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Magnesium fertilizer, weed control and clonal effects on wood stiffness of juvenile *Pinus radiata* at two contrasting sites

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ABSTRACT

Two field trials established at contrasting sites (Kaingaroa and Rolleston) with different silvicultural treatments [magnesium (Mg) fertilizer or plus or minus weed control (±WC)] but identical clones of *Pinus radiata* were measured at age 6 for tree height (Ht), diameter at breast height (DBH) and ground-line (GLD), and modulus of elasticity (MOE) of standing trees. This study was undertaken to (i) quantify the main and interactive effects of clone, site, Mg fertilizer or WC on stem slenderness and corewood MOE of juvenile radiata pine, and (ii) examine the relationships between clonal means of corewood MOE and stem slenderness from 15 selected clones.

At the Kaingaroa site, clone had a significant ($P < 0.001$) influence on stem slenderness and corewood MOE, which exhibited a 1.5-fold variation (1.48–2.33 GPa). The Mg fertilizer effect on MOE was not significant. At the Rolleston site, both WC and clone had significant ($P < 0.001$) influence on corewood MOE. Compared to −WC, +WC reduced MOE by 7%. The MOE exhibited a 1.7-fold variation (1.67–2.83 GPa) among the 15 clones. Across both sites, MOE exhibited a 1.5-fold variation (1.65–2.55 GPa) among the 15 clones. Overall, clonal differences in MOE were substantial and larger than the differences due to site and WC. Significant interactions were also found between clone and Mg fertilizer, clone and WC, and clone and site.

This study for the first time showed the clonal means of MOE was strongly and positively correlated to clonal means of stem slenderness. This study has the important implication for forest managers that clonal material can be closely matched to site conditions and management regimes to optimise product value.

1. Introduction

Radiata pine (*Pinus radiata* D. Don) is the most important plantation forest species in New Zealand. Advances in tree breeding and silvicultural practice have resulted in improved growth rates of this species and therefore in shorter rotation lengths (New Zealand Forest Owners Association, 2004). However, these faster-growing trees have lower economic value (Burdon et al., 2004; Gapare et al., 2006) as they have a larger proportion of juvenile corewood (Downes et al., 2000), which has lower strength and stiffness than mature outerwood (Macdonald and Hubert, 2002; Gartner, 2005; Gapare et al., 2007). In the past, managers have focussed on increasing total merchantable volume, but attention is now turning towards techniques that enhance tree growth and desirable wood properties concurrently (Watt et al., 2009).

Wood stiffness, measured as modulus of elasticity (MOE), is one of the most important mechanical properties for structural end-uses and has a direct impact on structural timber grade outturn (LindstrÖm et al., 2005; Ivković et al., 2009). MOE is also a key property for determining quality of laminated veneer lumber. Low MOE in radiata pine limits utilisation options, and is more prevalent when trees are grown on fertile sites over short rotations designed for rapid attainment of large piece-size (Burdon et al., 2001).

Corewood MOE is highly variable and affected by genetic factors (Kumar et al., 2002; Dungey et al., 2006), environmental factors (Roth et al., 2007; Watt et al., 2006a,b, 2009) and silvicultural practices (Watt et al., 2005; Mason, 2006; Waghorn et al., 2007a,b). In softwood species, large genetic variation in wood stiffness has been found at tree age 8 years or younger, with medium to high heritabilities in radiata pine (Kumar, 2004; Dungey et al., 2006) and slash pine (Li et al., 2007). The corewood MOE of radiata pine is also known to range widely across environmental gradients and may be influenced by site conditions (Watt et al., 2006a,b, 2009). The corewood MOE of radiata pine can be manipulated by

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silvicultural practices. Considerable gains in MOE have been obtained through increasing initial stand density (Grabianowski et al., 2004; Lasserre et al., 2005, 2008, 2009; Waghorn et al., 2007a,b), and use of clones with improved MOE (LindstrÖm et al., 2004). Vegetation control has also been shown to affect MOE of radiata pine, but the reported effects are quite variable. Woody weed competition has been found to increase MOE at a range of sites (Watt et al., 2005, 2009), however, competition from herbaceous species may have no significant effect on MOE (Mason, 2006). The different impact of herbaceous and woody weeds on MOE could be related to the different influence of these weed species on tree growth through competing site-resources such as light, temperature, root-zone water and nutrients. Further research is required to resolve this inconsistency. There is limited information on the effect of fertilizer application on MOE of radiata pine, but studies have shown that fertilisation may cause a small reduction in MOE (Downes et al., 2002; Watt et al., 2006b).

A better understanding of how clone, fertilizer application, competing vegetation control and site interact to influence corewood stiffness is needed. Separating the effects of forest management, environmental factors, and genetics on MOE is important to optimising management of intensively-cultured plantations. If specific silvicultural treatments improve corewood stiffness, and specific genotypes have stiffer corewood across sites or at certain sites, then such information is valuable for forest managers to manipulate the corewood stiffness of plantations under local site conditions. Our primary objective was therefore to quantify the effect of genotype, site, and silvicultural treatment (i.e. fertilizer application and weed control), alone and in combination, on stem slenderness and corewood stiffness of juvenile radiata pine.

Tree slenderness, defined as the ratio of total height (Ht) to diameter outside bark at 1.4 m above ground (DBH) or at ground-line (GLD) often serves as an index of tree stability, or the resistance to windthrow (Navratil, 1995). Recently, strong relationships between stem slenderness and MOE have been observed from spacing (i.e. stand density) trials for *P. radiata* (Waghorn et al., 2007a,b; Lasserre et al., 2008, 2009), *P. taeda* (Roth et al., 2007) and *Eucalyptus* (Warren et al., 2009), and from a range of trials with broad environmental gradients for *P. radiata* (Watt et al., 2006a,b, 2009) and *P. mariana* (Liu et al., 2007). However, little information is available on the association of MOE with stem slenderness across a range of genotypes. If there was a strong genetic link between stem slenderness and MOE, then stem slenderness could be used as a potential parameter for assisting the selection of clones with greater MOE. A secondary objective of the study was therefore to examine the relationships between clonal means of corewood MOE and stem slenderness from 15 selected clones planted at different sites.

2. Materials and methods

2.1. Trial locations and site characteristics

Two trials established on contrasting sites were selected for this study. The first trial was located at Kaingaroa Forest (38°37′S, 176°26′E) in the central North Island while the second trial was at Rolleston (43°37′S, 172°21′E) near Christchurch in the South Island. The soils at both sites were well drained. The Kaingaroa site had greater elevation, mean annual rainfall, total soil carbon (C), nitrogen (N) and phosphorus (P), and exchangeable potassium (K), but lower mean annual temperature, exchangeable magnesium (Mg), calcium (Ca) and cation exchange capacity (CEC) than the Rolleston site (Table 1). The Kaingaroa site was a third rotation *P. radiata* stand while the Rolleston site was in its first rotation (after-pasture).

2.2. Trial design and clonal material

Randomized complete block designs were used in the trials which were established in 2005. At Kaingaroa, four plots received Mg fertilizer at 180 kg ha^{-1} as Calmag (50% Mg), and another four were unfertilised. This treatment was applied as radiata pine plantations in central North Island frequently display upper mid crown yellowing (UMCY), which is symptomatic of Mg-deficiency associated with genetic, soil and climatic factors (Beets et al., 2004). No weed control (WC) treatment or other fertilizers were applied to this trial. At Rolleston, a WC treatment was applied to six plots while another six plots received no WC. Weed control was achieved by annual spray application of Valzine extra (AGPRO NZ

Table 1
Site characteristics and soil properties (0–10 cm) of the two trials used in the study.

Site	Kaingaroa	Rolleston
Elevation (m, a.s.l.)	630	47
Aspect	SE	0
Slope (°)	<5	0
Mean annual rainfall (mm)	1548	684
Mean annual temperature (°C)	10.1	11.5
Soil type	Kaingaroa sand	Lismore stony silt loam
Parent material	Tephra	Aggradation (in part glacial) gravel
NZ classification	Welded impeded pumice soil	Pallic firm brown soil
US taxonomy classification	Typic ustivitrand	Udic haplustept
Total N (g 100 g^{-1})	0.45	0.24
Total C (g 100 g^{-1})	8.0	3.1
Total C/N	18	13
Total P (g 100 g^{-1})	0.05	0.03
Olsen P (μg g^{-1})	9.11	11.4
Extractable K^+ (cmol$_c$ kg^{-1})	0.47	0.29
Extractable Ca^{2+} (cmol$_c$ kg^{-1})	1.14	2.24
Extractable Mg^{2+} (cmol$_c$ kg^{-1})	0.28	0.92
CEC (cmol$_c$ kg^{-1})	21.4	30.3
pH	4.80	4.81
Site index (m)	30	NA
Mean tree height at age 6 (m)	4. 77	4.54
Mean tree DBH at age 6 (cm)	8.0	7.6
Mean tree GLD at age 6 (cm)	13.6	11.6
Mean tree MOE at age 6 (GPa)	1.804	2.265