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Relating nutritional and physiological characteristics to growth of *Pinus radiata* clones planted on a range of sites in New Zealand

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Summary Six clones of radiata pine with known differences in growth rate were examined for clonal nutritional characteristics and for physiological determinants of clonal growth rate. We compared growth, foliar characteristics and nutrient, ^{13}C and ^{15}N concentration data for the six clones in 4- to 6-year-old field trials planted over a range of nutritionally contrasting sites. These data were also compared with growth, nutrient uptake and remobilization, foliar characteristic and gas exchange data from intensive physiological glasshouse experiments using 1- and 2-year-old plants of the same clones. Significant genotype × environment interactions in our field experiments conducted over strong nutritional gradients allowed us to identify radiata pine clones with consistent, superior growth and nutritional characteristics and clones that may be suited to particular site conditions. Our results suggest that the opportunity exists to exploit clone × site variation for site-specific clonal deployment and planting of fast-growing clones could be accompanied by planting of clones able to take relative advantage of site nutritional characteristics. Faster tree growth was not strongly related to any physiological characteristic, and the factors influencing growth rate differed among clones. The fastest-growing clone had consistent, high uptake of all nutrients, high fascicle weights and high water-use efficiency.

Keywords: foliar nutrients, G × E interaction, phosphorus, potassium, radiata pine, retrospective studies, site resource-use efficiency.

Introduction

New Zealand has an impressive diversity of climates and soils, all within a relatively small land area of 270 000 km^2. Annual rainfall ranges from 0.02 to 18.44 m (New Zealand Met Service 2009) and soils derive from recent volcanic, alluvial, glacial and coastal origins (Molloy 1998). During the last 1000 years, soils have been further influenced by extensive burning (Molloy 1998) and, more recently, by agricultural fertilization, particularly with phosphorus (P) (During 1984, Hunter et al. 1991). Across this varied landscape, exotic forests are planted on an area of 17 600 km^2, and 89% of these forests are radiata pine (*Pinus radiata* D. Don) (MAF 2009).

Soil diversity in New Zealand creates a challenge to optimize forest nutrition. Deficiencies of mineral nutrients are widespread. Based on 28 000 samples of radiata pine first-year foliage, Hunter et al. (1991) developed probabilities of nutrient deficiencies for pine throughout New Zealand. In general, many South Island soils have only marginal nitrogen (N) availability. Marginal P deficiencies occur in the northern half of the North Island and in the west coast forests and Canterbury plains of the South Island. Magnesium (Mg) deficiencies are likely in the volcanic central region of the North Island and on the west coast and higher inland areas of the South Island, but excess Mg may be found in the serpentine soils of the Nelson region. Boron (B) may be deficient in the central North Island and on the east and west coasts of the South Island. Potassium (K) is found at satisfactory levels in most areas of New Zealand; however, induced deficiency of K may be found on former agricultural soils (During 1984).

With such soil diversity, an opportunity exists to identify genotypes of radiata pine with nutritional characteristics tailored to maximize growth on particular sites. A number of studies of tree species have documented an increase in N utilization (biomass per percent of N) or N productivity (biomass increase per unit N per day) in fast-growing families (reviewed by Weih and Nordh 2005), and a smaller number of studies have shown that fast-growing families are better able to take up N than slow-growing families (Jahromi et al. 1976, Bell et al. 1979, Mari et al. 2002, Hawkins 2007, Miller and Hawkins 2003, 2007). In New Zealand, selection pressure also exists for nutrient uptake or exclusion efficiency of elements other than N. Studies in the 1960s and 1970s provided