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First order lateral root characteristics reflect the competitiveness of radiata pine genotypes in agroforestry systems

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(Paper presented at Australasia Forestry Conference, Queenstown, New Zealand. April 2003)

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Abstract

First order lateral roots (henceforth lateral roots) provide mechanical support to trees and are essential links to the fine roots that compete with roots of understorey plants. This paper examines a number of lateral root characteristics of three radiata pine (*Pinus radiata* D. Don) genotypes at age three years in an agroforestry experiment at the Lincoln University, and relates these characteristics to tree height, diameter, volume index, and above ground biomass. In the trial, the three genotypes (referred to here as clone 3, clone 4 and seedlings) were planted with two understorey treatments - lucerne (*Medicago sativa* L. cv. 'WL320') and ryegrass (*Lolium perenne* L. cv. Yatsyn') with clovers (*Trifolium* spp.), and a no understorey treatment – that represented high, moderate, and zero understorey competition environments. The number of lateral roots was 41% more in clone 3 than in the seedlings but did not differ significantly between the two clones. This corresponded with 52% more above- and belowground biomass in the clonal trees than in the seedling trees. Similarly, tree height, basal diameter, and volume index were 20% greater in the clonal trees than in the seedling trees. There were no interactions between genotype and understorey in any studied variables. Our results suggest that selection of planting materials (at age 3 years) based on the number of lateral roots could be a useful approach for selecting superior genotypes for deployment in agroforestry systems.

Keywords: Lateral root, silvopasture, above- and belowground biomass, New Zealand

Introduction

In New Zealand, radiata pine (*Pinus radiata* D. Don) cuttings or tissue cultured plantlets are used in plantations to gain greater growth rates and achieve better tree forms than using normal seedlings (Menzies *et al*. 2001). In recent years, cuttings and other forms of vegetative propagules provide at least 25% of the radiata pine plant stock in New Zealand (Menzies *et al*. 2001). In agroforestry systems where understorey pasture species are actively promoted, belowground competition between the trees and understorey is an important factor that can often lead to poor tree growth (Mead *et al*. 1993, Bandara 1997). Several studies have shown that weed competition can be the single most important factor to reduce growth rates in young radiata pine plantations (South *et al*. 2001, Mason *et al*. 1996, Albert *et al*. 1980). This paper examines whether root morphological characteristics could be used in selecting more competitive trees for planting in silvopastoral systems in New Zealand.

First-order lateral roots (henceforth lateral roots), which originate directly from tap roots or the root core, are the main framework for supporting lower order coarse roots that anchor trees (Coutts 1987, Gautam *et al*. 1999, Mason 1985). In addition, lateral roots are the main framework for the development of fine roots, the amount of which is related to tree growth (Gautam *et al*. 2003a, Nambiar 1984, Theodorou and Bowen 1993). Thus we hypothesize that tree planting material having a higher number of lateral roots will be more competitive with understorey species and have improved aboveground growth. In this paper we examine the relationship between first order lateral root production and tree growth.

Materials and Methods

The site

The site and the experimental design have been described by Mead *et al*. (1993). Briefly, the trial was established in July 1990 on a site 2 km southwest of Lincoln University (43°38'S, 172° 30'E, 11 m altitude), on Canterbury Plains, New Zealand. The main trial included six understorey treatments in the main plots and five radiata pine planting stock types (genotypes) in the subplots in a split-plot design. For the current study, we selected the control, i.e., bare ground, and two understorey types, perennial ryegrass (*Lolium perenne* L. cv. Yatsyn') mixed with clovers (*Trifolium* spp.), and lucerne (*Medicago sativa* L. cv. 'WL320'), and three *Pinus radiata* genotypes, i.e., tissue-cultured clone 3 (full-sib, set 11/8, GF 16/17), clone 4 (half-sib, set 38/9, GF 15), and seedlings (raised from open pollinated seed, "850", GF 14). The treatments were replicated in three blocks. Prior to planting at 1.4 x 7 m spacing (1000 stems/ha) the tree rows were ripped to 60-cm depth. At the time of this study, in July 1993 (at age three years), the trees had been thinned down to 800 stems/ha but had not been pruned.

The mean annual long-term rainfall is 660 mm, which is distributed more or less evenly throughout the year. Summer evapotranspiration usually exceeds summer precipitation by two to three folds, and therefore summer droughts are common (Gautam *et al*. 2002). The soil is well drained with 320 mm water holding capacity in the top 1 m. According to the New Zealand soil classification system, the soil is classified as Templeton silt loam (with 20, 63, and 17% clay, silt, and fine sand, at top 40 cm depth respectively). The wilting coefficient (unavailable soil water to plant) and field capacity of the soils are 10.3 and 32.0%, of soil volume respectively (Figure 1). The top 0.2 m contains about 2.8% carbon and 0.24% nitrogen, and has a pH of 5.8 (Chang *et al*. 2001). The soil is considered one of the most productive soils in the region for trees.

Data collection and statistical analysis

In winter 1993, fifty-four trees (two trees from each subplot) were selected that cover the wide range of tree sizes in the trial. Tree height and diameter at breast height over bark (DBH) were measured. Volume index was calculated as DBH^2 x height.

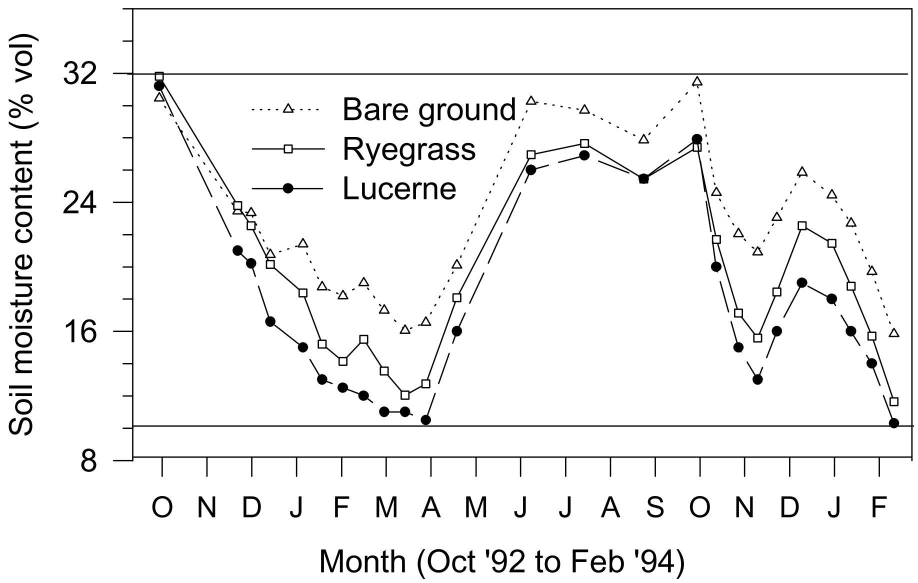

Figure 1. Mean soil moisture content in the 0-40 cm layer in the bare ground, ryegrass and lucerne plots in the Lincoln University Agroforestry Experiment, New Zealand. The upper and lower horizontal lines indicate field capacity and wilting coefficient of the Templeton silt loam soil. The field capacity and wilting coefficients were recalculated from Watt and Burghan (1992).

After measurement, the aboveground tree was harvested at ground level. Then a tractor with a hydraulic-ram of 2.5-ton lifting power and a four-footed steel frame was used to pull the root system from the saturated soil, assisted with digging up to a 50 cm depth. In doing so, the first order lateral roots did not break within 10 cm from their origin, these enabling determination of root diameter at 10 cm from the root core (i.e. dia_{10}). To establish the relationship between dia_{10} and root biomass, three to five complete lateral and vertical roots per tree, over the range of measured dia_{10}, were obtained. For the purpose of this study we define complete root as root emerging from the root core to the point along their length where first, second or lower order branch roots were 2 mm in diameter. The sample roots were dried at 70^o C to a constant weight. The relationship between dia_{10} and lateral and vertical root biomass was evaluated using linear regression models. The number of first order vertical and lateral roots >2 mm at dia_{10} was counted. All dia_{10} for first order lateral and vertical roots were measured to the nearest millimetre. The total root biomass was then calculated by using the regression equations developed above. Aboveground biomass of the sampled trees was measured and was reported in Bandara (1997).

Analysis of variance was performed following a split-plot model using the General Linear Models (GLM) procedure in SYSTAT (1992). Fisher's protected LSD test was used to test differences between the treatments if they were significantly ($p \leq 0.05$) different in the main model of ANOVA. Only significant results ($p \leq 0.05$) are presented in the text. Regression and correlation analyses were also performed using the SYSTAT software.

Results

Biomass estimation

Linear regression models representing relationships between $(dia_{10})^2$ and root biomass are listed in Table 1. As slopes and intercepts were different (p 0.001) between planting materials for both the lateral and vertical roots but were not different between the understory treatments, models were developed for each planting material by pooling the understorey data. Table 1 showed that the slopes for the models with combined understorey data were very different between clone 3 and the other two planting material types, for both lateral and vertical roots; however, the slopes were not significantly different between clone 4 and seedlings.

DBH, height and volume index

DBH was different (p=0.001) between planting materials and was affected (p=0.001) by understorey treatments (Table 2). DBH was 20% greater in the clones than in the seedlings, however, differences between clone 4 and clone 3 or seedlings were not significant. DBH was 35 and 11% greater in the bare ground than in the lucerne and ryegrass treatments, respectively, and was 21% greater in the ryegrass than in the lucerne treatment.

Table 1. Regression models developed from sampled complete lateral and vertical roots. The probabilities of all the regression equations were 0.001.

Root type	Planting materials	Root dry biomass (g) = a+b $(dia_{10}\ (mm))^2$		R^2	n
		a	b		
Lateral	Clone 3	-9.3363	0.2348	0.95	68
	Clone 4	7.7345	0.1616	0.90	52
	Seedlings	4.1743	0.1551	0.73	53
Vertical	Clone 3	12.0202	0.1220	0.85	27
	Clone 4	7.4051	0.0892	0.92	14
	Seedlings	-0.5564	0.0714	0.95	10

Tree height was different (p=0.001) between the planting materials and was also influenced (p=0.020) by understorey treatments (Table 2). Height was 6 and 23% greater in clone 3 than in clone 4 and seedlings, respectively, and 15% greater in clone 4 than in the seedlings. However, between the clonal trees height was similar. Tree height was 15 and 11% greater in the bare ground and ryegrass than in the lucerne treatment, respectively.

Volume index was different (p=0.008) between planting materials and was also affected by understorey treatments (Table 2). Volume index was 52% greater in the clonal than in the seedling trees, but was not significantly different between the clone 3 and 4 trees. Volume index was 28 and 87% greater in the bare ground than in the ryegrass and lucerne treatments, respectively; and it was 47% greater in the ryegrass than in the lucerne treatment (Table 2).

Table 2. Effects of treatments on studied variables and summary of the ANOVA results of sampled trees. SEM stands for standard error of the mean.

Treatments	DBH (cm)	Height (m)	Volume index (m^3 x 10^{-3})	Biomass (g)		Number of lateral roots
				Below-ground	Above-ground	
Planting material						
Clone 3	4.8	3.2	8.050	1848	10283	24.9
Clone 4	4.2	3.0	7.503	1192	9098	22.7
Seedlings	3.8	2.5	4.916	787	8213	17.6
SEM	0.14	0.05	0.347	242.4	642	1.6
Understorey						
Bare ground	5.1	3.1	8.856	2052	14819	22.5
Ryegrass	4.6	3.0	6.934	1085	7378	23.1
Lucerne	3.8	2.7	4.680	693	5397	20.0
SEM	0.16	0.05	0.465	103.1	628	1.6
Probability of significance (p)						
Planting material (P)	0.001	0.001	0.008	0.002	0.042	0.031
Understorey (U)	0.001	0.020	0.001	0.028	0.027	0.072
P x U	0.549	0.781	0.159	0.762	0.705	0.269

Biomass

Planting materials influenced (p=0.002; Table 2) the belowground biomass of trees. Belowground biomass was two times greater in clone 3 than in the seedling trees. However, there was no difference between clone 3 and clone 4 trees, neither between clone 4 and seedling trees. Also, belowground biomass was adversely affected (p=0.028) by the understorey treatments. Belowground biomass in the lucerne and ryegrass plots were 33 and 50% of that in the bare ground treatment, but were similar in the lucerne and ryegrass plots.

Aboveground biomass was affected by planting materials and understorey treatments (p=0.042 and 0.027, respectively; Table 2). Aboveground biomass of clone 3 was 52% greater than that of clone 4 and seedling trees, but was not significantly different between clone 4 and seedling trees. The aboveground biomass in the lucerne treatment was only one third that in the bare ground treatment, and it was similar between the lucerne and ryegrass treatments. There were no significant interactions between planting material and understorey treatments.

Number of first order lateral roots

For the purpose of this study, all lateral roots that had a dia_{10} greater than 2 mm were counted. Table 2 shows that the number of lateral roots was different (p=0.031) between planting materials. Clone 3 and 4 trees had 41 and 29% more lateral roots than the seedling trees, whereas the difference between clones 3 and 4 was much smaller. There was no significant understorey treatment effect or significant P x U interaction on the number of lateral roots (Table 2).

Table 3. Pearson correlation coefficients and P values (in brackets) between the number of lateral roots and other studied variables in the respective treatments.

Variables	Lateral root by planting materials			Lateral root by understorey treatments		
	Clone 3	Clone 4	Seedlings	Bare ground	Ryegrass	Lucerne
DBH	0.39 (0.041)	0.43 (0.025)	0.47 (0.003)	-0.12 (0.695)	0.13 (0.598)	0.21 (0.375)
Height	0.54 (0.002)	0.53 (0.025)	0.60 (0.009)	0.28 (0.256)	-0.10 (0.892)	0.41 (0.091)
Volume index	0.45 (0.048)	0.42 (0.031)	0.65 (0.003)	0.03 (0.873)	0.11 (0.675)	0.24 (0.043)
Belowground biomass	0.62 (0.005)	0.86 (0.001)	0.90 (0.002)	0.12 (0.638)	0.69 (0.004)	0.60 (0.001)
Aboveground biomass	0.57 (0.001)	0.87 (0.005)	0.86 (0.001)	0.64 (0.015)	0.42 0.079	0.81 0.029

Correlation coefficients range from 0.39 to 0.90 among the planting materials, and were statistically significant (p≤0.041). However, for the understorey treatment, the correlation coefficients were very erratic and so was their significance level.

Discussion

The dry weight of a root system could be accounted for by a few roots of large diameter or by many roots of small diameters. Therefore, the number of lateral roots of a fixed diameter (>2 mm at dia_{10} in this study) may indicate the morphological character of the first order lateral roots and may be related to the vigour of tree growth in the field (Kormanik 1986, Nambiar 1984, Theodorou and Bowen 1993). Our hypothesis is that planting materials with a greater number of lateral roots will be more competitive with understorey species and have improved aboveground growth. To test this we related the number of first order lateral roots to height, DBH, volume index and above- and belowground biomass. The responses of the latter measures to different understories were taken as indicators of planting material competitiveness. Our result shows that the growth of clone 3 trees were superior over clone 4 trees and particularly over the seedling trees, and the clonal trees had higher numbers of lateral roots than the seedlings (Table 1). The greater number of lateral roots of the clonal trees was correlated to growth measurements (Table 3) and supports our hypothesis that numbers of first-order coarse lateral roots can be used to determine the competitive ability of different planting materials. In this study the differing numbers of lateral roots might be due to genetic differences, or to differences in physiological age, as the clone 3 and 4 trees were physiologically older than the seedling trees (Mead *et al.* 1993, Whiteman *et al*. 1991, Burdon and Bannister 1985) or to propagation method (tissue culture or seedlings) (Fielding 1970). Unfortunately, in this study these effects were confounded and cannot be separated out.

Tree above- and belowground growth is also affected by the presence of understorey competition (Mead *et al.* 1993, Mead and Mansur 1993, Yunusa *et al*. 1995b, Sands and Nambiar 1984). Our study demonstrated that severe understorey competition resulted in lower DBH, height, volume index, above- and belowground biomass growth in the lucerne than in the bare ground treatment; while the values of these variables were often intermediate in the ryegrass treatment (Table 2). The adverse effects of understorey competition can result from competition for soil moisture (Yunusa *et al*. 1995a, Hallgren *et al*. 1991, Squire *et al*. 1987), and secondarily from competition for nutrients (Mead and Mansur 1993). Soil moisture content was lower in the lucerne than in the ryegrass treatment which was less than in the bare ground treatment, particularly in the summer (November to April), when the soil dried to a very low moisture level (Figure 1). This phenomenon was also true in autumn and winter between the bare ground and the ryegrass or the lucerne treatments (Figure 1).

Root biomass can potentially indicate the competitiveness and growth vigour of trees (Gautam *et al*. 2003a). The size of the root system and root biomass is determined by the sum of the size and biomass of lateral and vertical roots and the root core. The number of lateral roots is often related to anchorage, survival and vigour of trees in the field (Coutts and Lewis 1983, Kormanik 1986, Nambiar 1984, Theodorou and Bowen 1993). We found that lateral roots are associated with characteristics of planting materials. Lateral roots provide a framework for the development of second and lower order roots and eventually for the production of fine roots that is important for water and nutrient uptake. Coutts and Lewis (1983) demonstrated that lateral roots are important in providing anchorage strength in Sitka spruce. Our earlier study showed that clonal trees were more resistant to toppling as compared to the seedling trees (Gautam *et al*. 1999), which could have also been partly related to the greater number of lateral roots in the clonal trees.

Conclusions

Clonal trees were better than the seedling trees in above- and belowground growth and the superior performance was related to the greater number of lateral roots at age 3 years. Selection of planting materials that develop a greater number of first-order lateral roots at age three could identify genotypes that are more stable after planting and fast growing at young ages. This may be of special significance in agroforestry systems where the understorey often competes strongly with the trees at the early stage of tree growth. Similarly, if the aim of the agroforestry system is to produce a maximum amount of timber, then less competitive understorey, such as ryegrass, should be selected as the preferred pasture species.

Acknowledgements

Madan Gautam is grateful to the New Zealand Forest and Farm Plantation Management Co-operative for financial support and to the staff at the Field Service Centre, Lincoln University for technical help. The authors appreciate Dr. J. Raison, Chief Research Scientist at CSIRO, and Dr. J. Bauhus, Senior Lecturer, SRES, ANU for reviewing an earlier version of the manuscript. We also thank Dr. G. Bandara for providing the aboveground biomass data for this study.

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