The influence of initial stocking on corewood stiffness in a clonal experiment of 11-year-old *Pinus radiata* D.Don.

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Abstract

The influence of initial stocking on corewood stiffness of 11 year-old *Pinus radiata* D. Don was investigated at a Canterbury site. Dynamic stiffness was determined on standing trees using the stress wave method over the lower stem (0.2 to 2.0 m) of 135 trees. These trees were from two adjacent sub-experiments of the same age which comprised 10 different clones installed at three initial stockings of 833, 1250 and 2500 stem/ha.

Stiffness exhibited a significant ($p<0.01$) positive linear correlation with stocking. Values of stiffness significantly ($p<0.05$) varied between all stocking levels studied, with values of stiffness across clones ranging from 5.9 GPa at high stockings (2500 stem/ha) to 4.1 GPa at low stocking levels (833 stem/ha). Although stiffness significantly differed between clones ($p<0.01$) the clonal influence on stiffness was lower than that of stocking, with values ranging by on average 1.3 GPa (cf. 1.8 GPa for stocking) between the two clones representing the stiffness extremes. No significant interaction ($p>0.05$) was found between clone and stocking level. Tree diameter exhibited a significant ($p<0.01$, $r^2=0.5$) negative correlation with stiffness. After the influence of diameter had been accounted for, stocking still had a significant ($p<0.01$) positive influence on stiffness.

These results highlight the importance of stocking in regulating *Pinus radiata* corewood stiffness and indicate that initial stocking and genotype can be used as complementary approaches for improving corewood stiffness.

Introduction

Stand density influences patterns of tree growth and wood formation by altering competition between trees for solar radiation, water and nutrients. Another important component of the trees' physical environment that stand density influences is windflow, with higher stockings reducing windspeed within the stand (Green *et al.* 1995; Telewski 1995). The major visible effects of wider spacing, which have long been recognised, are increased rates of early diameter growth (due to reduced competition for resources) and longer retention of a deep living crown, as suppression of branches is delayed.

In *Pinus radiata*, evolving establishment and management practices have changed the nature of wood supplies. Changing silvicultural practice and advances in tree breeding over the last three decades have reduced rotation lengths from more than 35 (Chapman 1949; Macalister 1997) to 27 years (NZFOA 2004). These reductions in rotation length have resulted in an increase in the proportion of low value corewood present within the harvested crop. Although definitions of corewood can be subjective, it has often been defined as the innermost 10 growth rings (Cown 1992), where wood properties are changing most rapidly (Walker & Nakada 1999). Corewood is generally characterised by low density, thin cell walls, short tracheids with large lumens, high grain angle, and high microfibril angle, with the result that it has low strength and stiffness, and poor dimensional stability compared to mature wood (Harris & Cown 1991). Structural products containing corewood are more brittle and more likely to warp, creating trouble for manufacturers and consumers (Walker & Nakada 1999).

One useful means of determining corewood quality is to measure stiffness. This property, which measures the resistance of wood to deflection under load, is used as a criterion in machine stress grading of structural timber (Walker & Nakada 1999) and is also required for determining the quality of laminated veneer lumber. Stiffness is often considered more important than strength for predicting wood quality because *Pinus radiata* boards rarely break in normal use; much more frequently a load results in excessive deflection (Walford 1985). When compared with other internationally traded structural lumber species, plantation grown *Pinus radiata* has relatively poor stiffness and stability.

The growing awareness that *Pinus radiata* corewood from most plantations is of low stiffness and poor quality has spurred research to determine how best to balance growth rates with optimisation of corewood properties. Stiffness and stability are now accepted as top priorities for breeding solid wood (Jayawickrama 2001). Various studies of the behaviour of different *Pinus radiata* genetic material have been

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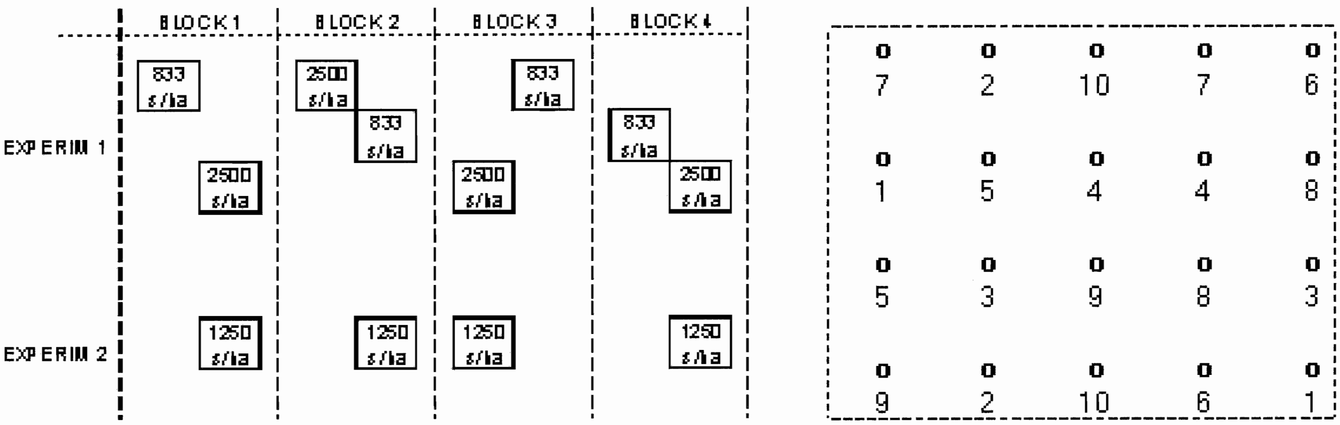
Fig. 1: Layout of the experiments and example of 833 stems/ha plot design, showing tree position and clone number. The diagram is not drawn to scale.



published, reveal that wood properties are often under elevated or at least moderate genetic control. Whole-tree clonal heritability of stiffness was estimated around 0.77, which is high (Shelbourne 1997). Clonal forestry may have the potential to markedly enhance the stiffness and structural end-product conversion of fast-grown *Pinus radiata* (Sorensson *et al.* 2002).

Changes in stocking level may be complementary to tree breeding as a way of enhancing corewood stiffness. Previous research has found an increase in stiffness as stocking increases for *Cryptomeria japonica* D. Don (Wang & Ko 1998; Chuang & Wang, 2001), *Tsuga heterophyla*, *Picea sitchensis* (Wang *et al.* 2001) and *Picea mariana* (Zhang *et al.* 2002). In contrast, for mature *Pinus radiata* Grabianowski (2003) did not find significant differences in outerwood dynamic stiffness between mature standing trees grown at stockings ranging from 100 to 625 stems/ha. Given that wood properties stabilise in outerwood, this lack of a response to stocking may be due to the age of the trees sampled. Previous research has emphasised the importance of considering the effects of stocking on corewood and outerwood separately (Yang & Hazenberg 1994; Panshin & de Zeeuw 1980).

The obvious benefits of segregating trees and logs based on stiffness have resulted in the development of many different methods based on acoustics for determining stiffness (Lindström *et al.* 2002). Among these, portable tools based on the longitudinal stress wave method offer a fast and accurate means of determining stiffness in standing trees. Recent research using *Pinus radiata* clones shows a strong correlation (r^2=0.96) between dynamic stiffness measured using one of these tools and static stiffness determined from traditional static bending (Lindström *et al.* 2002). Although stress-wave velocity is not affected by knots and other defects, it is important to note that this method only measures the sound velocity within the outermost growth rings in standing trees (Gorman *et al.* 2003).

The aim of this study was to determine the effect of the initial stocking on the stiffness of corewood in a clonal *Pinus radiata* experiment. A new tool that can measure stiffness of standing trees using sonics (Harris *et al.* 2003) was used on 11 year old trees growing in adjacent sub-experiments that contained 10 clones at three initial stockings: 833 stems/ha, 1250 stems/ha, and 2500 stems/ha. The use of clones improved the power of the analysis to detect differences in stiffness that might be difficult to detect in experiments with no control over genotype.

Materials and Methods

Site location and experimental design

Measurements were taken from 11 year-old *Pinus radiata* trees growing in two adjacent sub-experiments, established by the New Zealand School of Forestry. Both sub-experiments were planted with the same genetic material, and located at Dalethorpe (latitude 42°45'S, longitude 171°55'E, elevation 520 m a.s.l.), 70 km west of Christchurch. Although the mean annual precipitation of 1122 mm is evenly distributed (Met. Service database), seasonal water deficits do occur during February and March, when evapotranspiration exceeds rainfall. The soil was a well-developed silt-loam (NZ Soil Bureau 1968).

Although the two sub-experiments from which data were taken included a range of planting stock (GF1, GF27) and clonal planting designs (mixed and pure clones) only trees from the mixed clone plots were used in this study. The first sub-experiment was established to compare 10 different clones from genetically superior parents. These clones were established in mixed plots at 833 stem/ha and 2500 stem/ha. There are four randomised complete blocks of treatments (Fig. 1). In the second sub-experiment the same 10 clones were planted at 1250 s/ha (Fig. 1).

The sizes of the plots with 833, 1250 and 2500 stems/ha are 504 m^2, 320 m^2 and 256 m^2 respectively. Discounting the buffer trees and depending on stocking, there were a maximum of three trees per clone available for measurement in each plot. A total of 135 well-formed trees were selected to cover all the possible combinations of block, clone and stocking.

Both experiments were pruned to 2.2 m height in one lift at age 8 years. As one of the important variables to investigate was stem diameter, trees with double leaders (under 2.0 m height) were not used. One of the original ten clones was discarded from the analysis because of excessive malformation. Between four and five trees per combination of stocking and clone were measured. In cases where more than 5 trees were available, sampled trees were randomly selected.

Determination of stiffness

Green dynamic modulus of elasticity (E_d; Pa) was determined for all sample trees between 0.2 and 2.0 m from the following equation;

$$E_d = pV^2 \qquad (1)$$

where V is sound velocity (m/s) and p is green density (kg/m^3), assumed to be constant at 1000 kg/m^3.

Sound velocity was determined from sample length (l) and transit time (t) as; $V = l / t$. Transit time was determined using TREETAP Version 1, a prototype non-destructive acoustic tool developed at the University of Canterbury. Transit time was measured on both the windward and leeward sides of the standing tree, without removing the bark. Two probes connected with the TREETAP were introduced in the pruned log of the tree 1.8 m away from other. A third probe was introduced in the bottom part of the stem at approximately 15 cm from the lower probe. This third probe was tapped and the velocity of sound was measured between the other two probes. The sound flight velocity measurement was repeated eight times in each hitting position. Diameter at breast height over bark (dbh) was measured immediately after transit time was recorded.

Data analysis

The data were structured and analysed with SAS at the tree level using the following procedure:

1. An analysis of variance (Proc ANOVA) was conducted examining effects of block, initial stocking, genotype, and the interaction between genotype and stocking on measured corewood stiffness. The influence of initial stocking was tested against the block and initial stocking interaction.
2. To examine the effects of diameter growth rate and stocking on stiffness, the actual stocking was calculated for each tree, taking into account a small amount of mortality that occurred following planting. The following steps were then followed:

a. A regression was conducted with corewood stiffness as an independent variable, and diameter at age 11, actual stocking and genotype (a class variable) as independent variables.

b. In order to assess the independent effects of dbh and stocking, a procedure outlined by Cook & Weisberg (1999) was employed dbh was modelled against the significantly related independent variable stocking ($p<0.05$) using a second order polynomial, which when fitted to the data was found to exhibit little bias. Residuals from this model were then included as an independent variable in place of stocking in the model described in (a) above.

c. Plots of residuals were examined for bias.

Results

Stiffness was significantly influenced by stocking ($p<0.01$) and genotype ($p<0.01$). Examination of ANOVA output (data not shown) indicated that stocking had the largest influence on stiffness, with stiffness values in the highly stocked plots exceeding values in the low stocked plots by 1.8 GPa (5.9 *vs.* 4.1 GPa), or 42% (Table 1). Stiffness exhibited a linear increase with actual stocking at both the tree (Fig. 2) and treatment level. Multiple comparison testing showed that there were significant differences in stiffness between all three stocking levels.

Stiffness also exhibited considerable variation between clones. A plot of clones representing the extremes in stiffness showed a clonal influence on stiffness ranging from 1.1 GPa at low stockings to 1.5 GPa at high stockings. No significant interaction ($p>0.05$) was found between genotype and stocking (Fig. 3). Stiffness did not significantly ($p>0.05$) vary between the leeward and windward side of the tree.

Table 1. Stiffness values by initial stocking.

Initial stocking (s/ha)	No. trees sampled	Stiffness (GPa) Mean	Stiffness (GPa) std. error	Tukey grouping
833	47	4.1	0.10	A
1 250	44	4.6	0.11	B
2 500	44	5.9	0.11	C

Fig. 2: Relationship between tree level stiffness and actual stocking.

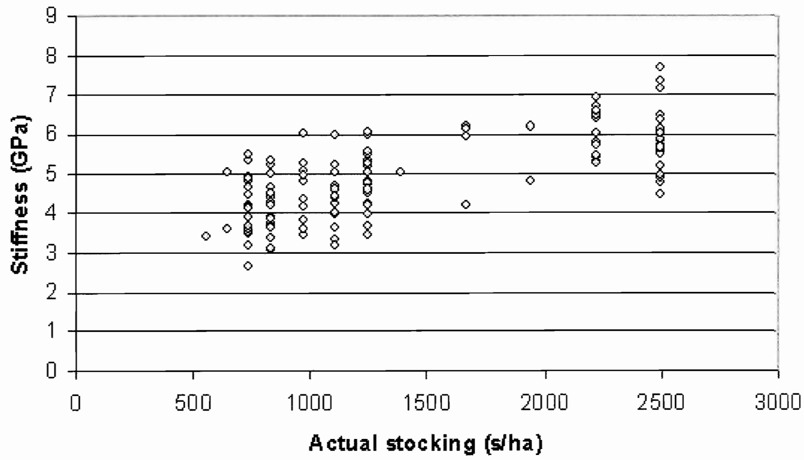


Fig. 3: Relationship between tree level stiffness and actual stocking for two clones representing the extremes in stiffness. Linear equations are shown for both clone 6 (dotted line) and clone 9 (solid line).

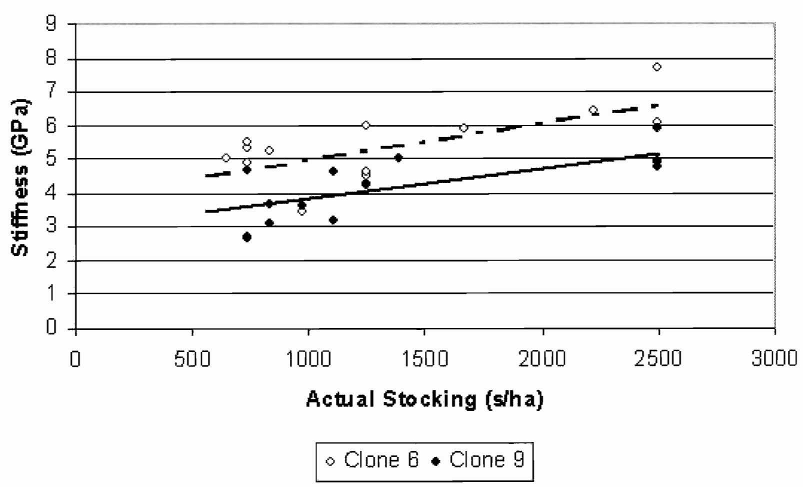
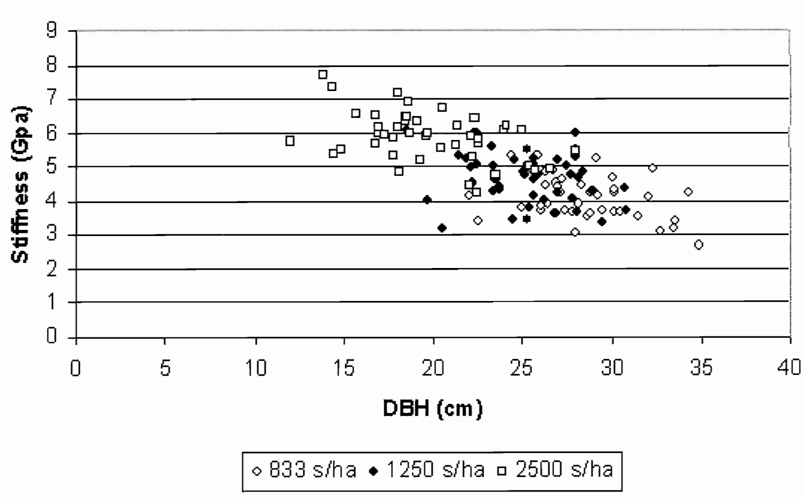


Fig. 4: Relationship between tree level stiffness and DBH for the three initial stocking levels.



There was a significant ($p<0.01$), negative relationship between dbh and stiffness among trees (Fig. 4). Tree diameter explained a moderate proportion ($r^2 = 0.5$) of the variance in stiffness with values ranging from 7.1 GPa at low dbh to 2.8 GPa for high values of dbh. Having corrected for the influence of dbh, stocking level still had a significant ($p<0.01$) positive influence on stiffness.

Discussion

Sawmillers often ask for longer rotations in our plantations, but they may have partly missed the point. It is accepted that older trees are likely to contain more outerwood, and that stiffness became a big issue in New Zealand only when sawmillers were faced with harvests of the second crop of *Pinus radiata*. The first crops from forests such as Kaingaroa had longer rotations, but they were also planted at much higher initial stockings than is typical in today's crops of *Pinus radiata*. The results presented here suggest that these higher initial stockings may have profoundly influenced stiffness of the corewood in these first crops.

Results also suggest that silviculture and breeding can be used as complementary approaches to improve stiffness. There was no significant interaction between stocking and clones, which indicates that gains obtained through planting high stiffness clones at high stockings are likely to be additive. As the clones used in this study had not been bred for improved wood quality, it would be interesting to determine gains that can be obtained through using high stiffness clones at high stockings.

The significant negative relationship found between rate of growth and stiffness in this study is consistent with research on other tree species including *Pseudotsuga mensiesii* (Walford 1985), *Pinus resinosa* (Deresse *et al.* 2003) and *Picea abies* (Kliger *et al.* 1995). One possible explanation for this relationship may be variation in latewood percentage between trees of high and low diameter. Previous research has shown that trees with a high diameter have a lower percentage of latewood and lower density than trees with a low diameter (Chuang & Wang 2001). Given that latewood fibres exhibit a higher stiffness than earlywood, the lower percentage of latewood in larger trees could account for the observed low stiffness within these trees.

Effects on stiffness beyond those attributable to radial growth rate may have been due to reduced tree sway in denser stands. General theory suggests that higher stockings reduce canopy windspeed and deflection of the tree stem (Raupach 1992; Green *et al.* 1995). Reduced stem deflection has been found to induce an increase in stiffness in a range of different tree species (Telewski & Jaffe 1986; Pruyn *et al.* 2000).

This study highlights the importance of stocking in regulating tree stiffness and shows the real improvements in corewood stiffness that can be gained through increasing initial stockings. Managers have already suggested that radically different, possibly more profitable, regimes with short rotations could arise from these findings. However, in order to ensure that managers can secure these benefits, several important questions remain:

1 To what extent was tree sway a factor in these findings? If sway was important, then increases in stiffness accruing from planting more trees may differ between exposed and sheltered sites. Study of tree sway within the experiments will help to answer this question.
2 Has initial stocking affected stiffness throughout the corewood region of these trees? Standing tree stiffness was measured through acoustics only in the outer few rings (Gorman *et al.* 2003). It is important to check on the stiffness of all the corewood rings in these experiments, and this will involve destructive sampling.
3 Has initial stocking affected other properties of corewood, such as density, latewood percentage and density components tracheid length and microfibril angle?
4 Can careful management of non-crop vegetation be used in conjunction with initial tree stocking to improve corewood stiffness?

Conclusions

- Stiffness of corewood increased significantly with increasing initial stocking.
- Stiffness was significantly different between all the three levels of stocking studied.
- Genotype had a significant effect on corewood stiffness, but its influence was lower than that of initial stocking.
- Growth rate as measured as dbh significantly affected stiffness.
- An analysis to segregate the effects of dbh and stocking showed that initial stocking influenced stiffness through its influence on dbh and also by at least one other mechanism.

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