FUTURE FORESTS RESEARCH

RADIATA MANAGEMENT TECHNICAL NOTE
Site Productivity

Number: RSPTN-021
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Within and between population variation in foliar nutrient concentrations in relation to radiata pine growth

Summary

Wide soil diversity in New Zealand creates a challenge to correct nutrient deficiencies and optimise productivity of radiata pine. The extent to which this variability can be addressed by better matching specific genotypes to specific sites is not well understood. Task 1.5 of the PEEF programme is exploring the extent of this soil diversity and the potential to develop a site-specific management solution based on understanding of the range in genotypic variation in nutrient use efficiency and tolerance to nutrient deficiency at problem soils. Serpentine soils are an example of one extreme in soil properties and are generally unsuitable for agriculture and forestry because they contain low levels of several essential plant nutrients (P, K and N) and high concentrations of Mg, Ni, Cr and Co. This study investigated the range of variation in foliar nutrient concentrations within and between three clonal populations on this extreme soil type and determined the main nutrients related to growth of radiata pine on this specific type at age 4 years. The trial with four plots was established in Aniseed Valley, Nelson in 2002. Three ramets of each of 40 radiata pine clones from three populations were randomly planted in each of four plots. Significant differences were found within populations (i.e. clonal) for most foliar nutrients, and between populations only for K, Ca/Mg, B and Fe. The variation in foliar nutrient concentrations within populations was larger than that between populations. The natural log transformed volume increment was best predicted by the log fascicle weight, foliar concentrations of Cu, Fe, K, Mn and Zn for GTI clones; log fascicle weight, foliar concentrations of Fe, K and P for Puruki clones; and log fascicle weight and foliar Mg concentration for serpentine clones. These relationships show that site-specific growth responses to soil properties occur and suggest that more site-specific studies of the relationship between tree growth and nutrition may be warranted. Overall, the current-year foliar nutrient status could better predict the annual growth increment than absolute tree size. This study highlights the potential for site-specific deployment of specific clones to this extreme site. Further investigation of the response of specific genotypes to variation in soil properties appears to be warranted.

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Introduction

Wide soil diversity in New Zealand creates a challenge to optimise forest nutrition. Deficiencies of mineral nutrients (mainly N, P, Mg and B) are widespread in radiata pine (*Pinus radiata*) stands [1]. With forest companies moving toward site-specific management, an opportunity exists to identify radiata pine genotypes with nutritional characteristics that maximize growth on particular sites. Serpentine soils derived from weathering of ultramafic rocks are widely distributed throughout the globe across all climatic zones. In New Zealand, such soils can be found at several sites in Northland, Nelson and Otago [2]. Serpentine soils are generally unsuitable for agriculture and forestry because they contain low levels of several essential plant nutrients (P, N and K), high concentrations of Mg, Ni, Cr and Co and a low Ca/Mg ratio [3, 4]. Large differences in the growth of individual radiata pine trees growing on a serpentine soil in New Zealand has previously been reported [5]. Because of these extremes in soil properties and tree growth, serpentine soils provide an excellent research opportunity to examine the variation in nutrient uptake and use efficiency within and between clonal populations.

In addition, this research may identify specific radiata pine genotypes that could adapt to these nutrient-limited environments.

The objectives of this study were to:

(1) estimate the range of variation in foliar nutrient concentrations within and between three populations of radiata pine, and
(2) determine the main nutrients accountable for the clonal growth within these populations.

Materials and Methods

Trial Location and Site Characteristics

The study site is located at Aniseed Valley, approximately 25 km southwest of Nelson in the South Island (41°25'S, 173°12'E). Aniseed Valley is situated at lower part of Dun Mountain serpentine Belt [5]. The mean annual rainfall at this site is 1600 mm and average annual temperature 11.7°C. The soil is a Mafic Brown Soil in the New Zealand Soil Classification System and is high in extractable Ca and Mg but low in extractable K and P.

Trial Design and Genetic Material

The trial has four plots. Three ramets of each of 40 radiata pine clones were randomly planted in each of these four plots. Of the 40 clones, 20 were created through fascicle cuttings from the control-pollinated families selected for high volume growth rate and improved stem form (GF24-31) but of unknown nutritional characteristics (referred to as GTI clones).

The remaining 20 clones were created through fascicle cuttings from open-pollinated families, which were originally selected from trees (GF7) growing on:

- pumice soil at Puruki in central North Island (referred to as Puruki clones). The parent trees of these clones (12) had different nutrition-related UMCY (upper and middle crown yellowing) symptom scores.
- serpentine soil near Nelson in the northern South Island (referred to as serpentine clones). The parent trees of these clones (8) had different diameter growth.

The trial was established in July 2002. The planting space was 4 m (between rows) × 4 m (within rows) to give a final stocking of 625 seedlings ha^{-1}.

Growth Measurements and Nutrient Analysis

Height and DBH were measured for individual trees in all four plots in July 2005 and 2006 (year 4). Tree stem volume (VOL) was calculated as follows:

$$VOL = (3.14 \times (DBH/2)^2 \times height)/3).$$

Needle dry weights and nutrient concentrations were determined on current-year needles sampled from the youngest second-order branches of each ramet of 40 radiata pine clones within each plot in 2006. In the laboratory the foliage samples from three ramets were bulked together for each clone within a plot. One hundred fascicles (bundles of pine needles) were randomly selected from each sample for oven dry weight measurement at 65ºC. Concentrations of foliar C, N and S were analysed using LECO CNS-2000 Analyzer and P, K, Ca, Mg, B, Cu, Zn, Fe and Mn using ICP-OES after a HNO_3/H_2O_2 digestion. Needle stable isotope ^{15}N (IN), an indicator of potential N availability, was determined on sub-samples using continuous-flow isotope ratio mass spectrometry.

Data Analyses

SAS mixed effects model of nested ANOVA was conducted to test the population (fixed) and clonal (random, nested within population) effects. Then the five-number summary, a descriptive statistic, was used to provide a concise summary of the distribution of the observations (i.e. clonal values within a population in this study). The five-number summary gives information about the location (from the median), spread (from the quartiles) and range (from the sample minimum and maximum) of the observations. It consists of the five most important sample percentiles:

1. the sample minimum (smallest observation);
2. the lower quartile or first quartile (25%);
3. the median (middle value, 50%);
4. the upper quartile or third quartile (75%); and
5. the sample maximum (largest observation).

It is possible to compare several sets of observations quickly by comparing their five-number summaries, which can be represented graphically using a boxplot (Figure 1).

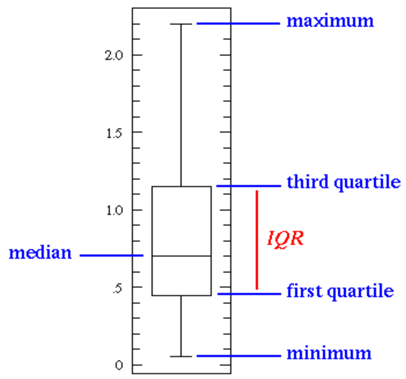

Figure 1. Explanation of boxplot - In the above boxplot, the central rectangle spans the first quartile to the third quartile (the *interquartile range* or *IQR*). A segment inside the rectangle shows the median and "whiskers" above and below the box show the locations of the minimum and maximum.

A stepwise regression was conducted using PROC REG, SAS to predict growth parameters as a function of foliar variables (i.e. nutrients). Natural log transformations (indicated by ln(X) where X is a variable of interest) were used for all nutrients and the foliar weight to improve data normality, while IN (stable isotope ^{15}N) remained untransformed.

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Results

Within-population (clonal) variation was significant for most nutrients (e.g. N, P, K, Ca, Mg, S, B, Fe, Zn), but between-population variation was significant only for K, Ca/Mg, B and Fe. Here we present the results of six nutrients (N, P, K, Mg, Fe and Mn) that showed a strong relationship with differences in clonal growth.

- For foliar N concentration, the maximum range between (maximum and minimum) clonal observations was similar for the GTI and Puruki populations. However, the interquartile range (IQR) was larger in the Puruki population than in the GTI population. The serpentine population had a smaller maximum range than the other two populations, but a larger IQR than the GTI population (Figure 2).

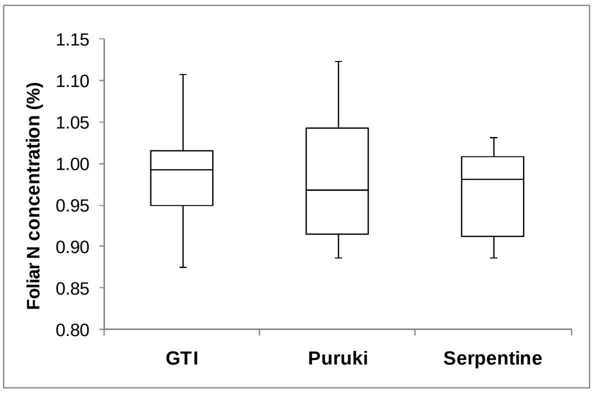

Figure 2. Clonal variation in foliar N concentration for three populations (GTI, Puruki and serpentine).

- For foliar P concentration, the maximum range between clonal observations was in the decreasing order of GTI >Puruki > serpentine populations. However, the IQR was larger in the Puruki population than other two (Figure 3).

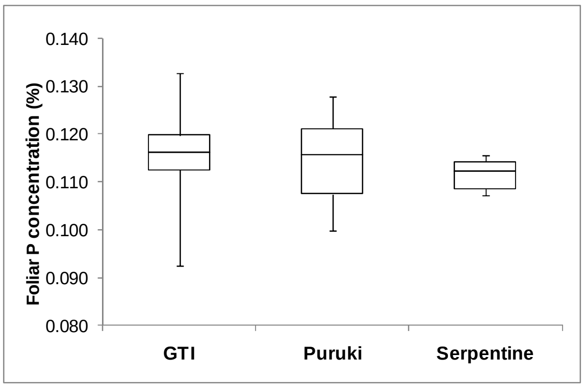

Figure 3. Clonal variation in foliar P concentration for three populations (GTI, Puruki and serpentine).

- For foliar K concentration, the maximum range between clonal observations was in the decreasing order of Puruki >GTI > serpentine populations. The IQR was smaller in the serpentine population than for the other two populations (Figure 4).
- For foliar Mg concentration, the maximum range between clonal observations was in the decreasing order of Puruki >GTI >serpentine populations. However, the lower and upper quartiles were larger in the serpentine population than in the other two populations (Figure 5).
- For foliar Fe concentration, the maximum range between clonal observations was larger in the Puruki population than in the other two populations. However, the IQR was larger in the serpentine population than in the other two populations. The lower and upper quartiles and median were smaller in the Puruki population (Figure 6).

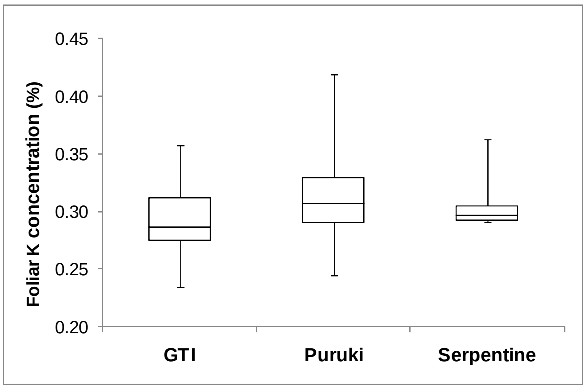

Figure 4. Clonal variation in foliar K concentration for three populations (GTI, Puruki and serpentine).

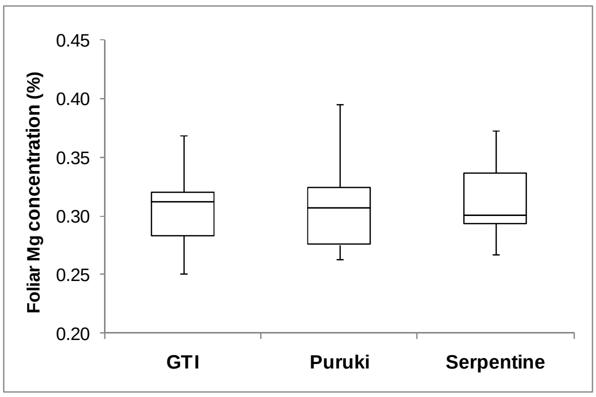

Figure 5. Clonal variation in foliar Mg concentration for three populations (GTI, Puruki and serpentine).

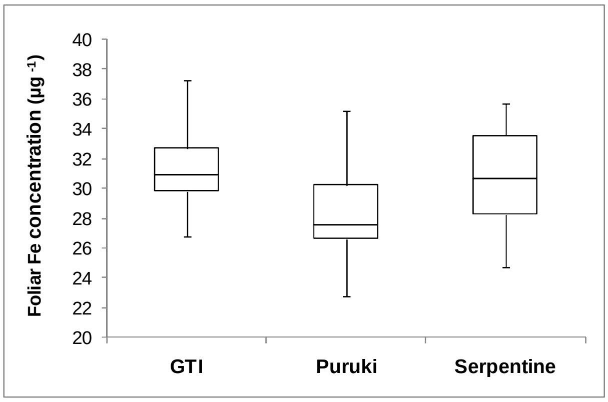

Figure 6. Clonal variation in foliar Fe concentration for three populations (GTI, Puruki and serpentine).

- For foliar Mn concentration, the GTI and Puruki populations had similar maximum range (between clonal observations) and the IQR, but the lower and upper quartiles and median were smaller in the Puruki population. Compared with the other two populations, the serpentine population had the smaller maximum range and IQR (Figure 7).

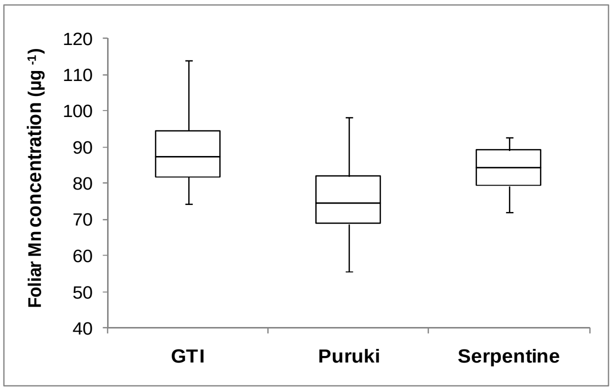

Figure 7. Clonal variation in foliar Mn concentration for three populations (GTI, Puruki and serpentine).

- Inter-nutrient relationship analysis showed there was a significant negative correlation between concentrations of foliar K and Mg (r = - 0.41).

- A stepwise multiple regression was conducted to determine which nutrients contributed to the prediction of the total diameter, height and volume at age 4 years, as well as the increment change between 2006 and 2005.

- The annual diameter and volume increment (DBH_{in} and VOL_{in}) were better predicted by the foliar nutrient status than by the total 4-year-old diameter (DBH_{06}) and volume (VOL_{06}). The converse was true for height (Table 1).

- The ln(volume increment) was predicted by the log fascicle weight, foliar concentrations of Cu, Fe, K, Mn and Zn for the GTI clones; log fascicle weight, foliar concentrations of Fe, K and P for the Puruki clones; and log fascicle weight and foliar Mg concentration for the serpentine clones (Table 1).

- Across all clones, the log volume increment was predicted by the log fascicle weight, foliar concentrations of Cu, Fe, Mg and Zn (Table 1).

Table 1. Results of stepwise regression models to predict Ht_{06}, Ht_{in}, DBH_{in} and $ln(Vol_{in})$. The significance level for a parameter remaining in the model was set at 0.15. Thus all parameters included are influential in explaining the variability.

Data used	Dependent variable	Model	R^2
GTI clones (n=77)	Ht_{06}	36.7 + 31.9 ln(FW) - 121.8 ln(Cu) + 108.5 ln(Fe) + 46.8 ln(K) - 48.6 ln(Mn) + 114.7 ln(Zn)	0.368
	Ht_{in}	43.4 - 38.2 ln(Cu) + 41.1 ln(K) + 61.7 ln(Zn) + 10.5 lN	0.313
	DBH_{in}	34.5 + 3.8 ln(FW) - 3.8 ln(Cu) + 7.7 ln(K) - 3 ln(Mn) + 4.3 ln(Zn) + 7.5 ln(N)	0.483
	$ln(Vol_{in})$	4.9 + 0.5 ln(FW) - 1.2 ln(Cu) + 1.1 ln(Fe) + 0.7 ln(K) - 0.6 ln(Mn) + 1.1 ln(Zn)	0.425
Puruki clones (n=51)	Ht_{06}	-30.7 + 35 ln(FW) + 123.1 ln(Fe) + 61.4 ln(K)	0.396
	Ht_{in}	-71.5 + 33.7 ln(Fe) + 67.4 ln(K) - 65.8 ln(P) + 89.2 ln(N)	0.397
	DBH_{in}	-3.3 + 2.6 ln(FW) + 5 ln(Fe) + 8.3 ln(K) - 6.5 ln(P)	0.450
	$ln(Vol_{in})$	1.9 + 0.4 ln(FW) + 1.2 ln(Fe) + ln(K) - 0.9 ln(P)	0.451
Serpentine clones (n=22)	Ht_{06}	156.3 + 56.6 ln(FW) - 115.5 ln(Mg)	0.563
	Ht_{in}	-145 + 28.8 ln(FW) + 69.2 ln(S)	0.626
	DBH_{in}	33.9 + 5.4 ln(FW) - 12.7 ln(Mg) + 11.7 ln(S)	0.702
	$ln(Vol_{in})$	3.8 + 0.7 ln(FW) - 2.4 ln(Mg)	0.604
All clones (n=150)	Ht_{06}	-294.5 + 31.4 ln(FW) - 66.5 ln(Cu) + 128.2 ln(Fe) - 68.4 ln(Mg) + 58.8 ln(Zn)	0.269
	Ht_{in}	168.4 + 14 ln(FW) + 14.5 ln(Ca) + 35.1 ln(K) + 35.4 ln(N)	0.221
	DBH_{in}	2.7 + 3.4 ln(FW) + 3.9 ln(Fe) + 3.5 ln(K) - 6.2 ln(Mg) + 6.6 ln(N)	0.393
	$ln(Vol_{in})$	0.1 + 0.4 ln(FW) - 0.6 ln(Cu) + 1.4 ln(Fe) - 1.1 ln(Mg) + 0.5 ln(Zn)	0.318

Ht_{06} – tree height in 2006; Ht_{in}, DBH_{in} Vol_{in} are respectively height, DBH, and volume increment between 2006 and 2005.
FW – Dry weight of 100 fascicles

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Conclusions

- On this extreme site large differences were observed in tree nutrition and growth that reflected the site-specific soil properties.
- Within-population (i.e. clonal) differences existed for most foliar nutrients, while between-population differences existed for only a few nutrients.
- The nutritional differences between the tested populations were not considerable, and the clonal differences within populations were larger.
- Overall, the clones with higher concentrations of K and/or Fe and lower concentration of Mg performed better on serpentine soil.
- The current-year foliar nutrient status could better predict the diameter and volume growth increment than the total growth.
- The negative correlation between foliar K and Mg concentrations implied that high foliar K level could induce Mg deficiency symptom (i.e. UMCY) on some susceptible clones grown on the soils with high K and low Mg (e.g. pumice soils).
- The relationships highlight the need to understand site-specific drivers of tree growth and to identify specific genotypes that are better matched to specific sites.
- The study implied there is potential for deploying some potential clones with greater tolerance to nutrient stress for optimising forest productivity in problem soils.
- Future work will examine the nutritional profiles at other sites to determine whether this result is consistent across sites with varying soil and climatic regimes.

Acknowledgements

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