RADIATA MANAGEMENT TECHNICAL NOTE
Site Productivity

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Nutritional Characteristics of Radiata Pine Clones Grown Under Field and Glasshouse Conditions

Summary

To investigate the nutritional characteristics and physiological determinants of clonal differences in growth rate, we compared growth, needle characteristics, and nutrient concentrations and patterns in water use efficiency of six selected clones planted at a range of nutritionally contrasting sites at age 4-6 years. These data were also compared with data on growth, nutrient uptake and remobilization, and needle characteristics from a series of intensive glasshouse experiments using 1- 2-year-old plants of the same clones. Our results suggest that the opportunity exists to exploit clone × site variation for site-specific clonal deployment, and that the factors determining growth rate differed among clones. The fastest growing clone had consistent, high uptake of all nutrients, high fascicle weights and high water use efficiency.

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INTRODUCTION

Soil diversity in New Zealand creates a challenge to optimize forest nutrition. Deficiencies of mineral nutrients (mainly N, P, Mg and B) are widespread in radiata pine [1]. With such soil diversity, an opportunity exists to identify genotypes of radiata pine with nutritional characteristics tailored to maximize growth on particular sites. Conversely, an opportunity exists to avoid deploying genotypes to sites where nutritional and moisture characteristics are not conducive to high performance. In New Zealand, radiata pine is a fast-growing, nutrient- and water-demanding conifer harvested on a rotation of 25 - 32 years. Understanding of radiata pine adaptation to soils with nutrient and/or moisture limitation is, therefore, of interest to many [2]. Although use of fertiliser and intensive site preparation, and even sustained weed control, have become common practice in New Zealand, the specific pursuit of genotypes that are better adapted to problem soils with limited nutrients and moisture has received much less attention, at least at an operational level (Burdon, pers. comm.).

Improving nutrient and water use efficiency (WUE) is a common practice in agricultural crops and has received increasing attention in forest trees [3] [4]. Forest productivity on infertile soils could be improved not only by application of fertilisers and weed control, but also by deploying genotypes that can better take up limiting nutrients and moisture and use them more efficiently under particular soil conditions. At least, the need for fertilisation and weed control could be minimized by using high water- and nutrient-efficient genotypes. Thus, more attention could be given to the selection of genotypes with desirable physiological characteristics, which would be associated with efficient uptake and utilization of limited soil nutrients and moisture.

Our objectives were to investigate whether consistent nutritional characteristics exist in clones of radiata pine with known differences in growth rate planted over a wide range of site qualities, and secondly, to explore the physiological basis for clonal growth rates over the long term.

MATERIALS AND METHODS

Clone Selection

This study focuses on six of the 40 clones planted in the 14 nationwide field trials established by Scion from 2002 to 2005 to examine the potential interaction between selected genotypes of radiata pine and sites with distinct nutritional characteristics, to highlight the opportunity for increased site resource use efficiency by better matching sites to genotypes. These six clones represent a gradient in field performance of clones planted in the Purokohukohu Experimental Basin [5].

- Clones P26C2, P26C5, and P02C7 were from parents assessed to have low susceptibility to Mg deficiency.
- P08C9 parent was assessed to have high susceptibility to Mg deficiency.
- Clone S02C1 was from a large diameter parent with high susceptibility to Mg deficiency.
- Clone S11C3 was from a small diameter parent with low susceptibility to Mg deficiency (P. Beets, pers. comm.).

The six clones were selected for in-depth physiological studies based on their growth rate and

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nutritional characteristics after five years of growth in a clonal trial at Puruki [5].

Field Trials and Measurements

The trials were established on a range of sites with N, P, B and Mg nutritional issues (Table 1).

All trees of six selected clones (see page 1) in seven of the 14 field trials, were measured for height and diameter (at ground level or 1.4 m), fascicle weight, foliar nutrients and $\delta^{13}C$ (a surrogate of WUE – 3 sites only) four or five years after planting.

All trees of six selected clones in six of the 14 field trials (i.e. another six trials) were measured for height and diameter at 1.4 m, only, four or six years after planting.

Physiological Investigations in Glasshouse

Intensive physiological experiments using 1- and 2-year-old plants of the six radiata pine clones were conducted in 2004-07 [6] [7] [8] [9]. The physiological experiments include:

(1) growth and N cycling experiments (NP-Ncycle, NP-Fv/Fm, NP-partition), and
(2) gas exchange experiments.

Height, root collar diameter, plant biomass, fascicle dry weight, the number of fascicles per plant, foliar nutrients and gas exchange were measured at the start and end of the experiments. These experiments provided an insight into the underlying physiological mechanisms for the clonal differences in growth performance.

Data Analyses

All statistical analyses were carried out using SAS software. Variables were tested for normality and homogeneity of variance, and transformations were made as necessary to meet the statistical assumptions of analysis of variance and regression.

RESULTS

- Of the six clones studied, some performed consistently across sites in terms of height and diameter, whilst the relative performance of others varied among sites.
- Consistently, P26C2 was a top performer, while P02C7 was a poor performer, particularly for height growth. P08C9, P26C5, S02C1 and S11C3 exhibited relatively large site-to-site variation, which makes these clones of greater interest for site-specific deployment (data not shown).
- In glasshouse experiments, P26C2 was the tallest, but S11C3 was the shortest of six clones studied. P26C5 had the greatest total biomass, whilst clones P08C9and S11C3 had the smallest total biomass (Table 2).
- On average, P26C2 had the highest foliar concentrations of N, P, S and B (Table 3). The interaction of site × clone was significant for foliar N, S and Mg and near-significant for P and K (Table 3).
- Overall, P02C7 and P26C5 had consistently low foliar N concentrations across all sites (Table 3).
- Foliar nutrient ratios, an indication of nutrient imbalances or interference in uptake between nutrient ions, showed significant site and clone effects (data not shown).
- There was a strong positive relationship between fascicle weight and stem diameter ($P < 0.0001$, $r^2 = 0.52$) (Figure 1) or stem height ($P < 0.0001$, $r^2 = 0.47$) five years after planting.

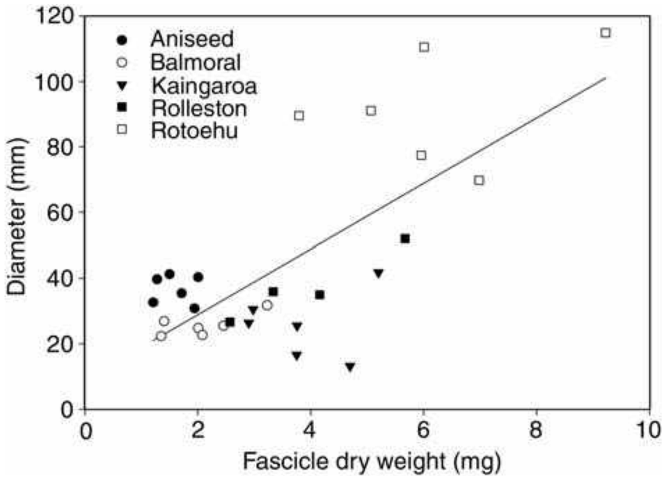

Fig 1. Relationship between mean fascicle dry weight and diameter for six clones of radiata pine planted on the five sites where diameters (at 1.4m) were measured five years after planting.

- P or K was the foliar nutrient with the strongest relationships with diameter and height (data not shown) in all clones.

Table 1: Site location, elevation, climate, soil classification and relative characteristics, year of establishment, and number of blocks for the 13 sites from which height (ht), diameter and, on some sites, foliar nutrient data were analysed for six clones of radiata pine. SI = South Island, NI = North Island.

Site	Location	Elevation (m)	Annual rainfall (mm)	Mean annual temperature (°C)	NZ soil classification[1]	Site characteristics[2]	Year trial established	Number of blocks
Ht, diameter & foliar nutrients								
Rotoehu, NI	37°56'S, 176°31'E	124	1860	13.3	Allophanic Orthic Pumice	high P, S; low Mg	2005	4
Kaingaroa, NI	38°37'S, 176°26'E	630	1548	10.1	Welded Impeded Pumice	med-high N, P, K, S	2005	4
Mahia, NI	39°07'S, 177°55'E	145	1248	13.7	Typic Orthic Pumice	high N, K; low S	2002	4
Aniseed Valley, SI	41°25'S, 173°12'E	321	1356	11.7	Mottled-magnesic Mafic Brown	Serpentine soil high Mg	2002	4
West Coast 1, SI	42°15'S, 171°34'E	192	2688	10.8	Silt-mantled Perch-gley Podzol	low K, Mg, pH	2004	2
Balmoral, SI	42°48'S, 172°37'E	315	864	10.4	Acidic Orthic Brown	high B, low K, S	2002	4
Rolleston, SI	43°37'S, 172°21'E	47	684	11.5	Pallic Firm Brown	med-high P, S; low B	2005	6
Ht & diameter								
Lochinver, NI	38°52'S, 176°21'E	715	1500	9.8	Immature Orthic Pumice	low Mg	2003	8
Crater Block, NI	38°16'S, 176°31'E	480	1572	11.3	Buried-pumice Tephric Recent	low N; med-high P	2004	4
West Coast 2, SI	42°16'S, 171°34'E	183	2700	10.9	Silt-mantled Perch-gley Podzol	low K, Mg, pH	2004	2
Forest Creek, SI	43°42'S, 170°53'E	740	1008	7.9	Acidic Orthic Brown	Low N, P, Mg, B,	2003	4
Lawrence, SI	45°55'S, 169°45'E	262	816	9.0	Mottled Fragic Pallidc	med-high N, P, K	2003	4
Berwick, SI	45°58'S, 169°59'E	381	924	8.3	Mottled Orthic Brown	med-high N; low P, B, pH	2003	4

[1]NZ Soil Classification (2010)
[2]Relative site characteristics obtained from local knowledge and soil sampling.

- K had a strong positive relationship with fascicle weight in most clones, but in clone P02C7, foliar N had the best relationship with fascicle weight. Foliar P concentration had a significant negative relationship with fascicle weight for most clones (data not shown).
- Among the six clones, P26C2 had the highest water use efficiency (WUE) on all three sites, whileP08C9 and S11C3 had the lowest WUE on two of three sites measured (data not shown).
- WUE was negatively correlated with diameter at Balmoral, the driest site, but not at Aniseed and Mahia. This indicates that the trees with higher WUE had smaller diameter on the dry site. WUE was positively correlated with fascicle weight at Balmoral and Mahia, indicating that heavier fascicles were more water use efficient.

Table 2: Mean (± S.E.) height, diameter, total dry weight, root:shoot ratio, and relative growth rate (RGR) for six clones grown in glasshouse experiments for 6-12 months. Means followed by the same letter are not significantly different (*P* ≤ 0.05).

Experiment	Parameter	P26C2	P26C5	P08C9	S11C3	P02C7	S02C1
NP-Ncycle	Height (mm)	958 ± 46 a	946 ± 71 b	893 ± 59 c	807 ± 49 d		
n = 24	RGR (height)	0.158 ± 0.008 a	0.135 ± 0.007 b	0.141 ± 0.009 b	0.145 ± 0.008 ab		
	Diam. (mm)	11.8 ± 0.25 b	13.2 ± 0.36 a	11.4 ± 0.32 b	11.6 ± 0.27 b		
	RGR (diam)	0.094 ± 0.006 a	0.089 ± 0.007 a	0.075 ± 0.007 b	0.087 ± 0.007 a		
NP-Fv/Fm	Height (mm)	297 ± 11 ab	267 ± 13 ab	293 ± 10 a	256 ± 11 b		
n = 31 - 39	RGR (height)	0.064 ± 0.004 a	0.040 ± 0.004 c	0.057 ± 0.005 ab	0.051 ± 0.003 b		
	Diam. (mm)	7.8 ± 0.1 b	8.2 ± 0.1 a	7.9 ± 0.1 b	7.2 ± 0.1 c		
	RGR (diam)	0.060 ± 0.002 a	0.055 ± 0.002 ab	0.052 ± 0.002 b	0.051 ± 0.002 b		
NP-partition	Height (mm)	539 ± 18 b	625 ± 19 a			451 ± 18 c	516 ± 23 b
n = 24	RGR (height)	0.178 ± 0.01 b	0.205 ± 0.01 a			0.161 ± 0.01 c	0.152 ± 0.01 c
	Diam.(mm)	8.3 ± 0.2 b	9.7 ± 0.2 a			9.6 ± 0.2 a	9.9 ± 0.3 a
	RGR (diam)	0.123 ± 0.006 ab	0.129 ± 0.006 a			0.121 ± 0.006 b	0.119 ± 0.006 b
NP-Ncycle	Total dry mass (g)	128 ± 5 b	131 ± 7 a	103 ± 6 c	106 ± 5 c		
	Rt:sht ratio	0.81 ± 0.06 a	0.64 ± 0.07 b	0.75 ± 0.05 a	0.82 ± 0.09 a		
NP-partition	Total dry mass (g)	49.0 ± 4.3 b	69.2 ± 4.1 a			69.1 ± 4.1 a	62.8 ± 4.3 a
	Rt:sht ratio	0.66 ± 0.03 a	0.59 ± 0.03 b			0.71 ± 0.03 a	0.60 ± 0.04 b

Note: (1) NP-Ncycle experiment: Clones P26C2, P26C5, P08C9 and S11C3 were used to study the influence of N and P on N uptake and internal cycling; (2) NP-Fv/Fm experiment: At six months in the NP-Ncycle experiment, potential maximum quantum yield of PSII (F_v/F_m) was measured for the photosynthetic performance of the clones; (3) NP-partition experiment was conducted to study the effects of N and P on carbon partitioning for the clones.

Table 3: Mean (± S.E.) N, P, K, S, Mg and B concentrations in the foliage of six clones of radiata pine planted on six (S) or seven (N, P, K, Mg, B) sites (n = 19 – 25). Means followed by the same letter are not significantly different (*P* > 0.05). Mean squares and *P* values from the ANOVA of transformed nutrient data are below.

	N (%)	**P** (%)	**K** (%)	**S** (%)	**Mg** (%)	**B** (ppm)
P26C2	1.29 ± 0.04 a	0.15 ± 0.01 a	0.70 ± 0.04 b	0.10 ± 0.05 a	0.13 ± 0.01 b	12.7 ± 1.0 a
P26C5	1.19 ± 0.03 d	0.13 ± 0.01 b	0.65 ± 0.04 c	0.08 ± 0.04 c	0.16 ± 0.02 a	13.1 ± 1.5 a
P08C9	1.25 ± 0.03 bc	0.13 ± 0.01 b	0.67 ± 0.04 bc	0.09 ± 0.03 b	0.12 ± 0.01 c	12.1 ± 1.7 ab
S11C3	1.27 ± 0.03 ab	0.12 ± 0.01 c	0.68 ± 0.04 bc	0.09 ± 0.03 b	0.11 ± 0.02 c	10.7 ± 1.0 b
P02C7	1.17 ± 0.03 d	0.13 ± 0.01 b	0.74 ± 0.05 a	0.08 ± 0.03 c	0.13 ± 0.01 b	12.8 ± 1.1 a
S02C1	1.21 ± 0.03 cd	0.13 ± 0.01 b	0.79 ± 0.06 a	0.09 ± 0.04 b	0.13 ± 0.01 b	11.3 ± 1.1 ab
Site (n=5 or 6)	0.133***	0.041***	0.374***	0.020***	0.264***	0.319***
Clone (n=5)	0.017***	0.003***	0.012***	0.002***	0.011***	0.014*
Site x clone (n=28)	0.002*	0.0005	0.002	0.0003*	0.001**	0.004

***** = $P \leq 0.001$, ** = $P \leq 0.01$, * = $P \leq 0.05$**

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CONCLUSIONS

1. Significant genotype effects and G×E interactions in our field experiments conducted over strong nutritional gradients allow us to identify radiata pine clones with consistent superior growth and nutritional characteristics, and clones that may be suited to particular site conditions.
2. P26C2 is a fast-growing clone with high nutrient acquisition. P26C5 appears to have poor nutrient uptake ability, but grows well in fertile conditions. P08C9 is a clone with relatively high N acquisition, but appears to have low uptake of P and K. P02C7 and S02C1 appear to have relatively high K uptake.
3. Foliar concentrations of K, and to a lesser extent S, were positively correlated with diameter, while concentrations of P were negatively correlated with diameter and height. This supports work showing available P limits growth on many sites in New Zealand.
4. In general, clonal ranking by size in glasshouse studies matched that in field studies; however, variation among glasshouse studies was observed, and more clones would be needed to assess this relationship reliably.

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