

THE POTENTIAL FOR IMPROVING THE STIFFNESS OF YOUNG SOUTH AFRICAN GROWN *PINUS RADIATA* LUMBER BY USING HIGH PLANTING DENSITIES

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Abstract

Faster growth and reduced harvesting ages is causing a reduction in the stiffness of lumber from South African grown pine plantations. The objective of this study was to determine whether higher planting densities of Pinus radiata from the Southern Cape, South Africa, could be used as a management intervention to increase the stiffness of its sawn lumber. A secondary objective was to determine the effect of planting density on other relevant properties including warp, knots, density, and modulus of rupture (MOR). Lumber properties of 61 Pinus radiata trees from four different spacing treatments from a 20-year-old spacing trial were recorded. Results indicated that initial planting density had a highly significant effect on the MOE_(edge) of sawn lumber. There was a large increase in MOE_(edge) of lumber from 403 spha to 1097 spha. However, MOE_(edge) did not increase significantly with planting densities higher than 1097 spha. Initial planting density also had significant effects on the number and size of knots and the MOR of lumber. These results did not follow the same trends as previously found on New Zealand-grown Pinus radiata.

Keywords: *planting density; pinus radiata; MOE; MOR; knot properties.*

INTRODUCTION

Although planted forests only constitute 7% of the global forest area, it provides an estimated 66% of the global roundwood production – a figure which could in future increase to about 80% (Carle and Holmgren 2008). In South Africa plantation forestry started more than a century ago and despite having virtually no productive indigenous forests available, South Africa is largely self-sufficient today in terms of forest products and, additionally, export forest products to the value of about US\$ 1.7 billion annually (Godsmark 2014). Since there is only limited land available in South Africa suitable for plantation forestry, there has been an emphasis in the last few decades on increasing volume production through better silvicultural practices and genetic improvement. The faster growth resulted in trees reaching merchantable size earlier and allowed forest growers to harvest trees at a younger age. The mean harvesting age in South Africa for pine trees allocated to sawlog production fell from roughly 28 years in 1994 to 23 years in 2004 (Crickmay and Associates 2004).

A big challenge for the South African forest products industry is the increased proportions of juvenile wood, with poor mechanical properties, at the final harvest from these younger tree resources. The stiffness or modulus of elasticity (MOE) of lumber is a property severely affected by lower rotation age and several studies confirmed the reduction in the MOE of lumber from young tree resources (Wessels et al. 2011, Dowse and Wessels 2013, Wessels et al. 2014). This problem is not isolated to South Africa but also has global significance with Cown (2006) stating that "researchers around the world have confirmed that aggressive silvicultural regimes have caused a significant reduction in mechanical properties" of plantation grown pines.

There are a number of possible solutions to the problem of the lower stiffness of plantation grown lumber including the increase of rotation ages as well as genetic improvement. One possible option is the increase of the planting density of trees. Studies have been conducted on standing trees where it has been shown that higher planting density increases the dynamic MOE on the outerwood of standing *Pinus*

radiata trees (Lasserre et al. 2005; Waghorn et al. 2007). Studies on *Pinus taeda* (loblolly pine) clearwood showed no significant differences in mean static MOE between two planting densities (Biblis and Meldahl 2006) and no significant differences between whole-tree MOE at seven different planting densities (Clark et al. 2008). In contrast, Roth et al. (2007) studying young *Pinus taeda*, found that planting density had a strong positive relationship with the dynamic MOE of outerwood of standing trees. A few studies were conducted where full-sized timber boards were tested to determine the impact of planting density on MOE (McAlister et al. 1997, Zhang et al. 2002, Ishiguri et al. 2005, Wang et al. 2005). Results were not consistent, as some results indicated no significant differences in stiffness or were inconclusive (McAlister et al. 1997, Ishiguri 2005) whereas others indicated significant differences (Zhang et al. 2002). Past research studies thus seems to give inconsistent results. The reasons for the inconsistency are not clear, but species, growth site, age and testing methods probably played a role.

In this study the focus was on young plantation grown *Pinus radiata* from the Southern Cape area in South Africa – the predominant species grown in that area. Studies in New Zealand investigated the effect of planting density on the dynamic MOE of the outerwood of standing *Pinus radiata* trees (Lasserre et al. 2005; Waghorn et al. 2007) – results in these studies indicated a strong positive influence by planting density on dynamic MOE of the outerwood. Ages of trees in the two studies were 11 and 17 years, suggesting that the effect on MOE was present to at least 17 years. No studies have been done measuring the effect of planting density on the MOE of sawn lumber of *Pinus radiata*. The question is firstly whether similar results will be obtained for South African-grown *Pinus radiata* than what was seen for New Zealand-grown *Pinus radiata*. Secondly, we want to establish the effect of planting density on the static MOE of lumber which is the actual property of interest in the end-product (as opposed to dynamic MOE of the outerwood of tree stems).

OBJECTIVES

The primary objective of this study was to determine the effect of planting density of *Pinus radiata* from the Southern Cape, South Africa, on the stiffness of its sawn lumber. A secondary objective was to determine the effect on other relevant properties including warp, knots, density, and modulus of rupture (MOR).

METHODS, MATERIALS AND EQUIPMENT

The study was conducted on an experimental spacing trial at Kruisfontein, Knysna in the Southern Cape region of South Africa. The trial was 20 years old at the time of sampling and planted on a well-drained, sloping site. Mean annual precipitation in this area is 716mm and occur throughout the year. The area has a mild climate with temperatures varying between a mean minimum of 7 degrees Celsius during the night in winter and a mean maximum of 28 degrees Celsius during the day in summer.

The spacing trial consisted of six spacing treatments but only the following were used for this study: 403 stems per hectare (spha), 1097 spha, 1808 spha and 2981 spha. Each treatment was planted in a 6x5 block with one shield row around each block. There were 5 replications of each treatment block. Between 14 and 16 trees of each treatment were selected for destructive testing. Data for the sampled treatments and trees can be seen in Table 1.

Table 1

Data for the sample treatments and trees

Planting density (spha)	Density at 20 years (spha)	Sample size (n)	Mean DBH (cm)	Mean height (m)
403	316	15	40.55	22.71
1097	878	14	33.90	25.39
1808	1266	16	35.75	24.73
2981	1821	16	31.49	23.58

According to the forestry company owning the trial, it was accidentally thinned at age 12 years. However, despite the thinning and natural mortality the differences in densities of the four treatments were still fairly large at 20 years of age when this sampling was conducted (Table 1). Trees with the most surviving neighbours were selected for destructive testing in order to get sample material with a competitive environment similar to the original planting density.

North direction was marked on the stem, trees were felled, and a single 3m-long log was removed from the base of the stem. The TreeSonic Micro Second Timer from FAKOPP industries was used to conduct time-of-flight measurements on each log and calculate the dynamic MOE for the outerwood of each log ($MOE_{(Fak)}$).

Logs were sawn at a local sawmill using a cant sawing pattern (Fig. 1) into lumber of cross-sectional wet dimension 40x120mm. The cant was aligned to the north-south axis of the tree stem. Boards were numbered from 0 for pith containing boards to 1 for the board next to the pith and 2 for the next one. Lumber were dried using a medium temperature schedule to a target moisture content of 12%. Boards were reconstructed in their original position in the log and the year rings were counted from the pith (0) to the outerwood. For each board the minimum, maximum, and mean year ring number was recorded – this will be referred to as the "cambial age" of a year ring. The moisture content, density, bow and twist was measured according to SANS 10173-1 (2004). The total number of knots per board as well as the knot area ratio (KAR) for the largest knot was recorded. Finally, the boards were destructively tested in a edgewise third point bending test according to SANS 6122 (2008) and the static modulus of elasticity on edge ($MOE_{(edge)}$) and MOR was calculated.

The effect of initial planting density and board position were analysed in terms of the year ring width, bow, twist, KAR, knots per board, density, MOR and MOE. For the board analysis, mixed model repeated measures ANOVA were used where the trees were defined as the random effect.

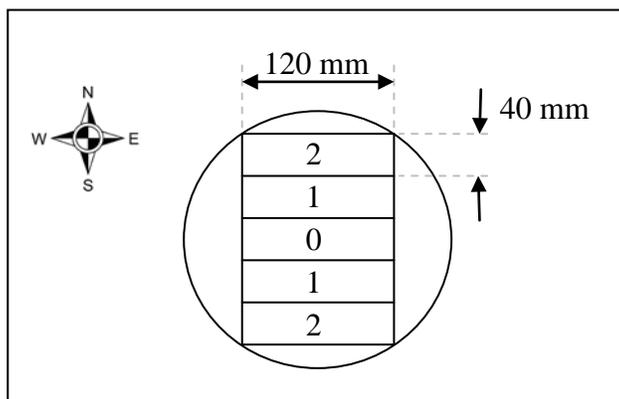


Fig. 1.
The cant sawing pattern used to obtain sawn lumber

RESULTS AND DISCUSSIONS

The spacing treatment had a highly significant effect on the dynamic $MOE_{(Fak)}$ ($p < 0.0001$) that was measured on the *P. radiata* logs (Fig. 2). However, the variation in values within treatments was high and after an initial upward trend from 403 spha to 1097 spha the mean $MOE_{(Fak)}$ per treatment stayed fairly even up to 2981 spha. It must be noted that this measurement will reflect the value for wood formed in the last few growth years – which in normal sawmilling operations are often chipped and do not form part of lumber end-products. When comparing the results with the dynamic MOE of New Zealand grown *Pinus radiata*, also measured on the outerwood, the trend looks quite different (Laserre et al. 2005; Waghorn et al. 2007) with the New Zealand grown wood showing an increasing trend up to 2500 spha.

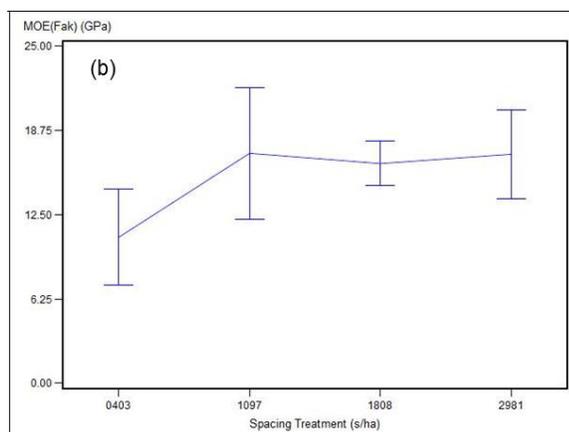


Fig. 2.

The means and 95% confidence interval of MOE_(Fak) measured on logs

The mean values of board properties for different spacing treatments as well as different board positions, can be seen in Table 2. The significance level of an effect is also indicated in Table 2. For example, one can see that spacing treatment did not have a significant effect on twist (n.s.) whereas board position had a significant effect on twist (p=0.0001). In none of the properties measured was there a significant interaction between the two main effects.

Spacing treatment had a highly significant effect (p=0.0001) on ring width which was expected since denser planting results in slower diameter growth of trees. It also had a highly significant effect on the knot area ratio. This was also expected since wider spacing results in larger branches and larger knots. Spacing treatment also had a significant effect on the number of knots per board (p=0.01). The property of most interest, MOE_(edge) was significantly influenced (p=0.0001) by spacing treatment as well as bending strength or MOR (p=0.05). Bow, twist and density were not significantly influenced by spacing treatment. It was interesting to note that the mean values of the properties that was significantly influenced by spacing treatment behaved similar. There was a relatively large difference between the 403 spha treatment mean values and the 1097 spha treatment mean values. However, the differences between 1097, 1808, and 2981 spha mean values were small and often inconsistent – which held true for ring width, KAR, knots per board, MOE_(edge) as well as MOR.

As expected, the radial board position had a significant or highly significant effect on all the properties listed in Table 2. Take note that the mean cambial age for board position 1 was 7.71 and for board position 2 it was 11.71. This suggests that if the unplanned thinning at age 12 years had any effect on wood properties it would probably not influence boards 0 and 1 and only partially influence board 2.

Table 2

Lumber property means for different spacing treatments and board positions

Spacing Treatment (spha)	n	Cambial Age (years)	Ring width (mm)	Bow (mm/m)	Twist (°)	KAR (%)	Knots/Board	Density (kg/m ³)	MOE _(edge) (MPa)	MOR (MPa)
p			0.0001	n.s.	n.s.	0.0001	0.01	n.s.	0.0001	0.05
403	81	7.29	11.54	1.63	1.41	0.55	7.33	540.0	6549	31.6
1097	60	8.18	8.97	1.45	1.53	0.44	6.42	529.6	7861	35.7
1808	71	8.53	7.96	1.41	1.20	0.41	6.73	544.7	7901	35.6
2981	59	8.36	7.20	1.58	1.60	0.42	6.86	546.7	8024	35.4
Board Position										
p			0.0001	0.01	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
0	66	3.92	12.18	1.79	2.42	0.56	9.00	505.0	5915	26.47
1	120	7.71	8.84	1.58	1.30	0.49	7.45	540.0	7433	32.47
2	85	11.72	7.05	1.25	0.83	0.35	4.38	568.5	8873	43.25

In Fig. 3 the $MOE_{(edge)}$ means and 95% confidence intervals for different radial board positions and spacing treatments are shown. As mentioned previously, $MOE_{(edge)}$ is becoming a problem in South Africa for fast growing plantation species which sometimes does not meet the minimum requirements for structural lumber. The lowest structural grade in South Africa (S5) has a requirement of a mean $MOE_{(edge)}$ of 7800MPa and the next grade (S7) a mean $MOE_{(edge)}$ of 9600MPa (SANS 10163-1, 2003). For the 403 spha treatment both the pith board and board 1 had means below 7800MPa. For the next spacing treatment, 1097 spha, the 1st board already had a mean $MOE_{(edge)}$ higher than 7800MPa. It is clear that treatment had a relatively large effect from 403 spha to 1097 spha. In fact, there was a similar difference in $MOE_{(edge)}$ of 403 and 1097 spha than the difference between board positions 0 and 1. The differences in mean $MOE_{(edge)}$ between the 1097 spha, 1808 spha and 2981 spha treatments were not significant and their means for similar board positions were almost the same. These results do not correspond to the mean dynamic MOE trends that Waghorn et al (2007) reported on 17-year old New Zealand grown *Pinus radiata* (although there were differences in measurement methodologies used). In the New Zealand study tree mean MOE on outerwood increased significantly up to 2500 spha. The reasons for the differences are unclear but an investigation by Watt et al. (2006) on *Pinus radiata* found that site had a highly significant influence on MOE. The different growth conditions in South Africa to that in New Zealand might be part of the reason for the difference in the effect of planting densities on MOE between the studies.

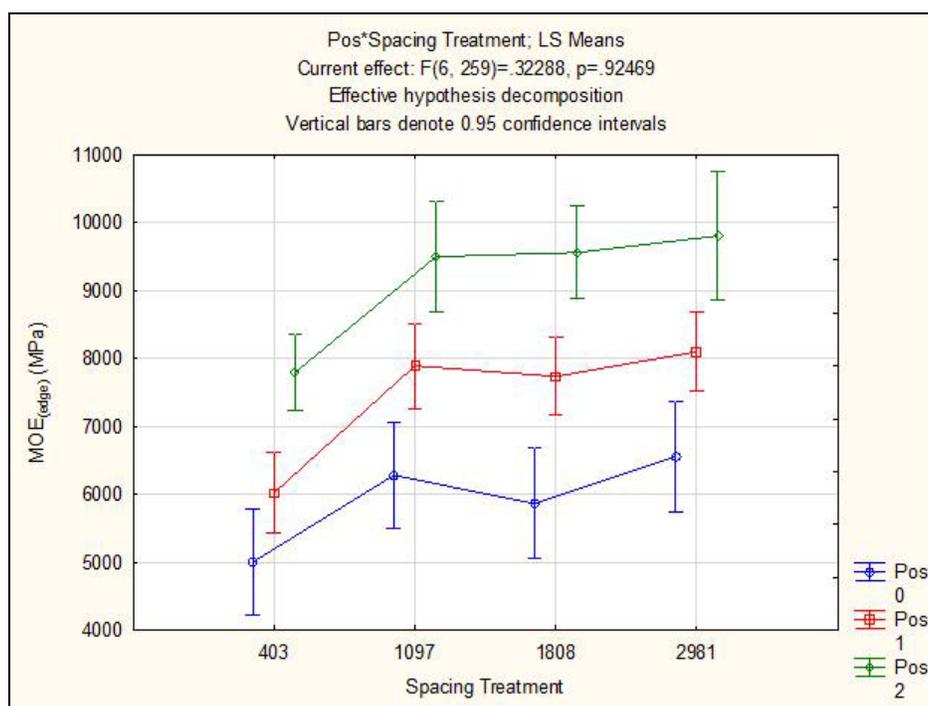


Fig. 3.
The means and 95% confidence intervals of $MOE_{(edge)}$ for boards at different radial positions and spacing treatments

In South Africa *Pinus radiata* is normally planted at a density of about 1111 spha and thinned, depending on site quality, at about 10 years of age. The results from this study suggests that higher initial planting density than the current norm would not result in significantly better $MOE_{(edge)}$ lumber properties. However, results also indicated that lower planting densities would lead to significantly poorer $MOE_{(edge)}$ values for lumber at similar radial board positions. Knot properties and MOR would also be negatively affected by planting densities lower than the current norm.

CONCLUSIONS

Based on the results from this study the following conclusions can be made:

- Initial planting density had a highly significant effect on the MOE_(edge) of sawn lumber of *Pinus radiata* from the Southern Cape region in South Africa. There was a large increase in MOE_(edge) of lumber from 403 spha to 1097 spha. However, MOE_(edge) did not increase significantly with planting densities higher than 1097 spha.
- Initial planting density also had significant effects on the number and size of knots in lumber and the MOR.

Further work should focus on the effect that site, together with planting density, and its interaction have on the MOE of *Pinus radiata*.

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