known to affect foliar concentration.

MATERIALS AND METHODS

Soil and Foliage Samples

Soil and foliage samples were collected in January 1993 from 75 0.04 ha temporary sample plots established in 1989 plantings of *P. radiata*. Plots were located in the central North Island, Nelson, Canterbury and Otago regions where magnesium and boron deficiencies were known to occur.

Plot information collected included location, forest and compartment, rotation number, soil type from published maps, year planted, previous land use (forest or pasture), visually estimated understorey vegetation cover (%) and type, and disturbance history (none, logging, raking, ripping, V blading). Fertiliser history was recorded where known.

Each soil sample was a composite of 15 0-20 cm depth cores collected randomly throughout the plot using either a hoffer tube or spade. All samples were divided in half and one half stored at -18°C for future study. The other half was air dried and sieved to separate the < 2 mm fine fraction. The percentage of the soil > 2 mm was recorded.

Composite foliage samples were collected from 15 trees in each plot from mature one year old needles on secondary branches in the upper crown (the standard NZ FRI sampling position), and also from directly adjacent two year old needles on primary branches. This latter sample position was chosen to investigate the added sensitivity in diagnosis of Mg deficiency suggested by Hunter (1991). Older needles show stronger deficiency symptoms. A subsample of 100 needles were counted from each sample, oven dried at 70°C, and weighed for use in determining needle nutrient content. Needles were counted separately rather than using fascicles, as the number of needles in *P. radiata* fascicles can vary. All foliage samples were dried at 70°C and finely ground prior to chemical analysis.

Analytical Methods

Soil magnesium and boron extraction methods chosen for this study were; Bray 2 extractable cations, 1N HCl extractable Mg, and hot 0.02 M $CaCl_2$ extractable B. These methods were chosen for their analytical simplicity, and to evaluate simple methods prior to evaluation of more complex ones.

Bray cations were extracted by shaking 2.5 g soil samples with 25 ml Bray solution (0.1N HCl + 0.03N NH_4F for 1 minute. Cations in the extract were determined by atomic absorption spectrometry (AAS) using lanthanum chloride as a releasing agent (Nicholson 1984). Acid extractable Mg was determined using a modification of Lanyon and Heald's (1982) method (Nicholson and Weatherby, unpublished data) where 1.0 g of soil was boiled with 25 ml of 1N HCl for 15 minutes in 150 ml digestion tubes on a digestion block. Magnesium concentration was determined by AAS.

Table 1. Summary of foliar nutrient concentrations and mass of 100 needles for 1 year (X_1)and 2 year (X_2) needle age classes. Sample population n = 75 for all elements except Ca and K, where n = 71.

	N_1	N_2	P_1	P_2	K_1	K_2	Ca_1	Ca_2	Mg_1	Mg_2	B_1	B_2	$Mass_1$	$Mass_2$
	(%)										(mg/kg)		(grammes)	
Mean	1.46	1.25	0.152	0.131	0.828	0.679	0.228	0.442	0.096	0.089	15.4	17.3	1.752	2.724
Sd	0.153	0.131	0.0297	0.0300	0.1496	0.1470	0.0565	0.095	0.0199	0.0200	11.9	11.7	0.4008	0.687
Min	1.03	0.99	0.073	0.060	0.458	0.277	0.095	0.179	0.053	0.052	6.0	6.0	0.998	1.154
Max	1.78	1.56	0.215	0.202	1.100	1.057	0.411	0.651	0.128	0.127	58.0	68.0	2.458	5.316

Table 2. Pearson correlation coefficients for foliar nutrient concentrations in 1 year and 2 year needle age classes. Intercorrelations for 1 year foliage in top right block, 2 year age class in the lower left block below the 1:1 line. Probabilities associated with the coefficients are shown in smaller type.

	N	P	K	Ca	Mg	B
N		**0.43190**	0.05481	**0.38943**	-0.05721	**-0.41068**
		0.0001	0.6498	0.0008	0.6259	0.0003
P	0.09294		**0.56513**	**0.31031**	0.18984	0.00483
	0.4227		0.0001	0.0084	0.1028	0.9672
K	-0.04704	**0.46814**		0.00849	**0.28784**	0.21991
	0.6886	0.0001		0.4631	0.0149	0.0654
Ca	-0.13008	**0.23878**	0.17623		**0.28663**	**-0.27566**
	0.2660	0.0391	0.1304		0.0154	0.0200
Mg	-0.10904	**0.25385**	**0.33863**	0.01397		-0.10989
	0.3517	0.0280	0.0030	0.9053		0.3480
B	**-0.25903**	0.12861	**0.34361**	-0.15440	0.14811	
	0.0248	0.2715	0.0025	0.1831	0.2048	

Soil boron was determined by a modification (Prince, unpublished data) of the hot $CaCl_2$ extraction of Spouncer *et al* (1992). Samples of 7.5 g of soil were extracted with 15 ml of 0.01N $CaCl_2$ for 30 minutes on a digestion block preheated to 120°C. After filtration, boron concentrations were determined colorimetrically using Azomethine-H solution.

Additional soil analysis was done for pH and Walkely Black organic carbon as per the methods of Nicholson 1984.

Foliar nutrient concentrations (N, P, K, Ca and Mg) were determined by digesting 0.2 g of sample in a mix of H_2SO_4/H_2O_2 and by dry ashing for B using the methods of Nicholson (1984). Concentrations of N and P were determined colorimetrically and cations by AAS. Boron was determined colorimetrically using the curcumin method.

Statistical Analysis

A SAS (SAS Institute 1994) dataset was constructed to include all plot, soil and foliage data. Additional variables were derived from the base data. These included; soil Ca:Mg and K:Mg ratios, percentage contribution of Mg to the base cation pool, and buffer power (the ratio of exchangeable to reserve Mg in the soil; needle nutrient contents were calculated from the concentration and needle mass.

A univariate analysis was done on all continuous variables to determine whether they were normally distributed. Where appropriate, transformations were applied before attempting statistical analysis of the data. Correlation analysis was done to determine the relationships between foliar nutrient concentrations for each age of needles, and also between soil nutrient concentrations. This was followed by analysis of the relationship between soil and foliar variables. Significant variables were used in a model building exercise to determine the best models for predicting foliar Mg and B concentration from soil and other measured plot variables. The General Linear Models procedure in SAS was used.

RESULTS

Foliage data

Data for both ages of foliage are summarised in Table 1. Mean concentrations of all elements except Ca were lower in the two year old foliage. Needle mass however was greater in the two year old needles, indicating generally a higher nutrient content per needle in that age class. Concentrations of the elements in one year old needles were compared to Will's critical levels (1985). Mean concentrations of all elements were adequate for tree growth, except Mg (0.096%) which was marginal. However the range indicated that N, P, Mg, possibly Ca, and B had concentrations below the critical level in a number of samples. Needle mass varied considerably, especially in the two year old foliage.

Analysis of the distributions of these variables indicated all were normally distributed, except for boron, where a number of high values caused by previous boron fertiliser application caused a skewed distribution. However it was decided not to apply a transformation in this case as the log transformation did not improve the distribution's normality.

Analysis of the correlations between foliar concentrations for each age of foliage showed positive correlations between all elements except between N and B in both age classes where significant negative correlations were recorded (Table 2). Of the other correlations, there were significant positive relationships between Mg and K and Ca in the one year old foliage, and between Mg and K in the two year old foliage. The relationship between Ca and Mg in the older age class may have fallen away due to the large increase in Ca concentration in this age class. The positive relationship between Mg and K is the reverse of that recorded by Ballard *et al.* (1971) where they suggested that a significant correlation of -0.467 could indicate an antagonism between K and Mg uptake.

Soil data

Values for Bray cations, acid extractable Mg (meq/100g), hot $CaCl_2$ B (mg/kg), Mg buffer power (%), organic carbon (%) and pH are summarised in Table 3.

Table 3. Summarised soil chemical data from sample plots

	mean	std deviation	min	max	n
Bray K	0.16	0.094	0	0.45	75
Bray Ca	2.38	1.723	0	7.99	71
Bray Mg	0.72	0.465	0.13	2.24	71
Acid Mg	18.2	17.87	1.3	98.3	75
Mg Buffer	9.84	8.785	0.32	30.95	71
$CaCl_2$ B	1.46	0.613	0.59	3.50	74
Carbon	3.12	1.132	1.21	5.68	74
pH	4.93	0.329	4.27	5.79	74

Of the base cations, Ca generally dominates the exchange sites, Mg is next and K concentrations the lowest. The mean concentrations reported in Ballard's study were similar for Ca but higher for both Mg and K, suggesting that our aim of selecting poorer sites nutritionally for Mg had been achieved. As a rough guideline average A horizon exchangeable Mg concentrations in New Zealand soils are of the order of 1 meq/100g (Metson and Brooks 1975), the mean for this study is below this, and minimum concentrations would be classified as very low by Metson and Gibson (1977). Boron concentrations showed a greater range than the six soils studied by Adams *et al.* (1991).

Correlation analysis, soil and foliar variables

Simple correlations were done between soil cation measures and foliar concentrations in both 1 year and two year needle age classes.

Table 4. Simple linear correlations between measures of soil cations and foliage concentrations of those cations for the two age classes of needles. Significant correlations are shown in bold typeface. Probabilities associated with the correlations are shown below each coefficient in smaller type.

Cations (meq/100g)	1 year needles			2 year needles		
	K	Ca	Mg	K	Ca	Mg
Bray K	**0.39468**	0.11937	0.06464	**0.40842**	0.07715	-0.01272
	0.0007	0.3214	0.5186	0.0003	0.5106	0.9137
Bray Ca	0.19241	**0.58622**	0.0069	0.16551	**0.34172**	-0.11986
	0.1079	0.0001	0.9545	0.1559	0.0027	0.3057
Bray Mg	**0.57867**	0.09182	**0.35649**	**0.54817**	-0.04167	**0.34995**
	0.0001	0.4463	0.0017	0.0001	0.7226	0.0021
Acid Mg			**0.31971**			**0.48012**
			0.0052			0.0001
Mg Buffer			-0.21273			**-0.48210**
			0.0669			0.0001
Carbon	-0.15403	**0.36402**	-0.10231	-0.1039	**0.31073**	**-0.26562**
	0.2030	0.0019	0.2857	0.3783	0.0072	0.0222
pH	-0.15060	**0.40264**	**-0.19227**	-0.02505	0.21131	**-0.30328**
	0.2100	0.0005	0.0094	0.8311	0.0688	0.0082

A number of significant correlations were found in both age classes of foliage. The strongest relationship was between soil and foliar Ca in 1 year old foliage with a coefficient of 0.58622 closely followed by the strong relationship between Bray Mg and foliar K concentrations in both foliage age classes. The relationships between soil and foliar Mg concentrations were significant for both foliage age classes with coefficients of about 0.35 for the Bray extraction for both foliage ages. The best correlation (0.48012) however, was between acid extractable Mg and foliar Mg concentration in the two year old foliage. This finding would support Hunter's hypothesis that the older foliage would be a more sensitive indicator of variation in foliar Mg concentration. This is because the older foliage acts as a source of translocatable Mg reserves for the younger needles and acts as a buffer if soil supply is limited, ensuring the Mg supply to the growing needles is smoothed. Adams' (1973) hypothesis that organic matter distribution might account for some of the variability in foliar Mg levels was not supported by these results for the one year old foliage, however there was a relationship with Mg concentrations in the two year old foliage, again suggesting that this age class of foliage is more sensitive for identifying site variation. Soil and foliar relationships are shown for both ages of foliage in Figures 1-4.

Metson (1974) suggested that soil cation ratios could be important in determining whether a Mg deficiency was likely to occur, and we evaluated the relationship between the ratio of Mg to total base cations, and the K:Mg and Ca:Mg ratios and foliar nutrient concentrations (Table 5). Correlations of ratios with foliar Mg were very similar to the simple correlations with single soil variables, and therefore added little benefit. Of interest however was the very strong relationship ($r = 0.61546$) between soil Ca:Mg ratio and foliar Ca concentration in one year old foliage and the negative relationship between Ca:Mg and K:Mg ratios and foliar Mg.

Effect of other environmental and management factors on foliar B concentrations

Neither history of site disturbance or understorey vegetation cover had any significant effect on foliar boron concentrations in either needle age classes. However the evaluation of the effect of rotation number showed the 3rd rotation sites to have significantly higher foliar B concentrations in both needle age classes than either the 1st or 2nd rotation sites which did not differ significantly from each other. Examination of the data showed this to be due not to the effect of successive rotations, but to the fertiliser history of the 3rd rotation sites at Eyrewell forest, where all plots had a history of boron application one or two years previously causing the mean foliage concentrations to be raised for this set of plots. Very few plots in either 1st or 2nd rotation had a history of applied B.

Models for predicting foliar Mg concentrations

Multiple regression models were constructed using the soil and site variables with the GLM procedure in SAS and a manual variable selection routine. As class variables (disturbance, rotation number) were to be evaluated, the REG procedure with the option of stepwise model building was not appropriate as it cannot handle class variables. Model r^2 values ranged from 0.1022 to 0.2305 for models with solely either Bray or acid extractable Mg as independent variable. Addition of understorey vegetation cover improved r^2 values to between 0.2151 and 0.3461, and disturbance history improved the models further. Addition of a variable identifying the plots by region produced the best models with a maximum r^2 value of 0.4846 for 2 year old foliage where the Bray 2 Mg values were used. For models based either on Bray or acid extractable Mg the predictive capability was better for the two year old needle age class, confirming Hunter's hypothesis that this age of foliage would be more sensitive to variation in Mg fertility. The predictive capability of these models was disappointing, the errors associated with predictions were quite large and given the short range between deficient and sufficient concentrations (0.07-0.10%) the models were of very limited use in this form. However the importance of the regional variable in the models suggests that development of regional models may be of better predictive capability. This was then tried for each region. No significant models could be constructed in any of the regions except Rotorua where r^2 values of 0.4405 and 0.4657 were recorded for Bray and acid extractable based models for the 1 year old needle age class. Lack of success in other regions may be due to the small number of samples available in each of the other three regions. Even with this regional model however the prediction of a soil critical level associated equivalent to 0.07% Mg in the foliage was accompanied by a large error and it was concluded that only semi quantitiative use could be made of the data.

Semi quantitative (probability) model for prediction of stand Mg foliar concentration

Figures 1 to 4 show the spread of points in the dataset, with the relationship between soil and foliar concentrations for both Bray and acid extractable Mg and one year old and two year old foliage. Overlaid on the plots are the 'critical levels' for Mg; <0.07% deficient, 0.07 - 0.1% marginal, and <0.1%, sufficient. For one year old foliage it can be seen that below 0.75 meq/100g Bray Mg and 5 meq/100g acid extractable approximately 20% of sampled stands fall in the deficient range, this equates to a 20% chance of a deficiency occurring at below these soil critical levels. The pattern is clearer for two year old foliage which reflects the soil Mg supply better than one year old foliage which is buffered by translocation of Mg from older to younger needles. Critical levels for this age, where there is a 30% likelihood of values < 0.07% are 0.75 and 9 meq/100g for Bray and acid extractable Mg respectively. If the site has a history of disturbance the probability of deficiency would be raised somewhat.

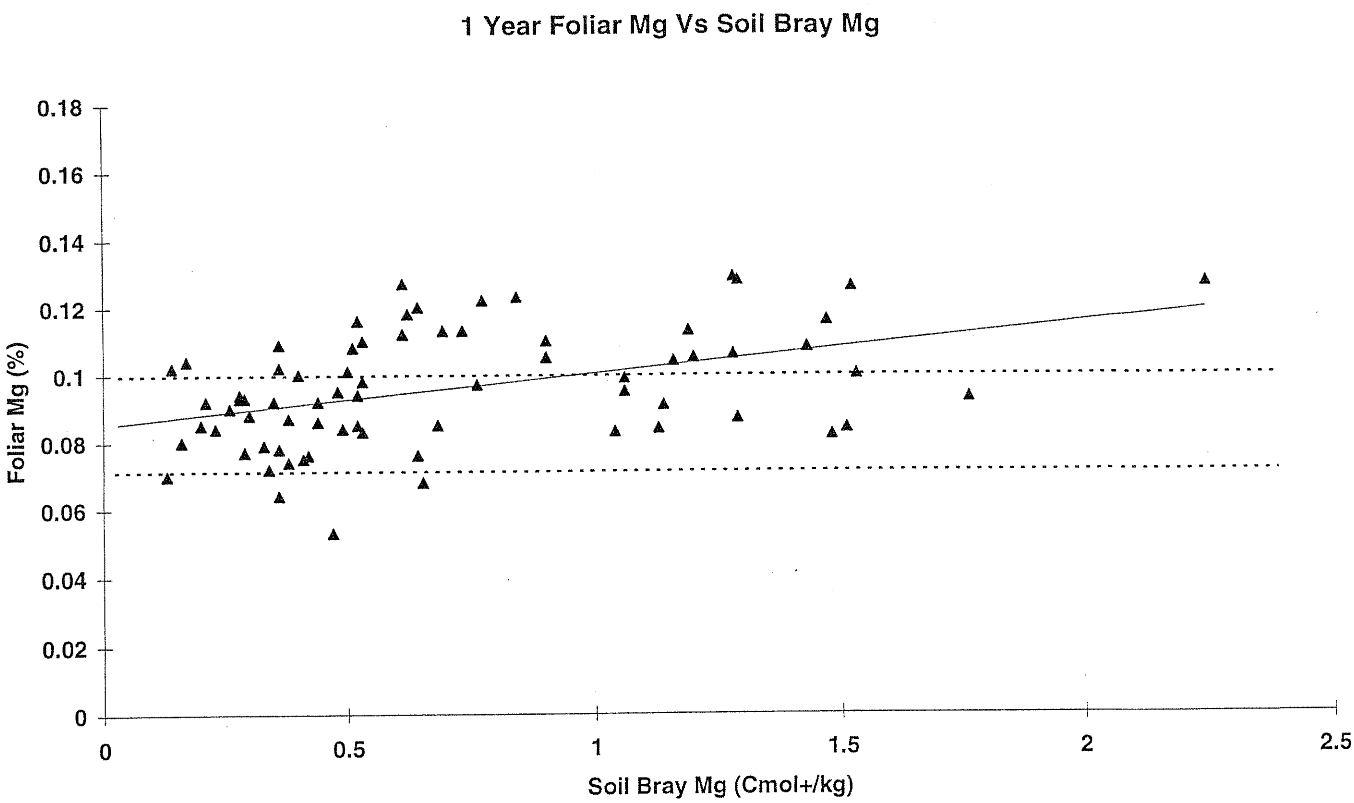

Figure 1 Relationship between 1 year foliage (standard FRI sampling method) Mg concentrations Bray extractable soil Mg.

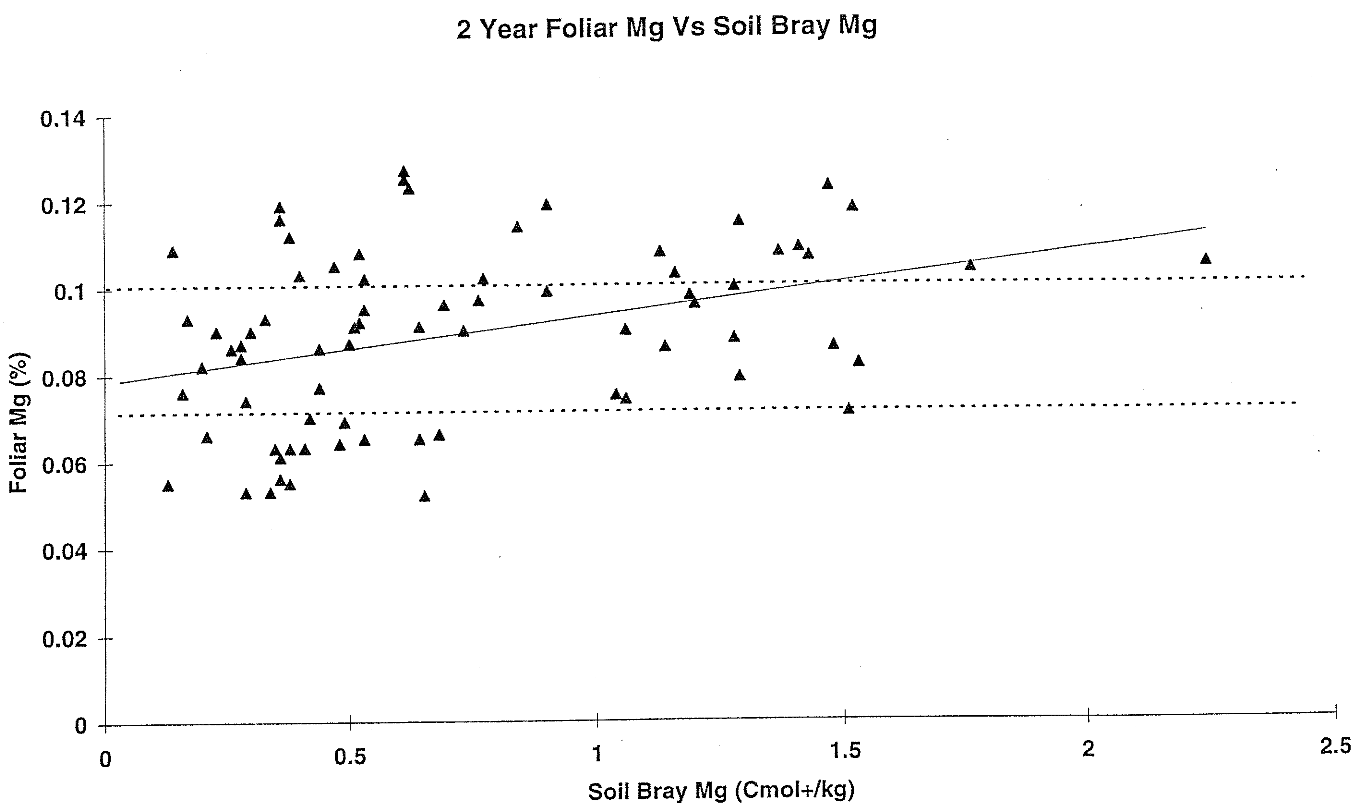

Figure 2 Relationship between 2 year old primary foliage Mg concentration and Bray extractable soil Mg.

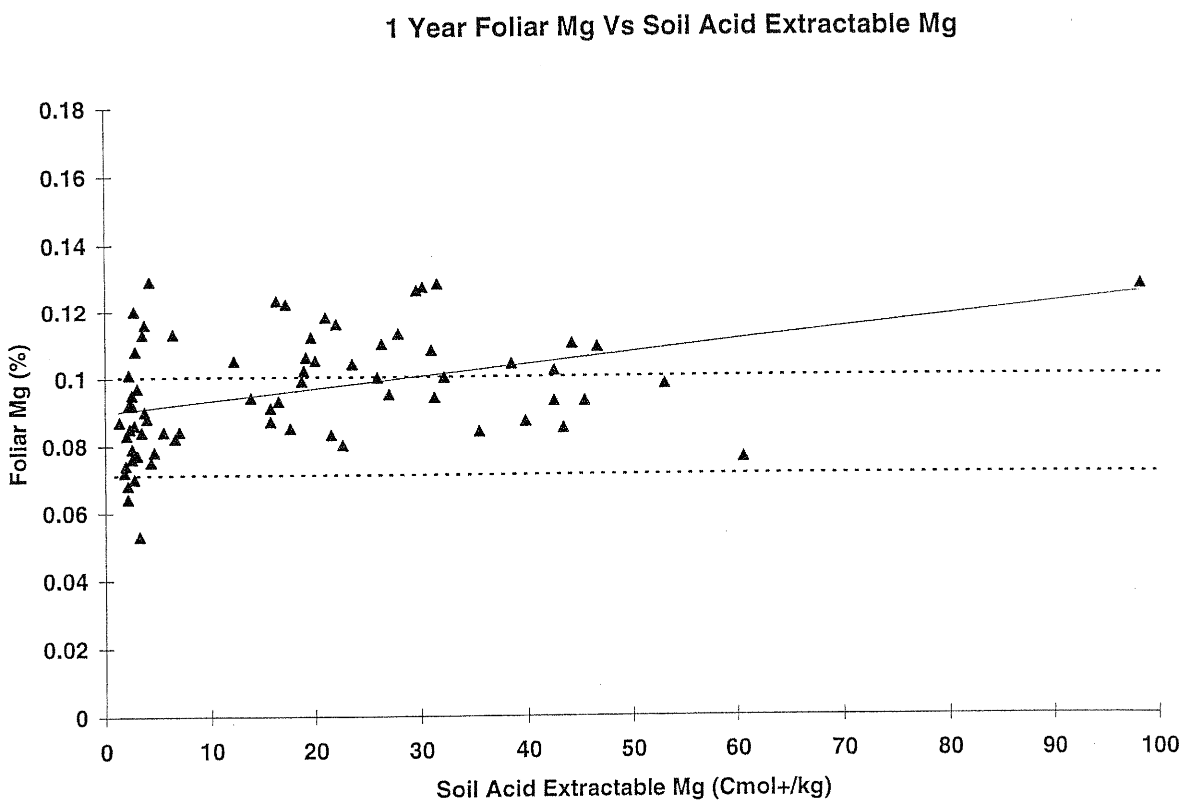

Figure 3 Relationship between 1 year foliage (standard FRI sampling method) Mg concentration and 1N HCl extractable soil Mg.

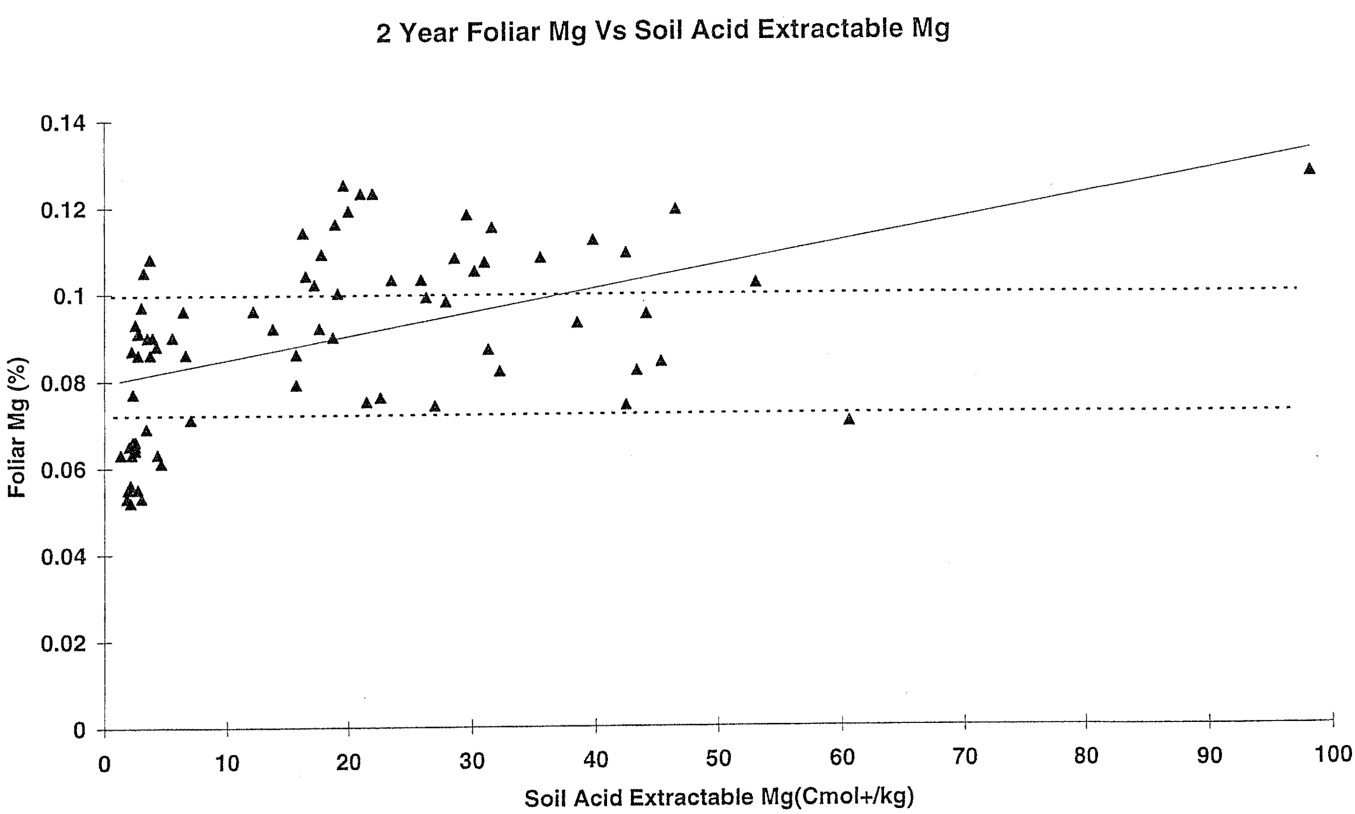

Figure 4 Relationship between 2 year old primary foliage Mg concentration and 1N HCl extractable soil Mg.

Table 5. Simple linear correlations between soil base cation ratios and foliar nutrient concentrations. Significant correlations are shown in bold typeface. Probabilities associated with the correlations are shown below each coefficient in smaller type.

Soil	1 Year Needles			2 Year Needles		
Cation ratios	K	Ca	Mg	K	Ca	Mg
Mg/Base	-0.04858	**-0.56077**	0.21381	0.00808	**-0.47583**	**0.34426**
	0.6875	0.0001	0.0655	0.9451	0.0001	0.0025
K:Mg	-0.14098	-0.10989	**-0.34832**	-0.13510	0.01834	**-0.39846**
	0.2412	0.3616	0.0022	0.2478	0.8759	0.0005
Ca:Mg	-0.21194	**0.61546**	**-0.26109**	-0.16351	**0.41344**	**-0.39233**
	0.0760	0.0001	0.0237	0.1610	0.0002	0.0005

Correlation analysis, boron

Significant correlations were found between soil and foliage boron in both age classes of foliage, an r value of 0.37457 (P=0.0010) for the one year old needles, and r = 0.41736 (P=0.0002) for the two year old foliage (Figures 5 and 6). No other correlations with other soil variables and foliar B were significant.

Effect of other environmental and management factors on foliar Mg concentrations

Rotation number

An analysis of variance of foliar Mg concentrations against rotation number showed no significant differences in Mg concentrations between rotations for either needle age class. It is likely that the spread in values for environmental variables may have masked any effect. It may be necessary to further test this hypothesis on a subset of data where environmental variables are more constant.

Disturbance regime

The effect of the history of disturbance on the foliar magnesium concentrations was evaluated using an ANOVA with both disturbance type as independent variable, and again with the presence or absence of disturbance (Yes/No) as the variable. Significant treatment differences were tested for using Duncan's Multiple Range test. Plots with a history of disturbance had significantly lower foliar Mg concentrations, with the most severe disturbance -V blading - causing the greatest decrease in Mg concentrations compared to undisturbed sites. The effect was similar for both needle age classes with mean foliar concentrations in the 1 year age class averaging 0.107% on undisturbed sites and 0.089% on disturbed sites, and 0.096% and 0.084% in the 2 year age class of needles. There were no significant differences between most of the disturbance classes, it appeared that foliar concentrations were affected similarly by most disturbance classes, and no consistent ranking in classes was apparent in the two age classes of needles. The important factor appeared to be whether the site had a history of disturbance or not.

Understorey vegetation cover

Understorey vegetation cover on the plots ranged from zero, where understorey vegetation control had been continuous under experimental conditions, through to 100% on some sites. The average cover was 76%. Correlation analysis showed that understorey vegetation cover was positively correlated with foliar Mg concentration in both needle age classes. This suggested that understorey vegetation improved Mg uptake. Further investigation of the effect of understorey vegetation cover on needle weight showed a weak negative correlation, thus we might interpret the previously noted positive correlation as a concentration effect, where Mg uptake continues at the same rate but accumulates more in the lighter needles of the plots with the greatest understorey vegetation cover.

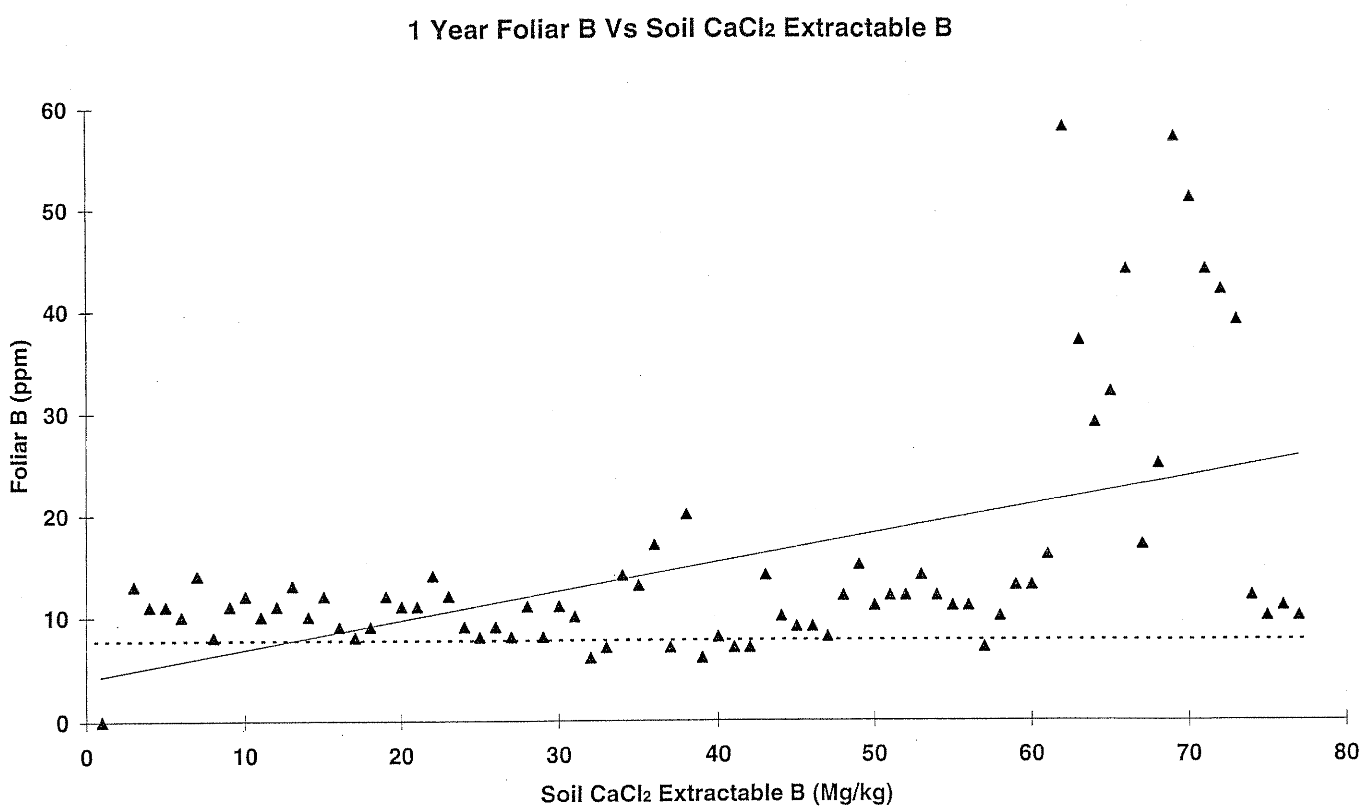

Figure 5 Relationship between 1 year foliage (standard FRI sampling method) B concentration and hot $CaCl_2$ extractable soil B.

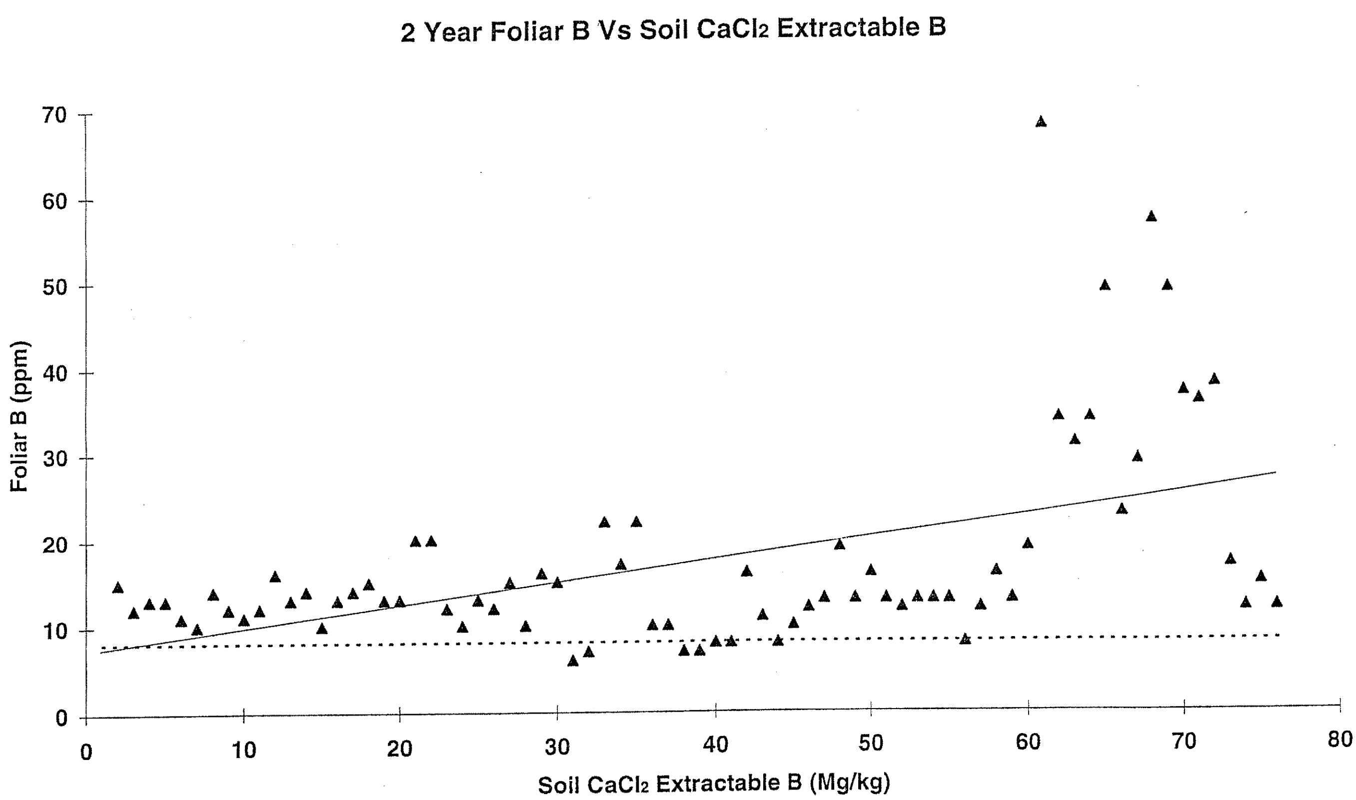

Figure 6 Relationship between 2 year old primary foliage B concentration and hot $CaCl_2$ extractable soil B.

Models for predicting foliar B concentrations

The models for predicting foliar B concentrations were poor when only $CaCl_2$ extractable B was used in the model. Values of r^2 were 0.1403 and 0.1741 for the 1 and 2 year needle age classes respectively. Other variables such as understorey vegetation cover and disturbance history were not included in the models due to the lack of relationship with foliar B concentration, however inclusion of region in the models caused a large increase in the values of the model r^2 for both needle age classes to values of 0.7952 and 0.7475. Further investigation showed that this was once again due to the fertiliser history of the plots in Eyrewell forest, causing the mean values for the Canterbury region to be very high in comparison to the other regions (in the order of 40 mg/kg compared to 15 mg/kg). This variable was therefore deleted from the model.

DISCUSSION.

The soil tests developed here were generally disappointing with only weak models resulting. The magnesium models were better than the findings of Ballard *et al.* (1971), Ballard (1978), and Hunter (1995); but not as good as Adams (1973). However some of the relationships identified will be useful in further development of useable soil tests. Addition of disturbance and understorey vegetation cover into the models was certainly useful, and the detrimental effect of disturbance on foliar Mg concentration has been recorded by Dyck and Skinner (1990) in Kaingaroa forest and also highlighted by Hunter (1991). The interpretation of the effect of understorey vegetation cover is slightly less easy, the concentrating effect due to decreased needle weight is possible, however it may also be that understorey vegetation cover is higher on higher fertility sites, and that this is therefore an indirect measure of site quality. If this was the case then foliar Mg concentrations might be expected to increase with improved site quality. No measure of site productivity was made in the temporary sample plots so it is not possible to relate productivity to understorey vegetation cover to investigate this relationship. However there is a positive correlation between Bray Mg and understorey vegetation cover so this explanation may hold. If so an overall productivity variable such as site index may be useful as a co-variate. The effect of region on the models would suggest that for improved relationships it may be better to concentrate on regions or even specific forests for developing soil tests for Mg. The fact that Adams (1973) found quite strong relationships between soil and foliar Mg and that this was based on a small site would support this. Concentration on smaller areas will remove some of the noise from the models caused, for instance, by climatic variation.

The greater sensitivity of the two year old needles to changes in soil Mg concentration is a useful observation and reinforces the importance attached to Mg translocation to the younger needles on stressed sites, however the improvement in the predictive ability of the models was not great enough to allow recommendation of concentration on this age class of needles when sampling for Mg status and nutritional decisions at this stage.

The methods used in this study suggest that some other form of Mg may be better related to foliage concentration. It was suggested by both Adams and Ballard that the influence of organic matter on Mg supply may be important, Adams relating the patchy nature of Mg deficiency in his study site to redistribution of organic material after logging. Organic exchange sites show less specificity for divalent cations than inorganic exchange sites (Wiklander 1964) and this may cause the actual availability of Mg to the plant to vary with organic content of the soil.

Ballard (1978) had suggested that soil tests for Mg may not be possible without considering soil K concentrations, and work by Beets (unpublished data) showed a negative correlation between foliar K and Mg concentration and the incidence of Upper Mid Crown Yellowing. However this study found no evidence for an antagonism between soil K or foliar K, and foliar Mg concentration.

From a manager's perspective quantitative soil tests alone, at this stage of development, will not supercede the methods for defining sites likely to show Mg deficiency used presently. These are based on a more heuristic approach, and rules for identifying at risk sites were developed by Payn (1991) from a number of sources. This approach has been expanded to include these finding in a decision tree (Figure 7). Sites where Mg deficiency may occur can be identified, but must then be confirmed once the trees are planted and can be foliage sampled, or confirmed from foliar concentrations in adjoining stands.

The work on a boron soil test showed little promise in the approach taken at this stage. Correlations with soil and foliar B were poor, and no effect of those management or environmental factors studied was found. The dataset was affected by the inclusion of a number of sites in Eyrewell forest where B fertiliser had been added a couple of years previously. The even poorer correlation between soil and foliar B in those samples suggests that a boron test is unlikely to succeed in stands which have been recently fertilised.

CONCLUSIONS

Soil Mg concentrations (Bray and Acid extractable) were only weakly related to foliar Mg concentration, with a stronger relationship in two year old foliage. Site disturbance caused a decrease in foliar Mg concentration, rotation number had no effect on foliar Mg concentration, and weed cover caused a slight increase in foliar nutrient concentration due to the weed's effect on needle mass. Soil organic matter and pH were not affecting foliar Mg concentrations except in one instance between the two year old foliage and organic carbon levels.

A soil test alone for Mg based on these results will not give enough information for identification of deficient sites. However in conjunction with additional site information the procedure for identification of at risk sites has been improved. This procedure has been outlined in a decision table.

Foliar boron concentrations were very poorly related to soil boron concentration and no management or environmental factors measured were correlated. A soil boron test based on these results was weaker than that for the Mg test, it is likely that another approach utilising soil textural data linked to drought risk indices in conjunction with soil series information may be the way to go.

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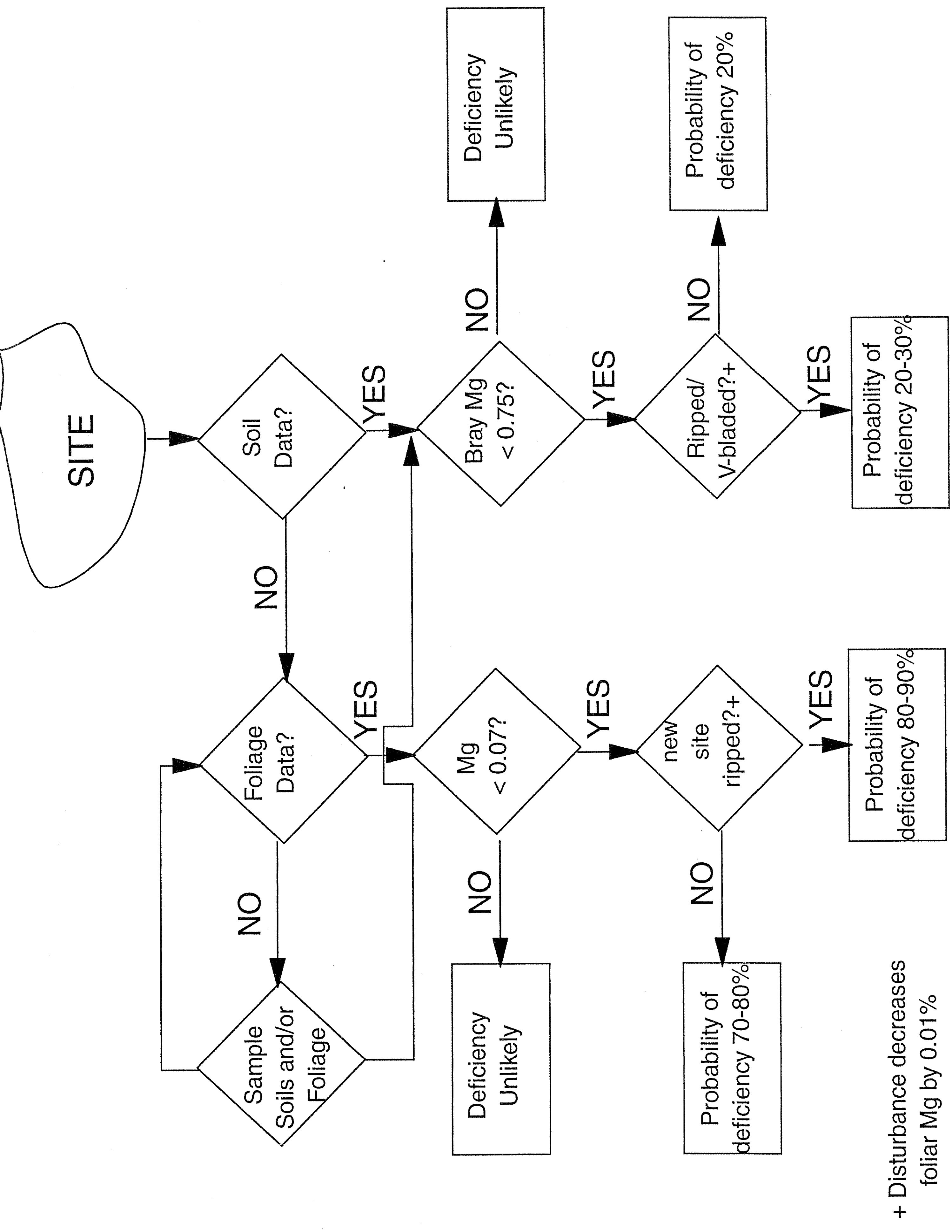
Figure 7 Decision tree for identifying a magnesium deficient site.



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