WOOD PROPERTIES OF 26-YEAR-OLD *PINUS RADIATA* FROM THE TIKITERE SPACING TRIAL

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Report No. 74 **November 2000**

FOREST & FARM PLANTATION MANAGEMENT COOPERATIVE

EXECUTIVE SUMMARY

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The "Predicting Forest Growth and Quality" project's broad scope is to develop knowledge and functions for the prediction of forest growth and quality, as affected by site, silviculture, and genetics. Under the PGSF funded component, stem and wood quality assessments in stands from the matrix of available forest trials defined by silviculture, age, site fertility and genetic quality will provide baseline data on the changing radiata pine resource.

In the first year of the new project structure, 35-year-old trees from a range of silvicultural regimes in the Tarawera spacing and thinning trial were assessed for wood properties in conjunction with the trial's clearfell operation (McKinley *et al*, 2000b). In the second year of existence of the new project structure, 26-year-old trees established at Tikitere (ex-farm site) in a spacing trial were to be clearfelled. This provided the opportunity to coordinate a multi-faceted study, including the documentation of wood properties from a ***Forest Research*** forest trial at the other end of the matrix of trials in terms of silviculture, age, site fertility and genetic quality.

Over recent years there has been much discussion and debate over wood quality of radiata pine grown on fertile farm sites. It is widely known the quality of logs and subsequent products produced from stands grown on fertile agricultural sites differs from those predicted for existing forest locations. The quality of these stands, particularly those established at wider spacings, will reduce the range of utilisation options available.

Earlier utilisation studies of radiata pine grown on fertile farm sites have shown lower than expected grade recoveries of F5 and better structural timber when compared to similar logs harvested from more traditional forest sites (R. Ball, unpublished). This is after adjusting for log diameter and branch index (BIX), and in the case of stress grading, wood density. When comparisons are made between actual grade recoveries and predictions from forest site data regressions, the disparity is also obvious. As branching morphology and 3-dimensional log models were prepared for these studies, it may be possible to investigate and explain the observed appearance grade recovery using sawing simulation.

Several earlier wood property studies have highlighted that wood properties of fast-grown trees on fertile sites may also be different from those expected from "traditional" forest sites. In particular, moisture content was found to be higher, along with higher levels of compression wood and spiral grain, and lower wood density when compared with "traditional" forest site trees of a similar age.
The clearfell operation of half the trial at Tikitere has provided the opportunity to coordinate:

1) a study which aims to investigate, quantify and explain any differences in branch morphology, and wood and timber properties of second log sawn timber when compared to corresponding material from forest grown stems, and
2) a further study attempting to identify site and treatment-related effects on wood properties for a range of stockings.

This report will concentrate on documenting a range of wood properties from the 100 spha, 200 spha and 400 spha plots. Separate reports will cover recovery of actual sawn timber grades with those generated by simulation, and the development of improved log descriptors for use in predicting timber grade recovery (Todoroki *et al,* 2000). A further study compares timber from a range of sites throughout New Zealand (Gaunt *et al,* 2000)

MATERIALS AND METHODS

The Tikitere trial was established in 1973 to determine the effects on agriculture and forestry of a two-tier land-use system. The main variable is the number of final crop trees on each hectare (nominally 50, 100, 200, and 400 spha).

Three main conclusions from the trial so far, affecting wood quality are:

1. The higher the tree stocking, the greater the volume of wood per hectare (Knowles *et al,* 1999).
2. Branch and stem size increase with lower tree stockings and higher site fertility (Knowles *et al,* 1999, McKinley *et al,* 1993).
3. Outerwood density tends to decrease with decreased stocking (McConchie *et al,* 1990) however whole tree density shows a slight increase (McKinley *et al,* 1993; Knowles *et al,* 1999). This can be explained by the higher proportion of juvenile wood (inner 10 growth rings) to outerwood in the higher stockings.

The stand history for Tikitere is presented in Table 1. It was established in 1973 using the "850" seed orchard seedlings with four replicates of each tree stocking. Each treatment consists of 2 ha with four plots in each replicate, and 28m buffers between treatments.

Table 1 - Stand details

Tikitere	
PSP *	RO382
Planting date	1973
Seed source	"850"
Initial stocking (spha)	250/500/1000/2000
Stocking (spha)	50/100/200/400
Pruned height (m)	6

* FRI Permanent Sample Plot.

Tree selection

For each of the 100 spha, 200 spha and 400 spha treatments, 24 well formed trees from within a number of PSP plots located throughout the trial were selected for the measurement of stem dimensions and individual branches, for the separate branching morphology study. Where possible these trees were also chosen for the wood quality study however due to intervention with the logging operation not all of the original 24 stems were available so substitute trees taken from the respective PSP plots have been included. Diameter at breast height over bark (DBHOB) and tree height values were measured in 1999 for the PSP data set. In the final tally 26, 27 and 27 trees from the 100 spha, 200 spha and 400 spha treatments respectively were selected.

An additional 30 trees were selected from the 400 spha treatment to provide second logs for the sawing study. The sampling strategy for these logs sought to cover the available range in DBHOB and branch size and were not selected as being representative of what was available.

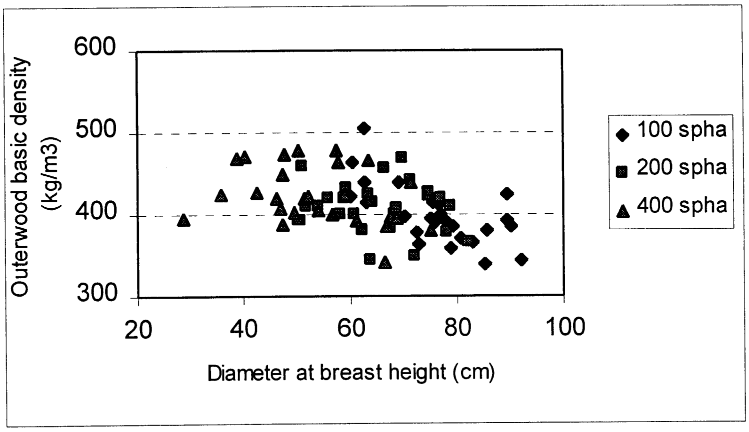
Tree characteristics

Prior to tree felling, two 5mm breast height outerwood increment cores were collected from each tree. In the laboratory the outer 50mm section was cut from the cores and assessed for basic density using the maximum moisture content procedure (Smith, 1954). Table 2 provides the plot details, DBHOB, tree height and outerwood basic density for each tree in the respective stockings. DBHOB averaged 76.5 cm (range 60.1 to 92.3), 65.1 cm (range 50.3 to 82.4) and 53.8 cm (range 28.8 to 75.2) for the 100 spha, 200 spha and 400 spha treatments respectively, showing a steady decrease in diameter with stocking increase.

Tree height showed an increase with increasing stocking level where mean values of 33.4 m, 36.6 m and 40.4 m were recorded for the 100 spha, 200 spha and 400 spha treatments respectively, consistent with results reported by Maclaren and Knowles (1999). Average outerwood density also showed an increase with stocking with values of 398 kg/m^3, 408 kg/m^3 and 423 kg/m^3 in ascending order of stocking, which repeats the general trend for earlier studies (McConchie *et al*, 1990 and McKinley *et al*, 1993).

Weak but significant relationships were evident between outerwood density and DBHOB (Figure 1).The equation derived from all stockings combined was $y = -0.0241x^2 + 1.8819x + 393.63$; $r^2 = 0.23$). Of the three stockings the 100 spha treatment showed the strongest negative relationship ($r^2 = 0.43$).

Figure 1 – Outerwood basic density versus breast height diameter (o.b.)



The 80 trees from the 100 spha, 200 spha and 400 spha treatments measured for outerwood density and DBHOB were tested for significant differences between treatments. Results are given in Table 3 where significant differences were indicated between trees from the 100 spha and 400 spha treatments for density and for all treatments for DBHOB.

Table 2 – Plot details, DBHOB, tree height and outerwood basic density

Study tree no.	Plot details		DBH OB (cm)	Tree ht. (m)	Basic density (kg/m³)
	Plot no.	Tag no.			
100 spha					
61	7/2	16	81	33.5	370
62	7/2	14	78.9	32	359
63	7/2	8	76.6	34.8	413
64	7/4	12	79.5	32.9	386
65	7/4	1	80.9	38	371
66	7/4	13	63.2	33.2	414
67	7/3	3	60.1	30.9	422
68	7/3	4	63	30	440
69	7/3	24	85.2	38.3	339
70	7/1	12	72.7	33.5	379
71	7/1	25	77.2	32.1	400
72	7/1	18	75.8	32.9	390
73	7/1	19	75.2	29.6	396
76	3/4	4	90.4	37.1	387
77	3/4	11	83.2	35.5	367
78	3/4	15	62.9	34.3	505
79	3/4	24	72.8	32.2	363
80	3/4	25	75.4	33.3	415
81	3/3	20	60.6	35.3	465
82	3/3	18	85.6	34.1	380
83	3/3	17	69.3	33.9	438
86	3/3	12	89.5	36.7	392
87	3/1	22	70.4	30.3	397
88	3/1	21	77.7	32.8	394
89	3/1	24	92.3	30.4	344
91	3/1	12	89.5	31.5	425
Mean			**76.5**	**33.4**	**398**
Min			60.1	29.6	339
Max			92.3	38.3	505
SD			9.4	2.4	37

Study tree no.	Plot details		DBH OB (cm)	Tree ht. (m)	Basic density (kg/m³)
	Plot no.	Tag no.			
200 spha					
31	6/2	3	71.3	37.3	441
32	6/2	5	70.1		468
33	6/2	19	59	37	420
34	6/4	7	51.2	32.5	459
35	6/4	14	66.4	37.2	457
36	6/1	18	74.8	34.9	422
37	6/1	12	74.9	33.5	426
38	6/1	21	63.4	33	424
39	6/1	23	50.9	34.8	392
40	9/4	19	54	39.9	409
41	9/4	23	64.5	39.2	414
42	9/4	24	50.3	39.2	392
43	9/4	5	59.5	39.7	431
44	9/3	23	82.4	41.8	367
45	9/3	16	56	36.6	419
46	9/3	14	64	39.2	344
47	9/3	8	61.1	39.3	400
56	2/2	17	78.3	35.8	379
57	2/2	9	68.6	34.1	400
58	2/2	12	72.1	30.8	348
59	2/2	14	62.6	37	382
60	2/4	21	77.2	41.6	420
60.1	2/4	4	52	40.3	410
60.2	2/4	19	58.2	42.1	400
206	6/1	11	69	33.3	408
207	6/1	2	79.1	28.9	410
210	6/1	20	67.6	33	383
Mean			**65.1**	**36.6**	**408**
Min			50.3	28.9	344
Max			82.4	42.1	468
SD			9.4	3.5	30

Study tree no.	Plot details		DBH OB (cm)	Tree ht. (m)	Basic density (kg/m³)
	Plot no.	Tag no.			
400 spha					
1	8/1	20	47.6	37.6	388
2	8/1	4	47.2	33.6	407
3	8/1	13	63.7	38.5	466
4	8/1	15	75.2	40.2	381
5	8/2	14	61.2	40.2	392
6	8/2	7	57.9	38.9	463
7	8/2	2	35.6	36.4	424
8	8/2	18	42.5	37.3	428
12	8/3	16	67.8	41.2	397
13	8/3	18	57.4	37	479
14	8/3	20	38.8	36.7	468
16	8/4	2	54.3	41.1	405
17	8/4	12	49.8	39.2	402
18	8/4	13	40.4	39.6	471
19	8/4	14	50.6	40.6	478
21	8/4	21	47.5	40.7	449
22	14/2	22	51.5	44.5	419
23	14/2	13	68.8	47	394
24	14/2	14	56.9	42.9	400
25	14/2	3	66.7	41.9	342
26	14/2	17	66.8	44.5	386
27	14/2	21	28.8	31	396
29	14/3	9	59	43.9	426
30	14/3	19	71.3	46.1	438
30.1	14/3	12	46.2	41.6	419
401	14/3	4	52.3	46.1	422
402	14/3	1	47.7	43.7	474
Mean			**53.8**	**40.4**	**423**
Min			28.8	31	342
Max			75.2	47	479
SD			11.6	3.8	36

Table 3 – Significant errors of difference between treatments for outerwood basic density and DBHOB

Treatment comparison	Sign. error of diff. Density (kg/m^3)	DBHOB (cm)
100 spha vs 200 spha	9.5(ns)	2.8
100 spha vs 400 spha	9.6	2.8
200 spha vs 400 spha	9.5(ns)	2.8

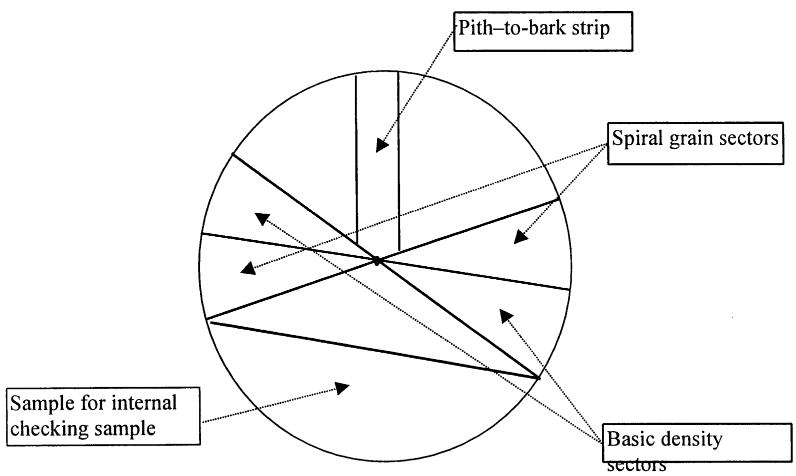
(ns) indicates not-significant (there is no evidence that those 2 treatments have significant differences)

For each treatment, 50 mm thick discs were cut on all trees at the small and large ends of the second log (ie. equating to approximately 5 m and 10 m tree height). On a subset of 5 trees (minimum), selected to represent the range in diameter at breast height, 50 mm thick discs were cut at regular intervals up the stem from the butt (regarded as 0 m tree height) and the small end of each log taken, roughly equating to 5 m lengths.

After tree felling by a commercial logging gang, a ***Forest Research*** field team measured stem dimensions and individual branches as the stem lay *in situ*.. Following these measurements the tree stems were hauled to a skid site and processed into logs by the logging gang. ***Forest Research*** staff were present for the cross-cutting of study trees and supervised disc-cutting, and labeled samples.

Bark thickness, heartwood and juvenile wood dimensions and compression wood were measured on all discs prior to sectioning into samples for basic density, spiral grain and internal checking assessments (Figure 2). Also prior to sectioning, the incidence of any defects within the clearwood zone were recorded, namely blemishes, resin pockets and resinous patches with both incidence and the year of formation noted. Area weighted values (incidence /m^2 of log cross-sectional area) have been calculated to allow for meaningful comparisons between the three treatments.

Figure 2 – Disc breakdown



A representative radial pith-to-bark strip was also cut from all discs and stored for further wood properties if deemed appropriate eg. microfibril angle. The two discs cut from both ends of the second log of the 30, 400 spha trees selected for the sawing study were processed in a similar fashion. These results will largely be presented in a separate report however some results will be incorporated in this report to increase the sample size for the 400 spha treatment.

Basic density was measured on ten-ring groups from the pith to enable the density of juvenile wood (inner 10 growth rings) and outerwood (rings 11+) to be calculated separately. Spiral grain was measured on two diametrically opposed radii where measurements were taken at rings 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 using the method described by Young *et al* (1991). Compression wood was visually assessed as the percentage of each quartile of the disc that was affected, plus an overall percentage for the whole disc.

The recently adopted internal checking assessment procedure (McConchie, 1999) involved marking the heartwood boundary on the part disc sample prior to oven drying at 103° C. Oven dried samples were then cut in half in the thickness plane and sanded to allow for maximum detection of internal checks. Counting back from the outer ring, checking incidence by year was recorded as was any evidence of shelling. The last year of the heartwood zone was also noted for the checked discs as studies to date have indicated it is unlikely for checking to occur within the heartwood region of the tree unless present in the green stem.

For the sawing study sample (30 second logs from the 400 spha treatment) the incidence of internal checking will be compared using both the disc method described above and by assessment of the respective sawn lumber. Results will be documented in a separate report.

STATISTICAL ANALYSES

A mixed linear model is developed for each wood property using linear effects of fixed variables such as disc height, ring from the pith, height above the ground, final crop stocking and their interactions. The covariance effects of those fixed effects in estimating different wood properties such as density, bark thickness and compression wood were explored. Mixed model analysis is the same as ordinary least square equation except that it allows both random and fixed effects in the model. Effects are random if they come from a distribution with some variance while fixed effects have no variance and theoretically can be repeated exactly. Regression models were developed for each wood property using linear effects of disc height, log level from the ground, treatment and their interactions. Least Square Means (LSM), or the population marginal mean, computes the expected mean of each classification with all the covariates in the regression. For example juvenile, outer and overall disc densities were classified by treatment and disc height as the fixed effects, and the trees within plots of each treatment are distributed randomly.

The significance of effects in the model were tested using the F-test. All tests were performed at the 5% level. A P-value from the F-test less than 0.05 indicates that effect is significant at 5% level while a P-value of 0.0001 indicates a highly significant effect at the 1% level. Least Square Difference (LSD) is the minimum difference between two averages which are statistically significant at the 95% level.

RESULTS AND DISCUSSION

For many of the properties described below the data for individual disc, log and tree values are included in the series of Appendices at the end of this report. In general, discussion of results will relate to mean values only.

Disc Properties

DIB, bark depth, heartwood, juvenile wood, compression wood, basic density and ring count

Table 4 details the average and standard deviation values at each stem level for the 100 spha, 200 spha and 400 spha treatments. These values are derived from the individual measurements presented in Appendices I and II. When interpreting these results the number of samples must be taken into account as a minimum of five trees selected across the diameter range provided a complete set of discs up the stem. The bulk of the discs were sampled at approximately 5 m and 10 m heights to provide second log wood properties information on a minimum of 25 trees.

Heartwood and juvenile wood (inner 10 rings) are calculated as the proportion of cross-sectional area of the entire disc excluding bark. Compression wood also represents the percentage of the cross-section containing this type of wood. Compression wood was visually assessed and therefore subjective, with no attempt made to describe severity, however Appendix I provides an approximate distribution of this reaction wood by assessments of individual disc quartiles.

Figures 3 to 7 reproduce the information from Table 4 for DIB, bark thickness, heartwood and juvenile wood respectively, by treatment. Figure 3 shows the expected decrease in DIB with increasing height in the stem for the three stocking levels. A diameter difference in the magnitude of 100 mm is maintained between the treatments up to 10 m tree height with the 100 spha trees producing the largest diameters and the 400 spha trees the smallest. Above 10 m the rate of decrease in DIB was shown to vary for the three stockings with the greatest reduction occurring in the 100 spha trees and the least in the 400 spha trees. These results agree with the analysis of stocking on height growth and therefore taper (Maclaren and Knowles, 1999).

Figure 3 - Variation in DIB by treatment

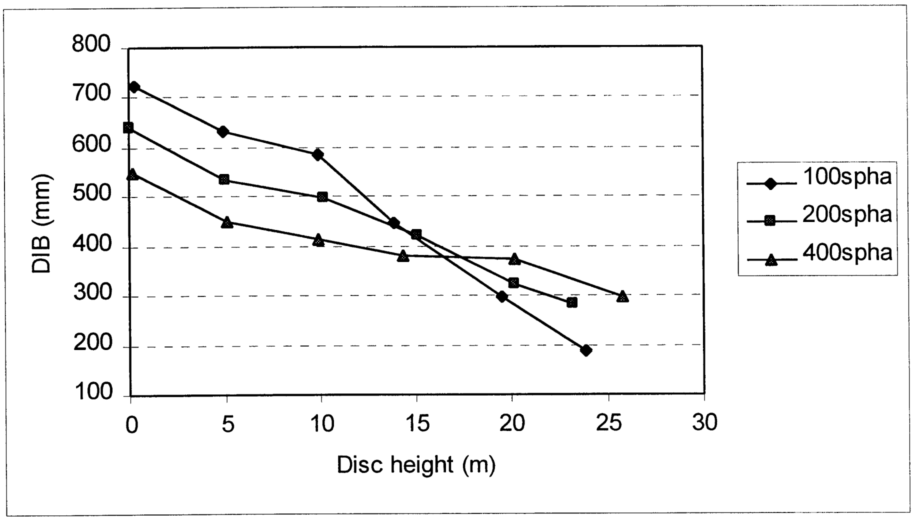


Table 4 – Disc dimensions and selected wood properties by stocking
– averages and standard deviations

Disc ht. (m)	No. of samples	DIB (mm)	Bark thick. (mm)	Heart wood (%)	Juv.* wood (%)	Comp. wood (%)	Basic density (kg/m³)			Ring count
							Juv.*	Outer	Disc	
100 spha										
0	5	725	39	13	27	6	386	380	379	24
		102	6	2	6	2	24	34	33	1
5	26	633	21	18	37	12	359	381	374	22
		77	5	6	6	7	24	31	28	1
10	24	586	14	14	42	11	368	382	375	18
		70	4	7	8	6	28	28	25	1
14	7	445	11	11	54	10	370	387	377	15
		41	4	5	8	4	25	21	24	1
20	6	295	7	5	90	7	356	392	359	10
		52	1	3	16	3	12	19	14	2
24	4	187	5	3	100	13	344		344	8
		38	2	4	0	9	13		13	1
200 spha										
0	5	638	28	22	30	7	363	360	360	25
		112	5	8	6	8	34	17	13	0
5	27	535	16	25	43	8	352	391	373	22
		78	5	10	7	5	28	27	26	1
10	25	499	12	26	49	8	360	391	374	18
		78	4	11	7	4	28	30	27	1
15	8	421	9	20	61	11	340	373	354	16
		71	2	9	14	7	23	28	24	2
20	5	322	6	15	83	10	347	356	351	12
		75	2	8	11	4	30	41	28	2
23	3	281	6	11	96	7	347		347	10
		27	1	1	8	3	23		23	1
400 spha										
0	7	548	26	24	38	5	362	400	383	25
		163	12	14	9	3	38	47	42	1
5	28	450	12	33	53	8	346	409	373	22
		93	4	9	8	5	22	37	26	1
10	23	415	9	31	58	6	346	409	371	20
		99	3	8	9	3	21	39	23	1
14	12	382	8	28	61	9	353	395	368	17
		109	2	9	13	5	26	49	32	2
20	6	375	8	20	62	7	353	383	363	15
		95	2	8	8	4	26	43	29	1
26	5	298	5	11	80	6	335	350	338	11
		102	1	9	19	5	10	13	9	2

* Inner 10 growth rings
NB. Averages in larger text; standard deviations in smaller text

The disc diameters also indicate taper where levels were similar in the lower segment (0 m to 5 m) averaging 18.4 mm/m, 20.6 mm/m and 19.6 mm/m for the 100 spha, 200 spha and 400 spha treatments respectively. At the higher levels in the stem (approximately 15 m to 20 m) the differences were more dramatic at 25 mm/m, 19.8 mm/m and 1.2 mm/m for the 100 spha , 200 spha and 400 spha treatments respectively. The F-test of LSM for DIB below 15m shows a significant difference between treatments at the 1% test level however above 15m in disc height the differences between treatments were not significant.

For bark thickness (Figure 4), the general trend for all treatments was observed where the largest reduction occurred in the lower 5 m of the stem. For the majority of disc heights the 100 spha trees were producing thicker bark with levels decreasing as stocking increased. Statistical analysis though did not confirm this and indicated no significant evidence of either a stocking or tree size effect. However the variation in bark thickness was shown to be strongly influenced by relative height in the tree (p-value of <0.0001).

Figure 4 - Variation in bark thickness by treatment

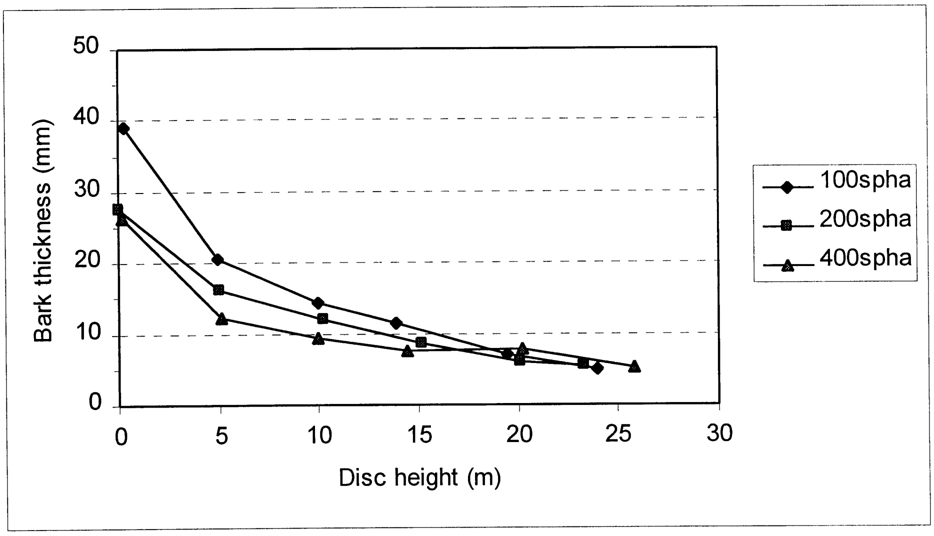
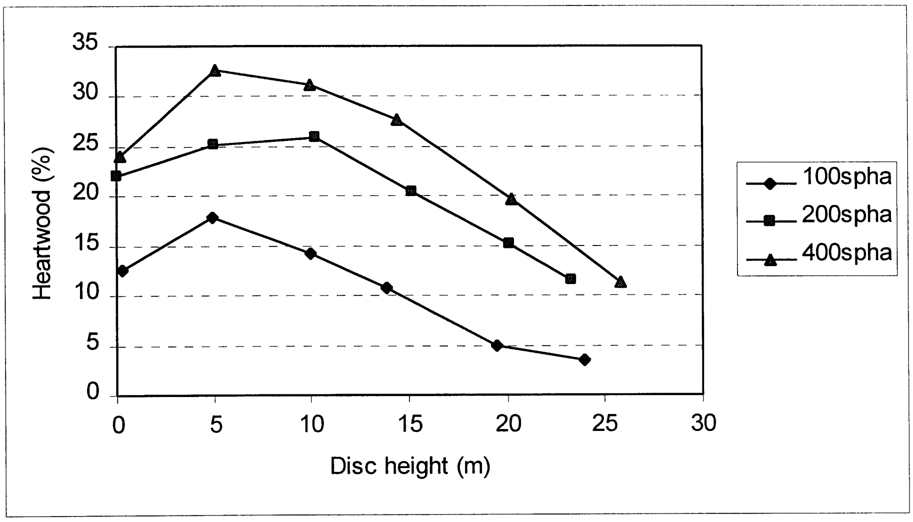


Figure 5 shows the normal patterns of variation in heartwood for the three treatments, with the highest levels at 5 m to 10 m stem height ie. the second log. Distinct heartwood levels were apparent for the three treatments with the less suppressed trees in the lower stockings producing low heartwood percents. The F-test on the interaction of disc height and treatment showed a significant relationship between these two fixed effects.

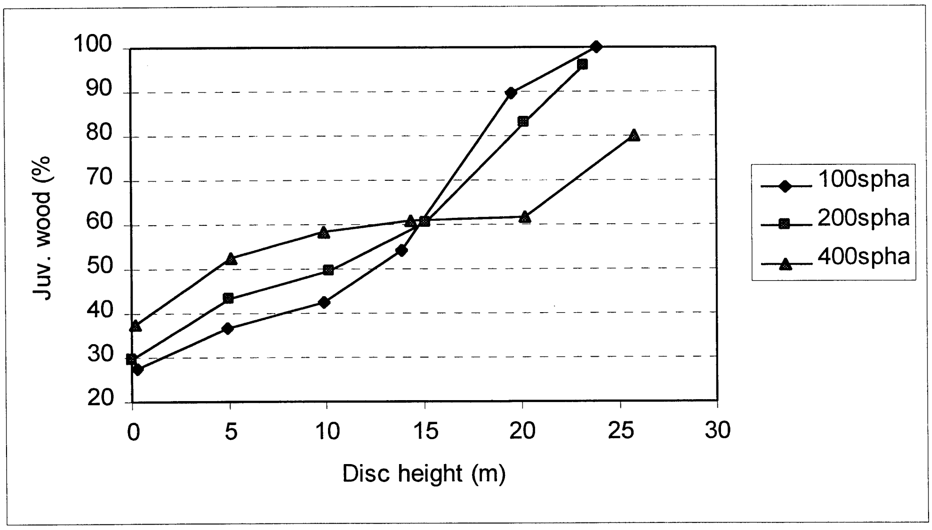
Figure 5 - Variation in heartwood by treatment



Heartwood values in the current study show a twofold increase on those recorded for an earlier study on the trial at age 19 years (McKinley *et al*, 1993) also investigating the 100 spha, 200 spha and 400 spha treatments. The order of magnitude was the same albeit at a lower level, with the lower stocked treatments producing less heartwood.

For juvenile wood percent (Figure 6), the general trend of increasing proportions of juvenile wood with increasing height in the stem, typical for radiata pine, was evident for all three treatments. The gradients for 100 spha and 200 spha treatments were generally steeper when compared to the gradient for the higher stocked 400 spha treatment. At the lower stem levels (0 m to 15 m) the reduced portions of juvenile wood for the 100 spha and 200 spha treatments can generally be attributed to a higher proportion of outerwood, due to their faster and less uninhibited growth rate. At the higher stem levels the larger proportions of juvenile wood for the 100 spha and 200 spha treatments are generally the result of the open growing conditions under which these trees have developed. The larger diameter, shorter trees would reach a given height, for example 20m, with a much reduced ring count compared to the smaller diameter, taller trees, which have grown under more competitive conditions.

Figure 6 - Variation in juvenile wood by treatment



Juvenile wood is defined as that zone within the tree, near the pith where wood typically has wide growth rings, low percentage of latewood, low density, short tracheids, and high spiral grain angles, longitudinal shrinkage, compression wood and microfibril angles. In radiata pine it is normally described as that zone within 10 rings of the pith (Cown, 1992a) and it is this definition illustrated in Figure 5. An alternative measure of juvenile wood, based on wood density (Cown, 1992b), will be discussed later in this report.

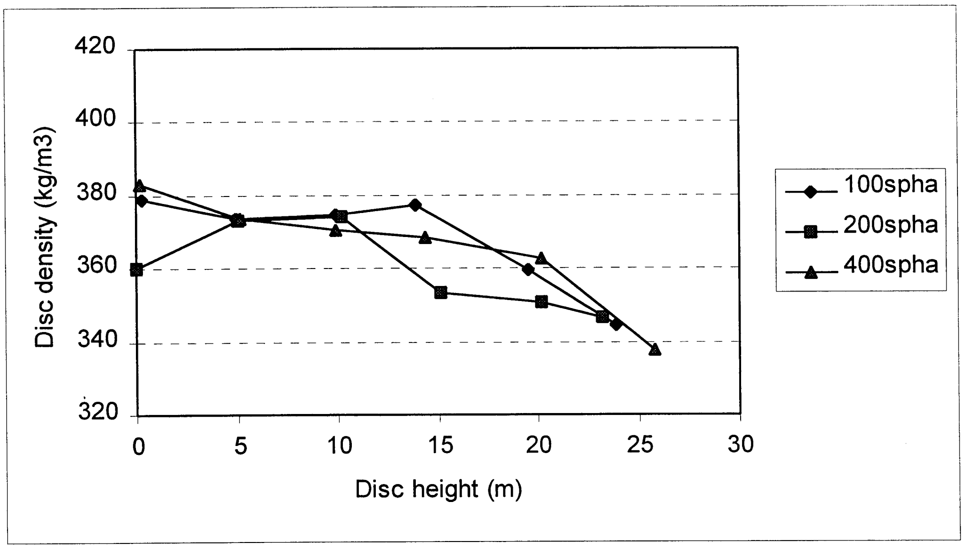
From Table 4 it can be seen that compression wood levels were variable with no clear patterns between treatments or with height in the stem. General indications are that the higher stocked 400 spha treatment may have a slightly lower incidence of compression wood.

Table 3 also presents average juvenile wood, outerwood and disc density by position in the tree for all three treatments (full results in Appendix II). The densities recorded are un-extracted values (ie. they include the effect of resin), so the higher value recorded for juvenile wood density in the butt disc (386 kg/m^3, 363 kg/m^3 and 362 kg/m^3 for the 100 spha, 200 spha and 400 spha plots respectively) reflects the higher incidence of resin normally found in this region of the tree. The effect of resin in juvenile wood diminishes rapidly with increasing height in the stem. Some discs were particularly resinous and the more severe cases have been noted in Appendices I to III.

Overall, the lower density of the juvenile wood is clearly demonstrated. The expected decrease in disc density with increasing height in the stem is also shown for all treatments. The range between juvenile wood density and outerwood density was similar for the 100 spha and 200 spha stocking trees (ranging from approximately 355 kg/m^3 to approximately 380 kg/m^3). For the tighter stocked 400 spha treatment the range was increased slightly (approximately 350 kg/m^3 to approximately 400 kg/m^3) with higher outerwood densities being primarily responsible.

Figure 7 presents the average disc density data by stem position for each treatment. For the 5m and 10 m heights where larger sample sizes were taken the differences between treatments were negligible. The variation shown for the remaining heights could be due to the following factors; sample size, resin (particularly for the butt discs) and compression wood. In practical terms, the three treatments could largely be described as having similar density patterns with height. Statistical analysis confirms this by identifying no detectable differences in disc density between treatments at different disc heights (p-value > 0.05).

Figure 7 - Variation in disc density by treatment



Cown (1992b) proposed an alternative definition for the juvenile wood zone that is particularly relevant when mechanical properties are being considered. This technical definition is density-based (juvenile wood = wood<400 kg/m^3) rather than ring-based (juvenile wood = first 10 rings from the pith). Using the technical definition it is all juvenile wood with the exception the small proportion found in the butt and second logs of the 400 spha treatment. The results documented here indicate that for this site with the genetics and silviculture applied, the wood produced will not meet the requirements for some processing options where mechanical properties are important.

Log and Tree Properties

In Table 5, the disc values from Table 4 for the 100 spha, 200 spha and 400 spha treatments have been used to calculate results for individual log height classes and for whole trees. Values for second logs and individual trees are presented in Appendix III. Smalian's formula was used for calculation of volume. Based on the minimum five tree sample, sawlog volume for the 100 spha, 200 spha, and 400 spha treatments averaged 4.8 m^3, 4.2 m^3 and 3.4 m^3 respectively, with the butt logs containing about a third of the volume for each treatment. An earlier study at this trial at age 19 years yielded averages of 3.2 m^3 , 2.6 m^3 and 2.1 m^3 for the 100 spha, 200 spha and 400 spha which indicates good volume growth over the seven year period at this ex-farm site. An earlier study (Young *et. al.*, 1992) on 26-year-old trees grown on a forest site under a typical forest regime to a final crop stocking of 350 spha averaged 3.2 m^3 which is slightly less than the 400 spha treatment in the current study.

Tree values for bark thickness show a decline with stocking increase where values of 20 mm, 15 mm and 13 mm were recorded for the 100 spha, 200 spha and 400 spha treatments respectively. For second logs the same pattern emerged with bark thickness averaging 18 mm, 14 mm and 10mm for the respective treatments. Differences for bark thickness for all treatments in the butt log are generally significant at the 5% level.

Approximately 10 % of the sawlog volume was heartwood for the lower stocked 100 spha treatment with values closer to 25 % recorded for the 200 spha and 400 spha plot trees. The second logs indicate a similar pattern however the 400 spha logs had the highest heartwood contents. Values were 16 %, 25 % and 30 % in ascending order of stocking.

The variation in heartwood percent is dependent on the growth rate of the inner heartwood rings in relation to the remainder of the growth rings. For the 100 spha treatment the growth rate of the rings outside the heartwood zone would have been somewhat higher in comparison to the 200 spha and 400 spha treatments. Current heartwood values are well up on those recorded for 19-year-old trees at this site by McKinley et al (1993); 6 %, 10 % and 11 % for the 100 spha, 200 spha and 400 treatments respectively. The earlier study by Young *et al* (1992) on the similar aged "forest regime" trees yielded an average whole tree heartwood value of 16 %. The statistical test also confirms that the heartwood variation in the 100 spha treatment is significantly different for most logs (except the 5th log) compared to 200 and 400spha treatments.

Juvenile wood averaged 41 %, 51 % and 55 % of tree volume for the 100 spha, 200 spha, and 400 spha treatments respectively, with similar results for the second logs. Percentage of juvenile wood in the 100 spha treatment was shown to be significantly different from that in the 400 spha treatment at all log levels. The variation between treatments indicates the effect of contrasting growth rates for the inner ten growth rings compared with those laid down subsequently. At this site at age 19 years, the respective treatments were yielding approximately 15 % more juvenile wood at 58 %, 65 % and 70 % of tree volume (McKinley *et. al.*, 1993). West (1997) predicts using the stand modelling system STANDPAK for 26 year-old trees grown on a typical "direct sawlog" regime, an overall proportion of 54 % juvenile wood, comparable with that recorded for the 200 spha and 400 spha treatments.

Table 5 – Log and tree values by stocking
- averages and standard deviations

Log height class	No. of samples	Volume (m^3)	Bark thickness (mm)	Heart wood (%)	Juv. * wood (%)	Comp wood (%)	Ring count	Basic density (kg/m^3)
100 spha								
Butt	5	1.636	31	13	29	8	23	371
		0.729	6	2	4	4	0	28
2nd	26	1.517	18	16	39	11	20	375
		0.413	4	6	6	6	1	26
3rd	5	1.045	13	9	47	10	16	367
		0.421	4	3	10	2	1	14
4th	5	0.497	9	7	70	10	12	362
		0.139	2	3	8	3	1	13
5th	3	0.281	7	5	93	7	10	356
		0.108	1	3	13	2	1	17
Tree	5	4.764	20	11	41	9	19	367
		1.174	4	2	5	3	1	17
200 spha								
Butt	5	1.308	23	25	37	8	23	350
		0.549	7	8	5	5	1	8
2nd	27	1.136	14	25	46	8	20	373
		0.368	4	10	6	3	1	25
3rd	5	0.953	10	27	55	9	17	345
		0.523	4	9	11	1	1	18
4th	5	0.470	8	20	67	12	14	347
		0.155	2	8	11	4	1	23
5th	4	0.305	6	12	84	12	11	357
		0.105	1	2	5	7	1	17
Tree	5	4.193	15	26	51	9	19	346
		1.576	5	9	6	3	1	12

400 spha								
Butt	7	1.151	20	28	44	6	24	374
		0.645	8	12	9	2	1	38
2nd	58#	0.796	10	30	54	7	20	373
		0.311	3	8	8	3	1	22
3rd	10	0.689	9	29	60	8	18	369
		0.409	3	7	9	4	2	29
4th	5	0.496	8	23	66	8	16	355
		0.313	3	9	17	4	3	33
5th	3	0.411	8	18	64	4	14	358
		0.239	1	9	10	1	1	39
6th	2	0.358	6	13	73	6	12	338
		0.158	0	11	14	5	1	5
Tree	7	3.383	13	26	55	7	20	367
		2.084	4	7	10	2	2	34

NB. Averages in larger text; standard deviations in smaller text

* Inner 10 growth rings
# Includes 31 logs from sawing study

Whole tree weighted values for compression wood showed no discernible difference between the three stockings with averages of 9 %, 9 % and 7 % for the 100 spha, 200 spha and 400 spha treatments respectively (p-value = 0.2357). For the second log weighted values, compression wood averaged 11 %, 8 % and 7 % for the respective treatments. At this level, compression wood in trees from the 100spha treatment were significantly different from those from the 200 spha and 400 spha treatments (p-values of 0.0043 and 0.001 respectively). However, differences between trees from the 200 spha and 400 spha treatments were not statistically significant (p-value of 0.62).

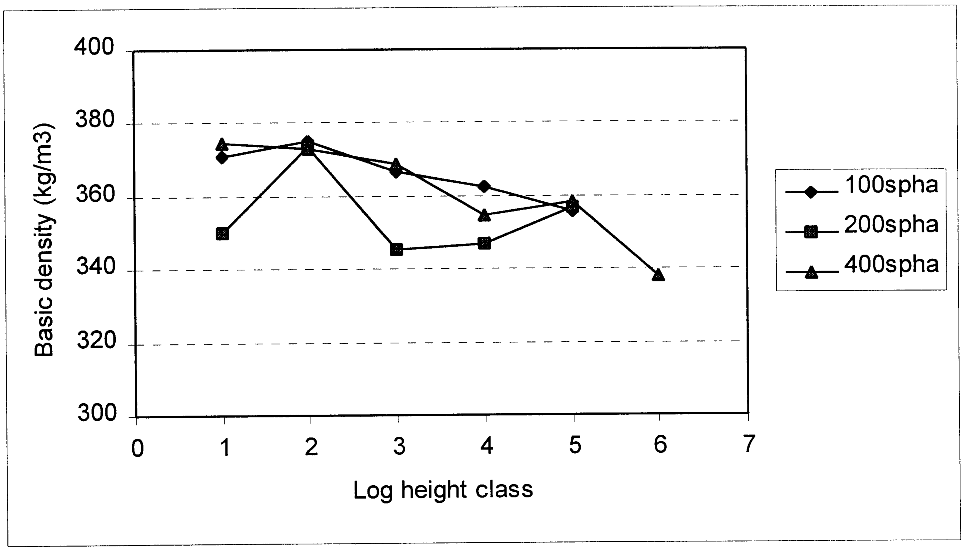
These average values show an approximate threefold increase on those recorded for three stockings at the 35-year-old Tarawera spacing trial. Previous research has shown high proportions of compression wood in fast-grown stems (Cown 1992a and McKinley *et al*, 1997).

Note: Although these trees were nominally straight, this site has been damaged by three cyclones since establishment (1976, 1982 and 1988). Damage resulted in increased levels of butt sweep, some of which has been minimised by high growth rates. The increased incidence of compression wood is however still contained within the stems.

Average whole tree basic density results were 367 kg/m^3, 346 kg/m^3 and 367 kg/m^3 for the 100 spha, 200 spha, and 400 spha treatments respectively, with F-test results indicating an insignificant difference between treatments (p-value = 0.3016). These values are in generally in line with expectations for this trial however the five trees from the 200 spha treatment are lower than anticipated. Corresponding outerwood densities for these trees averaged 380 kg/m^3, 374 kg/m^3 and 405 kg/m^3 for the 100 spha , 200 spha and 400 spha treatments respectively indicating the five 200 spha trees do not accurately represent this stocking in terms of basic density (see Table 2). Contributing factors include tree selection based on DBHOB and the small sample size.

Presented in Figure 8 is the variation in log density by log height class for each treatment. As expected the general pattern is for density to decrease with log height class with the exception of the 200 spha treatment where the pattern is less evident for the reasons discussed above. For all treatments however, the larger sample size taken representing the second log, show no difference in second log density with values of 375 kg/m^3, 373 kg/m^3, 373 kg/m^3 for the 100 spha, 200 spha and 400 spha treatments respectively.

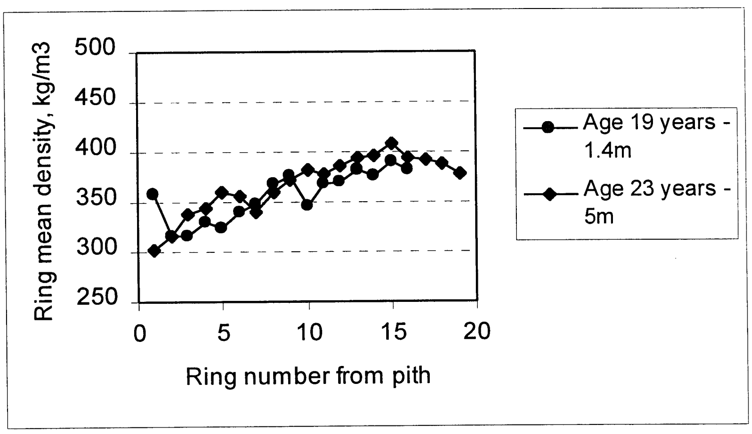
Figure 8 – Variation in log density by treatment



Average whole tree density for all treatments combined averaged 361 kg/m^3. Basic density has not changed dramatically over the last seven years with two wood quality studies at ages 19 years (McKinley *et al*, 1993) and 23-years (McKinley *et al*, 1997) yielding study averages of 370 kg/m^3 and 358 kg/m^3 for whole tree densities respectively. It must be noted that the study on the 23-year-old trial trees selected stems representing slow and fast growth from the 200 spha and 400 spha treatments only.

Figure 9 helps explain the constant basic density value over the intervening period with densitometric ring mean densities at ages 19 years (McKinley, 1992) and 23 years (McKinley *et al*, 1997). Despite the different sampling heights both gradients are similar and show basic density to be fairly homogenous after ring 10.

Figure 9 – Tikitere mean ring densities



From Cown *et al* (1991a) predictions were made of density of whole trees at various ages on three site/density classifications. This particular site is classified medium density and the report predicts that at 25 years of age, density should be around 410 kg/m^3, approximately 12 % higher than the current study average of 361 kg/m^3. The fertile site and genetics have both contributed to this low density result - past studies have indicated a 7 % reduction in density with the "850" seed source. As a comparison, a study on 26-year-old trees from Kaingaroa Cpt. 1013 (classified as a low density site) and grown under a typical "forest" regime yielded a study average of 384 kg/m^3 (Young *et al*, 1992). The difference documented between studies is influenced by the move from a medium density site to a low density site and therefore appears less than if both stands were established in the same density site class. Assuming Young's study was established with unimproved genetic material the difference documented would again reflect the influence of the "850" breed and high site fertility.

Earlier studies have highlighted that wood properties of fast-grown trees on fertile sites may be different from those expected from "traditional" forest sites with the current results adding further weight to this hypothesis in terms of wood density.

Relationships Between Outerwood Density at Breast Height and the Density of the Whole Tree and Log Components

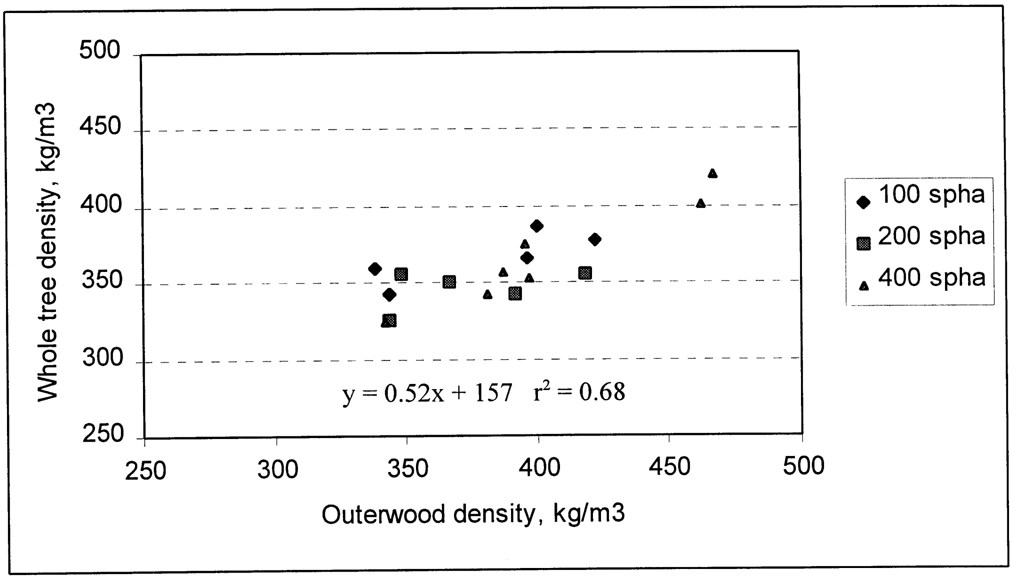
The relationship between breast height outerwood density and the density of the whole tree, and also the relationships between whole tree density and the density of the individual logs are given in Table 6 for the 100 spha, 200 spha and 400 spha treatments combined. Figure 10 depicts the relationship between breast height outerwood density and the density of the whole tree. These relationships were all found to be significant at the 99% level.

Table 6 - Relationships between breast height outerwood density, whole tree density and the density of individual logs

Log height class	No. of logs	Intercept	*x* *	Correlation	R-square	Residual st. dev.
Butt	17	-36.5	1.12	0.95	0.90	9.9
2nd	17	1.0	0.99	0.98	0.97	4.8
3rd	17	23.1	0.93	0.94	0.89	8.5
4th	15	51.1	0.85	0.88	0.78	11.6
Tree	**17**	**157**	**0.53**	**0.82**	**0.68**	**14.8**

* *x* = outerwood density

Figure 10 - Relationship between outerwood density to whole tree density



The raw data used to produce the above regressions have been included in this report as Appendix IV.

Spiral Grain

The most comprehensive spiral grain study to date on radiata pine was completed by Cown *et al* (1991b) investigating 25-year-old forest grown trees. The general pattern was for highest levels of spirality to occur near the pith and for an increase with height in the stem. An average spiral grain angle of 4.7° was reported for the juvenile wood zone (inner 10 growth rings). Cown *et al* also found that where angles exceeded 5°, there was significant drying degrade, strength loss and movement in service.

For the current study Appendix V details the spiral grain measurements by treatment, tree and sampling position with average values presented in Table 7 by treatment and combined. Figures 11a, 11b and 11c show the average trends by height for the 100 spha, 200 spha and 400 spha treatments respectively.

Table 7 - Mean pattern of spiral grain by treatment and disc height

Disc ht. (m)	No. of samples	Spiral grain (°) by ring number from the pith									
		2	4	6	8	10	12	14	16	18	20
100 spha											
0	5	3.8	3.9	1.5	0.7	1.0	0.6	1.2	0.9	1.4	2.3
5	26	5.2	5.9	6.5	6.5	5.2	4.8	4.0	3.5	3.0	2.9
10	24	5.4	7.9	7.8	6.9	6.3	5.3	4.7	3.8	3.6	
14	7	4.8	6.2	6.4	5.5	4.8	4.5	4.1			
20	6	3.5	4.4	5.6	4.3	4.6					
24	4	3.8	4.2	1.7							

200 spha											
0	5	3.2	1.6	1.1	0.9	2.3	2.6	2.5	2.3	3.7	2.1
5	27	5.1	6.1	6.3	5.6	4.5	4.2	3.1	2.8	2.6	2.4
10	26	5.3	7.5	8.5	8.3	7.1	6.4	5.3	4.2	3.2	2.8
16	7	5.9	7.9	7.5	6.8	7.4	6.7	7.2			
20	5	5.7	6.9	7.9	8.5	6.7	6.3				
23	3	5.4	6.8	6.6	6.3						
400 spha											
0	7	5.0	4.3	3.4	1.8	2.2	1.6	1.3	2.5	2.4	2.3
5	28	6.2	7.3	6.6	6.0	4.7	3.4	2.7	2.3	2.3	2.0
10	23	6.6	8.2	7.8	5.7	4.8	3.8	3.4	2.7	2.1	1.3
14	12	7.5	7.4	7.6	7.4	5.6	4.8	4.1	2.5	1.7	
21	6	6.1	6.7	7.5	7.1	7.1	5.5	4.2			
27	5	7.1	8.3	8.1	8.5	9.6	8.4				
Combined											
0	17	4.1	3.4	2.2	1.2	1.9	1.6	1.6	2.0	2.5	2.2
5	81	5.5	6.5	6.5	6.0	4.8	4.1	3.2	2.8	2.6	2.4
10	72	5.7	7.8	7.9	7.0	6.1	5.2	4.5	3.6	3.0	1.6
15	27	6.4	7.4	7.5	6.8	6.0	5.3	4.8	2.8	1.6	0.3
20	17	5.1	5.9	6.9	6.5	6.3	5.5	4.6	2.6		
25	10	5.3	6.3	5.4	6.5	7.3	9.1	5.0			

Figure 11a - Spiral grain variation by sampling height – 100 spha

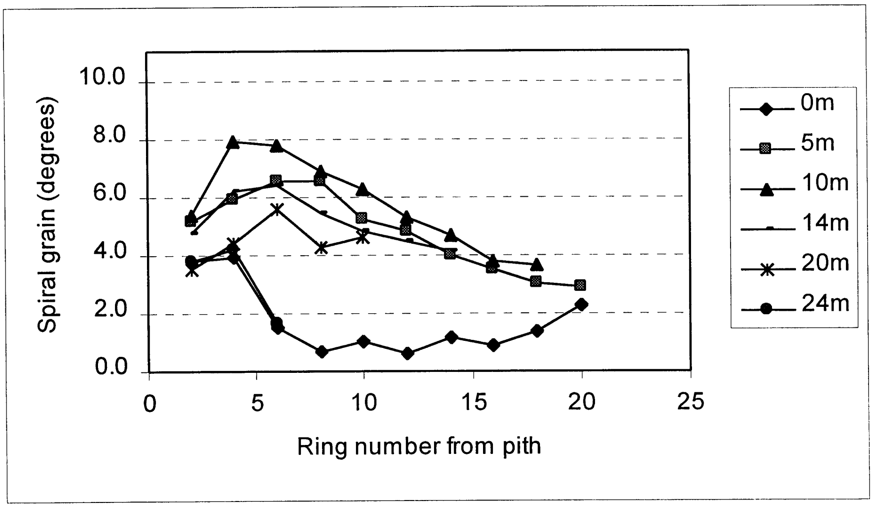


Figure 11b - Spiral grain variation by sampling height – 200 spha

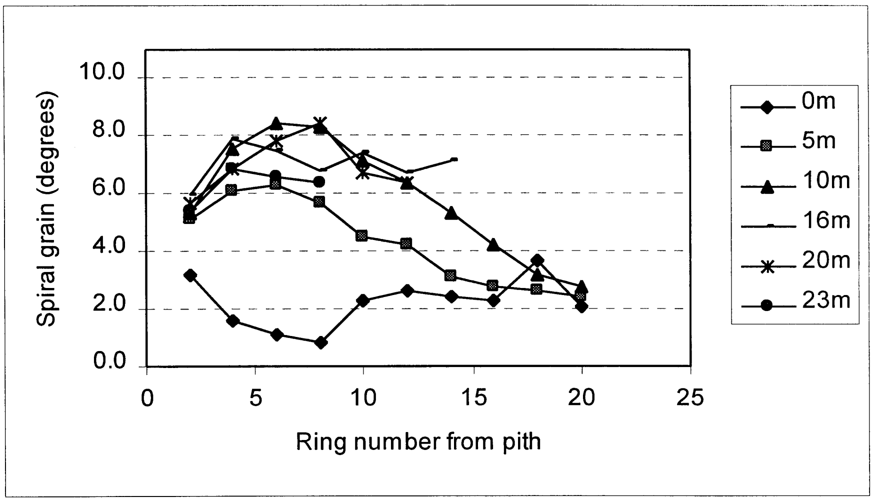
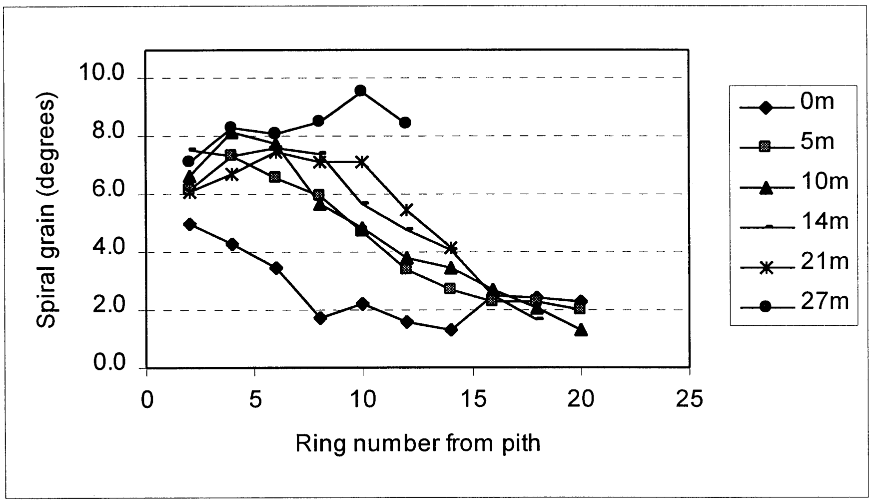


Figure 11c - Spiral grain variation by sampling height – 400 spha

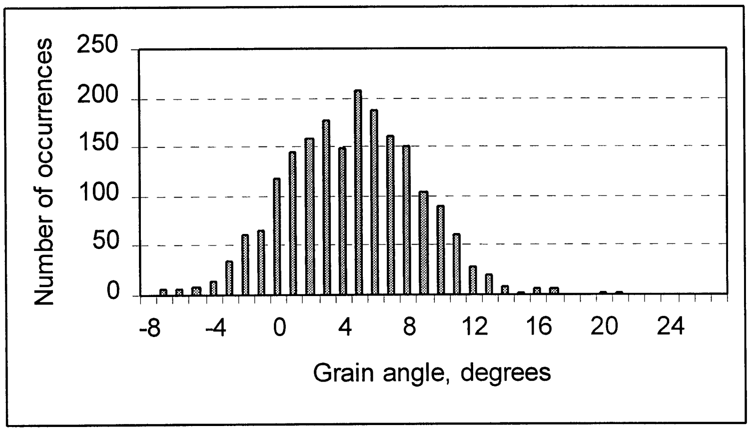


F-test analysis on the interaction of disc height and ring from pith shows that there is a significant influence of these two fixed effects in spiral grain values (p-value = 0.0014) while the interaction of disc height, ring from pith and treatment is found to be not significant (p-value = 0.6586).

In practical terms, the spiral grain trends were similar between treatments and were consistent with the general pattern described by Cown *et al* (1991b) where the greatest spirality occurred near the pith and showed an increase with height in the stem. However, angles recorded in the current study are generally higher and show a slower rate of decline from pith to bark which can be expected to increase the proportion of wood likely to cause problems on drying. The two earlier Tikitere studies at age 19 years (McKinley *et al*, 1993) and 23-years (McKinley *et al*, 1997) also produced similar results and highlighted this outcome for these agroforestry grown trees.

All the observations in each of the three treatments conform very well to the normal distribution with means of 4.4°, 4.5° and 4.1°, and standard deviations of 3.8°, 4.7° and 4.0° for the 100 spha, 200 spha and 400 spha treatments respectively. Figure 12 presents the grain angle frequency distribution for all treatments combined with a mean angle of 4.3° and standard deviation of 4.2°. The average angle of the inner 10 growth rings (traditional juvenile wood zone) at 6.0° is considerably higher than the 4.7° recorded by Cown *et al* (1991b).

Figure 12 – Grain angle frequency distribution – all treatments combined



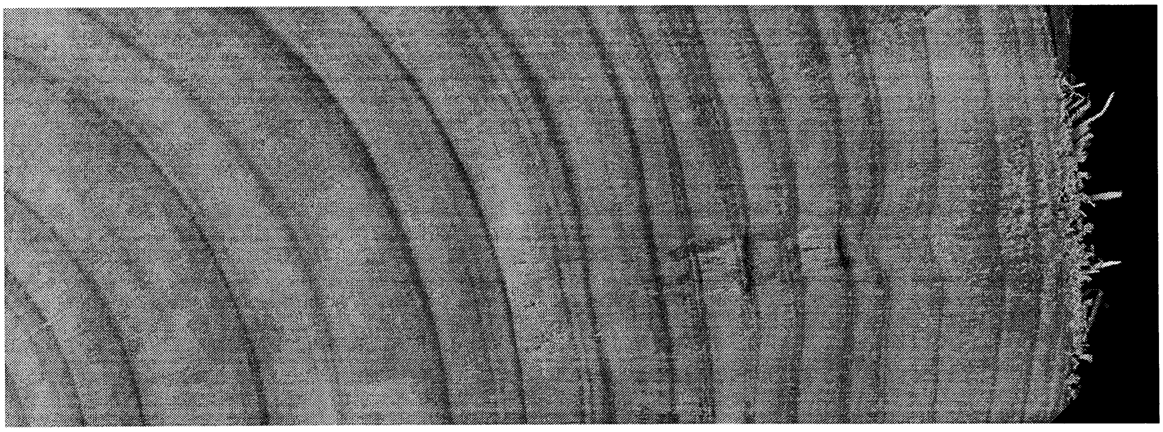
If a technical definition based on spirality was used to define juvenile wood (eg. 5 °), then it could be assumed that the juvenile wood zone would extend to approximately the 15th ring from the pith for all treatments. The small proportion of wood laid down outside this region is unlikely to cause major problems with regard to drying degrade providing the timber has been correctly dried. Recent results from a 35-year-old spacing trial in the Tarawera valley (McKinley *et al*, 2000b) which included a 1350 spha control, and two treatments consisting of 750 spha and 380 spha indicated only the inner five rings would be likely to cause problems.

Clearwood characteristics

The incidence of clearwood characteristics, namely blemishes (Appendix VI), resin pockets and resinous patches (Appendix VII) were recorded for each disc. Considerable variation was shown to exist between trees for all characteristics. It should be noted that blemishes were for the most part categorised as any clearwood characteristic other than resin pockets although small Type 3 resin pockets (as described by Somerville, 1980) with minimal associated resin could possibly have been included. Figure 13 shows examples of typical blemishes in the clearwood zone on a cross-sectional disc. Resinous patches were generally small localised regions with no discontinuity in the wood and extending across several years growth (rings). For each defect the growth year was also noted. A summary of incidence by defect class is provided in Table 8 by disc height for all treatments however due to the uneven distribution of samples per disc height only the totals per treatment will be discussed. The total values were used to calculate on a cross-sectional m^2 basis (using disc area), the number of characteristics by type and combined for all treatments and are presented in Table 9. A sample of random width boards is available to assess characteristics in the clearwood at a later date.

This study highlights the presence of resinous characteristics (referred to as blemishes and resinous patches) in addition to resin pockets. This finding suggests that further work is required to target this issue an establish protocols for future studies.

Figure 13 – Example of cross-sectional disc containing blemishes in the clearwood zone



Blemishes

For an individual disc, a maximum number of 28 blemishes were recorded for Tree 83 from the 100 spha treatment. The total incidence of blemishes (Table 8) appeared to follow a trend of decreasing with an increase in stocking ie. 214, 82 and 31 being recorded for the 100 spha , 200 spha and 400 spha treatments respectively. When values were calculated on a m^2 area basis as presented in Table 9 removing the diameter effect, the same trend continues with 12, 6 and 3 blemishes recorded for the 100 spha , 200 spha and 400 spha treatments respectively. An ANOVA test on the covariance effect of treatment returns a significant p-value of 0.0113. The value indicates there is a difference on average number of blemishes between treatments with the highest incidence at the lower stockings.

Presented in Figure 14 is the breakdown of blemish incidence by year formed for the three treatments. The figure clearly shows the greater number of blemishes recorded for the 100 spha treatment. It also shows the years 1987, 1988 and 1989 to be particularly bad for the clearwood of the 100 spha treatment trees. For the 200 spha and 400 spha treatments the lower number of blemishes recorded and their distribution make it more difficult to identify the worst years. It is assumed that blemish incidence is not related to climatic factors as no common years were found to be equally adverse in terms of resin pocket incidence for all treatments.

A covariance test shows that the interaction of treatment and year is not significant in the presence of blemish incidence. The result implies that year is not an important factor as far as blemish incidence is concerned as suggested above and confirms the importance of treatment as the random source of variation.

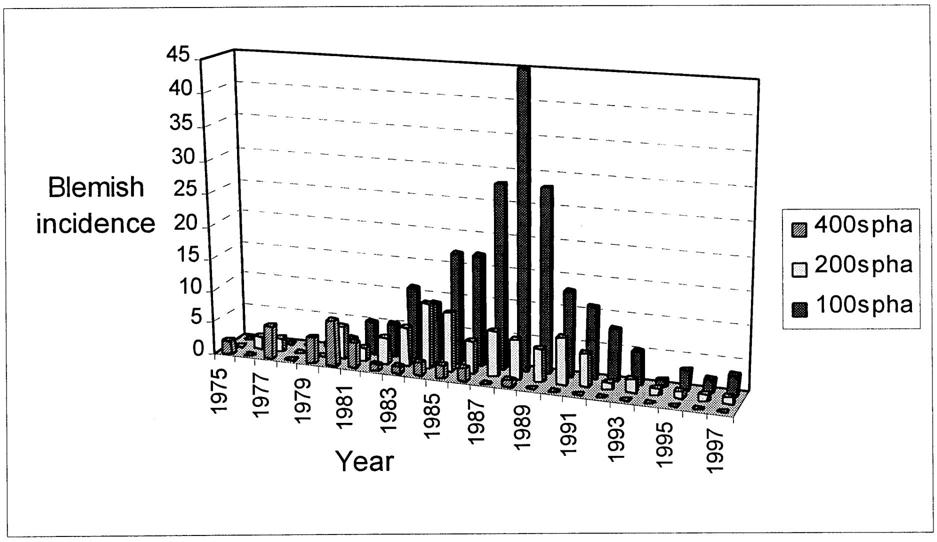
Table 8 – Clearwood characteristic incidence by sampling height and treatment

Disc ht. (m)	No. of samples	Blemishes Sum	Resin pockets Type 1 Sum	Resin pockets Type 2 Sum	Resinous patches Sum
100 spha					
0	5	7	10	0	31
5	26	105	17	3	20
10	24	80	17	6	56
14	7	14	5	1	9
19	6	7	2	2	1
24	4	1	1	0	0
All	**72**	**214**	**52**	**12**	**117**
200 spha					
0	5	8	0	0	0
5	27	31	5	2	18
10	25	22	5	4	18
15	8	14	2	0	0
20	5	5	0	0	0
23	3	2	0	0	0
All	**73**	**82**	**12**	**6**	**36**
400 spha					
0	7	1	1	0	15
5	28	19	3	0	11
10	23	9	2	1	0
14	12	1	6	1	3
20	6	1	1	1	4
26	5	0	0	1	0
All	**81**	**31**	**13**	**4**	**33**

Table 9 – Clearwood characteristics per m^2 by treatment

Stocking	Blemishes	Resin pockets		Resinous patches	Total Defects
		Type 1	Type 2		
spha	m^2				
100	12	3	1	6	22
200	6	1	0	2	9
400	3	1	0	3	7

Figure 14 – Blemish incidence by year and treatment



Resin pockets

The Type 1 variety was the most common resin pocket recorded in this study. As for blemishes, the discs from the 100 spha treatment were shown to contain the greatest numbers of Type1 and Type 2 resin pockets with a total of 64. Three trees from this treatment recorded the maximum number of resin pockets per disc at six (Trees 70, 71 and 91). Differences between the 200 spha and 400 spha treatments were less clear with totals of 18 and 17 respectively.

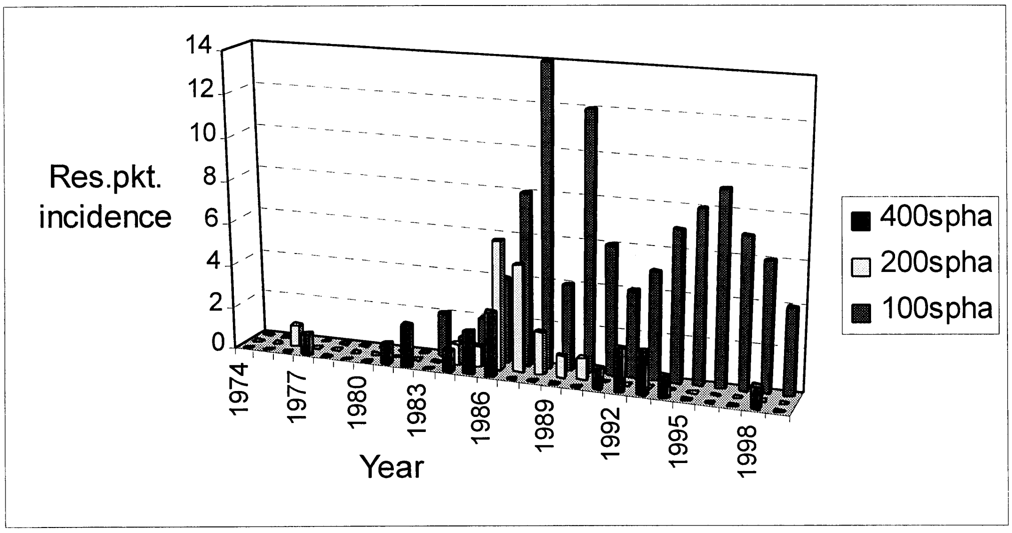
Again the 100 spha treatment discs contained the highest incidence of both resin pocket types when calculated on a m^2 basis. Values were 4, 1 and 1 for the 100 spha, 200 spha and 400 spha treatments respectively. An ANOVA test on mean frequency of resin pockets by treatment confirms a significant difference (p-value of 0.0251).

A separate study by Dean and Barker (1999) visually assessed the log ends of 50 pruned butt logs from each of the 50 spha, 100 spha, 200 spha and 400 spha treatments at Tikitere for the presence of resin pockets. Incidence values per cross-sectional area were converted to sawn surface area (Somerville, 1997) for all treatments with the lower stocked stands having a higher incidence. Overall, for all treatments combined the incidence of resin pockets at Tikitere falls within the range established for 95 sites surveyed in the central North Island (J.C. Park – INTERFACE Forest and Mill consultants). However, it is unclear how past studies have allocated blemishes and resinous patches.

Figure 15 presents the breakdown of resin pocket incidence (includes Type 1 and 2 combined) by the year formed for the three treatments. For the years 1986 to 1988 the highest number of resin pockets were recorded for all three treatments with 14, 6 and 3 being recorded for the 100 spha, 200 spha and 400 spha treatments respectively. Two other lesser peaks were detected for the 100 spha treatments at rings 1990 and 1996 with 12 and nine resin pockets respectively. It is interesting to note that from meterological records for Rotorua Airport over the 21 year period from 1976 to 1997, 1986, 1991 and 1996 had low spring rainfalls which loosely correspond to the three peaks found in the 100 spha treatment. More detailed research would be required to substantiate this hypothesis.

The figure also shows low resin pocket incidence in the first decade of growth. This will have implications for geneticists who are attempting to develop early screening procedures to segregate those trees with more desirable characteristics at a young age from which to establish future forests. External signs of resin bleeding early in the rotation may provide an indication of propensity to form resinous characteristics including Type 2 and Type 3 resin pockets.

Figure 15 - Resin pocket incidence by year and treatment



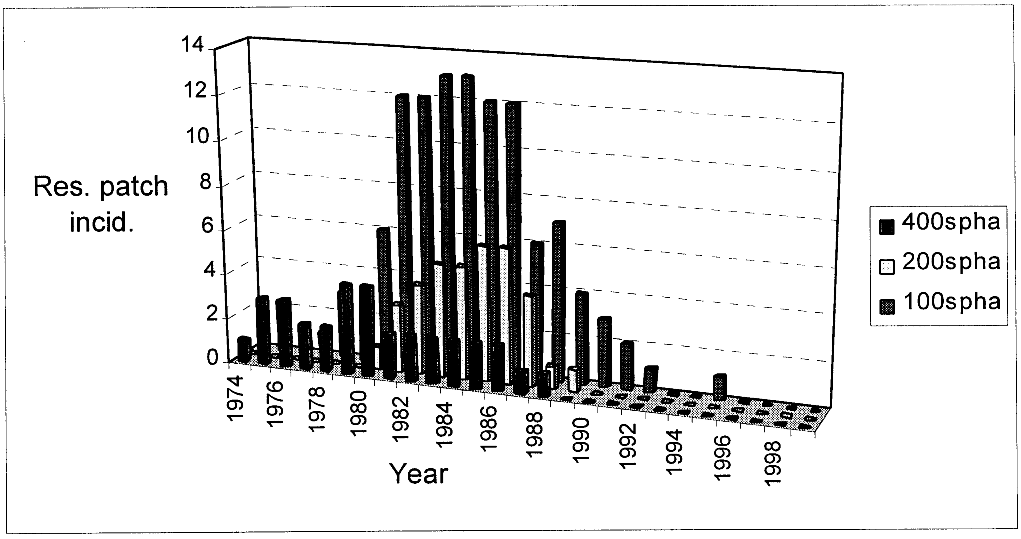
Resinous patches

As for blemishes and resin pockets the highest incidence of resinous patches occurred in the 100 spha treatment where 117 growth rings contained this defects compared to approximately 35 for both the 200 spha and 400 spha treatments. Tree 89 of the 100spha treatment recorded the highest number per disc with 13 rings containing this defect. When the number of resinous patches per m^2 were calculated values of 6, 2 and 3 were established for the 100 spha, 200 spha and 400 spha treatments respectively.

Figure 16 shows the breakdown by year for resinous patch incidence for the three treatments. One feature to note from the graph is the higher incidence of growth years containing this defect for the 100 spha treatment over the period 1981 to 1986. Unlike resin pockets the resinous patches do not appear to extend to the outer rings quite the same. Of the 22 years tested using LSM analysis, seven years (1980 to 1986) were shown to have the largest number of significant differences between years. Of the seven years, 1986 was also identified a having a high incidence of resin pockets.

Statistical analysis generally confirmed the lower the stocking the higher occurrence of resinous patches. Differences at the 5% level were shown between the 100 spha and 200 spha treatments (p-value = 0.0115) and between the 100 spha and 400 spha treatments (p-value = 0.0157). No evidence of a difference was shown between 200spha and 400spha treatments (p-value = 0.9050).

Figure 16 – Resinous patch incidence by year and treatment



Internal Checking

Previous processing studies of logs from Tikitere have indicated the presence of internal checks in products produced from the clearwood sheath of pruned butt logs, and in structural timber from unpruned second and third logs. At that stage a procedure to screen logs for their propensity to form checks was unavailable and our understanding of contributing factors was limited. Over the past 12 months advances have been made towards understanding factors involved in the formation of checks, not least has been the development of an effective procedure to identify check prone logs prior to processing.

Full results of the current internal checking assessment for each disc are provided in Appendix VIII. This appendix also documents the occurrence of shelling. Shelling is due to the presence of traumatic rings, which are known to have various causes including drought or unseasonal frosts. Traumatic rings consist of closely packed resin canals and hyertrophied wood rays which may result in ring shake/shelling under severe drying. As for other studies no green within ring internal checks were identified and no checking was found to occur within the heartwood zone following drying. Most of the checks occurred within approximately five rings of the heartwood boundary. Although the last heartwood ring was not marked for those discs where shelling was observed, in most instances it would appear that shelling also occurred outside the heartwood zone.

Table 10 summarises the internal checking and shelling incidence by sampling height and treatment. For internal checking the general pattern for all treatments was higher levels of checking at the lower stem levels ie. 0 m, 5 m, and 10 m. This result is consistent with other studies (McConchie 1999; McKinley *et. al.* 2000a). Shelling was also more prevalent at the lower disc heights. With regard to internal checking an ANOVA test on treatment effect shows a significant p-value of 0.0193. The interaction of disc height and treatment is proven highly significant (p-value of 0.0002).

As disc samples were heavily weighted towards the 2nd log height class these logs have been used to illustrate the relationship between propensity to form within ring internal checks and stocking. Table 11 shows the percentage of 2nd logs identified as check prone for each stocking treatment and shows propensity to check increasing from 27% at 100 spha to 48% at 400 spha. Shelling showed the reverse effect with higher levels recorded at the lower stocking.
Figure 17 shows the incidence of checking in relation to year of formation by treatment. The treatments show similar patterns in relation to year of formation although differing numbers associated with stocking. 1985 was the year containing most checks for each treatment with 36%, 25% and 30% of total checks for 100, 200 and 400 spha respectively. 1984 was the second most significant year with respect to checks at 100 and 200 spha and the fourth most significant year for the 400 spha following 1986 and 1987 which are second equal. If the checks for the worst 3 years are combined for each treatment they account for between 52% and 58% of total checks. The low numbers of checks associated with years between 1978 and the peaks of 1985 and to a lesser extent 1984 are related to the variable location of the heart/sap boundary. This boundary varies between 1978 and 1984 for 100 spha, between 1978 and 1987 for 200 spha and between 1980 and 1986 for 400 spha. Following the peak years, both the number of logs identified as prone to checking and the number of checks drops off rapidly, with no checks recorded in the last three years at 100 spha and last 2 years at 200 and 400 spha. It may be concluded that an increase in rotation age by several years would reduce the incidence of checking due to the progressive nature of heartwood formation. The formation of heartwood has been shown to dramatically reduce or totally prevent the formation of within-ring checks on drying. However the larger log size produced form the longer rotation could create other problems for processors.

Table 10 – Internal checking and shelling incidence by sampling height and treatment

Disc ht. (m)	Internal checks		Shelling
	Sum	Rings affected	Sum
100 spha			
0	94	7	8
5	77	12	7
10	34	8	10
15	0	0	1
20	0	0	0
25	0	0	0
All	205	27	26
200 spha			
0	33	9	0
5	74	13	8
10	3	3	3
15	14	4	0
20	0	0	0
25	0	0	0
All	124	29	11

400 spha			
0	124	16	1
5	155	13	3
10	100	4	0
15	1	1	0
20	1	1	0
25	1	1	0
All	382	36	4

Note: Actual sampling height has been rounded to the nearest 5 m increment and numbers of discs varied between height and treatment.

Table 11 - The percentage of 2nd logs identified as check prone by treatment

	Treatment - spha		
	100	**200**	**400**
Number of 2nd logs	26	27	27
% check prone	27	33	48

Figure 17 – Internal checking incidence by year and treatment

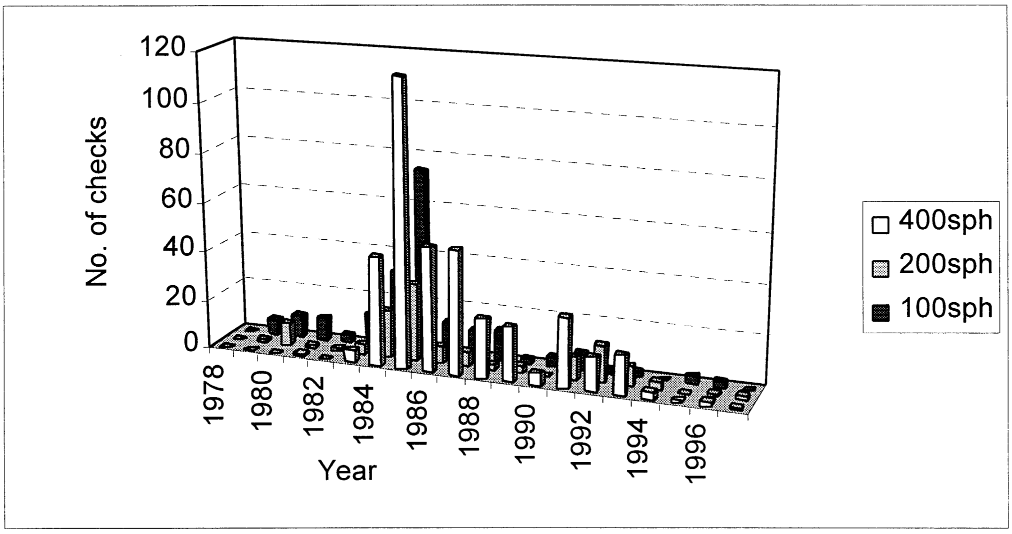


Table 12 presents the incidence of checking in relation to the heart/sap boundary and clearly shows the high incidence of checking within 3 to 5 growth rings of the boundary. It also indicates that the number of logs affected over a larger number of rings from the heart/sap boundary drops off rapidly with only 9% of logs affected after the 5th ring.

Table 12 - The incidence of checking in relation to the heart/sap boundary

Spha	Total logs	Total checks	Heart + 3 rings		Heart + 5 rings		>5 rings from heart	
			% logs*	% checks	% logs*	% checks	% logs*	% checks
100	44	205	27	78	14	89	9	11
200	46	124	22	45	9	67	9	34
400	54	382	30	61	15	76	9	24

* refers to the % of logs identified as prone to checking

Individual trees and logs from these trees are shown to be major contributors to checking in each of the three stockings. These trees may represent that genetic component that is most easily stressed by a combination of higher stocking and environmental factors expressing this stress by the formation of checks in the sapwood on drying. At 100 spha the worst affected log was a butt log which accounted for 30% of total checks. The worst log at 200 spha was a second log accounting for 21% of total checks and at 400 spha again a butt log accounted for 36% of total checks. The worst three logs accounted for 59%, 57% and 66% of total checks at 100, 200 and 400 spha respectively.

It is also worth noting that there appeared to be no relationship between those that showed a propensity to check and diameter. The mean diameter and range was similar for both the "checkers" and "non-checkers". The data also shows that in most cases if the small end of a log showed a propensity to check the large end was also affected.

At 100 spha shelling was observed in 14 of the 70 discs assessed representing stem heights from the butt to 14.1 m. Up to 3 years/disc were affected between 1985 and 1995 however 86% of occurrences were recorded in 1988 (50%) and 1989 (36%). At 200 spha the incidence dropped to 6 of the 73 discs assessed in this case representing stem levels from 5 m to 11.1 m. Up to 4 years/disc were affected between 1981 and 1991. The worst years were 1983, 1987 and 1990 with 2 occurrences/year accounting for 55% of the total occurrences at this stocking. The incidence of shelling reduced further at 400 spha with only 3 of the 81 discs assessed affected from the butt to 5.3 m. Between 1 and 2 years/disc were affected between 1982 and 1992. There was too low an incidence to identify significant years. A further 6 of the 62 discs assessed in relation to the sawing study showed shelling between 1985 and 1991 but again no years were significant.

CONCLUSIONS

1. The results of this comprehensive study supports earlier wood quality research on fast-grown radiata pine established on fertile ex-pasture sites.

2. Earlier studies at Tikitere have recorded relatively flat pith-to-bark density gradients for several of the treatments. Current results corroborate the earlier finding where wood density has changed little over the last seven years. At this site basic density values are still well below predictions where the fertile ex-farm site and the "850" seed source have both contributed. No differences were shown for whole tree density values between the 100 spha, 200 spha and 400 spha treatments.

3. Spiral grain levels were similar between treatments and again as for earlier studies at this trial show generally higher angles with a slower rate of decline from pith-to-bark compared to samples taken from "traditional" forest sites.

4. This study has provided the most comprehensive breakdown of clearwood characteristics for radiata pine grown on a fertile ex-farm site at a range of stockings. The frequency of blemishes, resin pockets and resinous patches show an increase with decreasing stocking level. Individual logs and trees have been shown to be particularly susceptible. Overall the incidence of resin pockets falls within the range established in an earlier study.

   The incidence of internal checking was largely confined to growth rings immediately outside the heartwood/sapwood boundary and decreased rapidly with increasing height in the stem. The study has established a link between propensity to check and stocking, with susceptibility increasing with increasing stems/hectare. Individual logs and trees have been shown to be particularly susceptible.

5. With the genetics and silviculture applied at this site the timber produced will be unlikely to meet the requirements for a range of processing options where mechanical properties are important. Both basic density and spiral grain in conjunction with the known branching behaviour on such sites will contribute to this result.

6. With regard to appearance grades, clearwood characteristics, compression wood and internal checking will individually and combined, adversely affect potential grade recovery.

7. The knowledge provided in this report will assist the decision making process when defining appropriate silvicultural regimes for fertile farm sites. The ability to grow regimes that produce acceptable recovery of structural products appears limited, therefore appearance grades are a more appropriate option. However further research is required to determine the most appropriate stocking rates, which will ensure acceptable recoveries of clearwood, free of degrade from both characteristics associated with resin and internal checks. With regard to internal checking, increasing the rotation length can help decrease the impact of this form of degrade.

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