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Managing subtropical exotic pine plantations for improved wood production

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Managing subtropical exotic pine plantations for improved wood production:

Prepared for

Forest & Wood Products Australia

by

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Publication: **Sub-tropical exotic pine taxa, growth, form and wood properties comparisons across multiple sites in coastal Queensland in: thinning and clearfall age trials; in family and clonal hybrid pine trials and in a genetics × fertiliser × weed control trial.**

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Executive Summary

This project supports improved management and deployment of sub-tropical pines for solid wood products. It had three major objectives, in respect of both growth rate and standing tree wood properties: 1) to compare major and potential pine species and hybrids for south-east Queensland; 2) to investigate selection strategies for identifying improved families and clones, and make selections; and, 3) to evaluate both the separate and combined effects of fertiliser application, weed control and genetic improvement in a young hybrid pine trial.

Comparisons at both thinning and clearfall ages indicated that Caribbean pine and the slash × Caribbean pine hybrid (hybrid pine) have similar stem volume on average across a range of sites, far surpassing that of slash pine. Additionally, outerwood stiffness of the hybrid (predicted using acoustic methods) was more similar to the stiffer parent, slash pine, than to Caribbean pine on three of the four sites examined. For wood density, the superiority of slash pine over Caribbean pine and the hybrid began to emerge only after the first five growth rings, and was greatest in the outerwood after rings 16-20, while the hybrid remained intermediate between the parental species. In contrast, slash pine had significantly higher spiral grain than Caribbean pine at both south-east Queensland sites (Tuan and Beerburrum), while the hybrid, though intermediate, varied greatly between the two sites.

The available clearfall resource in south-east Queensland is progressively changing from slash pine to Caribbean pine to the hybrid between these species. The clearfall-aged trial sampled in this project represents the only mature age trial where the hybrid and its parental species have been grown on the same sites. Both sites are scheduled for harvesting in the near future. It is recommended that a batch sawing study be initiated for this trial to ultimately define whether the observed differences between taxa are of practical importance for structural timber grade recovery.

The hybrid pine clonal and family studies identified some outstanding hybrid clones and families for priority use in tree improvement. These combine desirable growth and form with superior wood quality traits (predicted stiffness, acoustic velocity, wood density and spiral grain). Importantly, acoustic velocity and stem volume were only very weakly (though adversely) genetically correlated. This indicates favourable prospects for concurrently selecting for growth and wood quality in the slash × Caribbean pine hybrid. In both the clonal and family studies, the very best full-sib families for stem volume had low within-family variance. These were also the families yielding the highest proportion and number of clonal selections in the clonal study. The results indicate potential for selecting a suite of outstanding families with low variability for deployment in full-sib family forestry. The value of selecting variable families for more highly heritable traits may merit further investigation in clonal programs.

The low genotype by environment interaction for acoustic velocity in the clonal study supports previous findings that parents and families rank similarly for wood density and stiffness at different sites in south-east Queensland. Acoustic velocity measures on different sides of the tree were also very strongly genetically correlated. The need to conduct only one velocity assessment per tree at a limited subset of sites creates major efficiencies in genetic screening and selection for wood quality.

Results at around age 8 – 9 years from the genetics × weed control × fertiliser hybrid pine trial indicated that maximum treatment response for stem volume is achieved through repeated, intensive ("luxury") weed control, considerably outweighing the effect of improved genetics. Luxury weed control provides a benchmark for the maximum growth rates achievable on a typical exotic pine site in south-east Queensland without resorting to special inputs such as

irrigation. Unfortunately, current costs and technology as well as sustainability and forest certification imperatives towards reduced herbicide use are likely to render luxury weed control uneconomical or unattractive for routine commercial use. Under these circumstances a single post-plant tend has as much long-term benefit on growth as two to four post-plant tends. The "nil" and the "minimum" weed control treatments were very similar to, and not statistically significantly different from, corresponding treatments with more intensive "routine" weed control. If the responses from these "low-input" treatments do not deteriorate in the future then they might provide economic alternatives. Results from this trial suggest that there is scope for plantation managers to make further reductions in herbicide use, achieving cost savings and environmental benefits, without compromising long-term production.

The F_1 hybrid clones tested in the silviculture trial have, on average, superior growth, superior straightness, higher standing tree acoustic velocities, and probably superior wood stiffness to the F_2 hybrid seedlings. There were no significant differences in basic density. However, in commercially thinned stands the superior growth and straightness of the F_1 clones might not translate into higher stem volume at clearfall, but will merely translate to improved volume of better quality stems in the thinned fraction. Under this scenario, the economic advantage of clones, considering their high up-front costs compared to seedlings, may be marginal. There was very little evidence of strong interactions among the genetic stock, fertiliser and weed control factors in the silviculture trial. If this lack of interaction continues through to advanced ages then it is very good news for forestry research and enhances confidence in some inferences drawn from experiments.

In summary, the project has provided a wealth of detailed comparative information on the performance of sub-tropical pine taxa under a range of site and silvicultural environments, at different ages, and for different levels of genetic improvement. Results from this project will assist forest growers and processors to make more informed decisions regarding the deployment and management of improved sub-tropical pines, especially those destined for the production of structural timber. The recently approved comparative sawing study of clearfall-aged material will add to the findings from this study providing further industry confidence regarding the future pine resource becoming available in Australia's sub-tropics.

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Introduction

The Australian exotic pine estate in the sub-tropics and tropics totals around 155,500[1] hectares (ha) and is concentrated in south-east Queensland (116,500 ha) with smaller estates in coastal central Queensland (12,500 ha), north Queensland's wet tropics (13,500 ha) and northern NSW (13,000 ha). The majority of the estate is managed by Forestry Plantations Queensland Pty Ltd (FPQ) and the balance mainly by Forests NSW. Table 1 presents a broad summary of this resource and Figure 1 shows the location of major estates. The composition of the estate is progressively changing, especially in south-east Queensland, as older plantations of slash pine (*Pinus elliottii* var. *elliottii*) (PEE) and Honduran Caribbean pine (*P. caribaea* var. *hondurensis*) (PCH) are harvested and replanted with their F_1 and F_2 hybrids (hybrid pine). Figure 2 shows a summary of the coastal SEQ estate by taxa by age class. Honduran Caribbean pine remains the dominant taxa planted in north Queensland and PEE × PCH hybrid pine is the taxa of choice for low frost risk areas in northern NSW. Loblolly pine (*P. taeda*) is planted on frost-prone sites in northern NSW and south-east Queensland, although the total area is less than 4,000 hectares. Figure 3 shows the predicted volume of final crop material becoming available from the FPQ estate in south-east Queensland (Beerburrum and Fraser Coast) over the next 15 years, highlighting the dramatic changes that will occur in the composition of the harvested resource.

Table 1: Sub-tropical and tropical exotic pine areas as at 30 June 2010

	Central Qld	North Qld	South-east Qld	North NSW	TOTAL
Slash pine (PEE)	16	3	16,319	1,928	18,266
Caribbean pine	6,207	12,848	31,611	45	50,711[1]
Hybrids	5,485	63	63,828	8,165	77,541[2]
Other pines	3	78	1,448	2,521	4,050[3]
Total	**11,711**	**12,992**	**113,206**	**12,659**	**150,568**
clearfelled for re-plant	594	559	3,353	450	4,956
Grand Total	**12,305**	**13,551**	**116,559**	**13,109**	**155,524**

[1] 98 % *P. caribaea* var. *hondurensis* (PCH)

[2] Mainly PEE × PCH hybrids

[3] cont Mainly *P. taeda* and *P. patula* (excludes *P. radiata*)

The continuous improvement of this resource relies on tree improvement programs that produce trees of superior wood properties and growth. The sub-tropical pine resource is primarily processed to produce structural framing products which are marketed and sold based on grades determined by stiffness. Therefore, targeting wood properties that result in improved timber stiffness may lead to an increase in grade recovery and increased economic return per unit of log input. In addition to structural framing products, final crop logs support veneer mills and pulpwood thinnings and clearfall and mill residues support medium density fibreboard (MDF), roundwood and wood chip export operations.

The early detection and screening of taxa, families and clones (to avoid low stiffness) is critical to the financial performance of wood processors who are producing a structural framing product.

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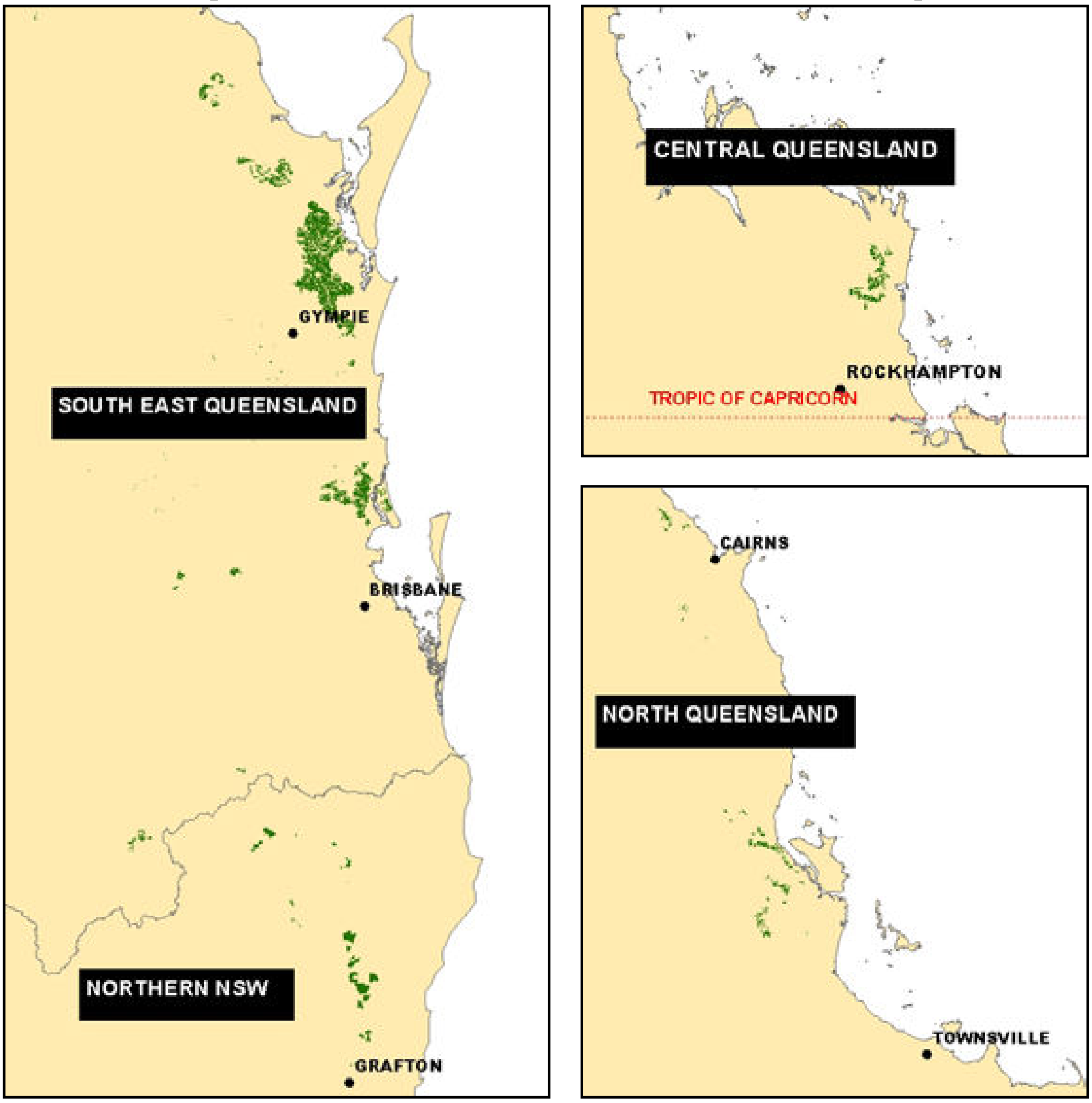
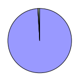
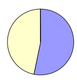
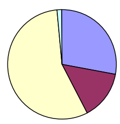
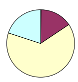
[1] As at 30 June 2010

Figure 1. Map of Queensland and northern New South Wales exotic pine estate



	Latitude	Av. Rainfall (mm/yr)	Proportion of Queensland estate	Estate Size and Spp Composition
North Queensland	18 -19°S	1400 - 2500	9%	 13,000ha
Central Queensland	23°S	1000-1400	8%	 12,000ha
South East Queensland	25-27°S	1000-1600	75%	 113,000ha
Northern New South Wales	28-30°S	1000-1200	8%	 12,500ha

Blue	Caribbean Pine
Maroon	Slash Pine
Pale yellow	Hybrid
Pale cyan	Other

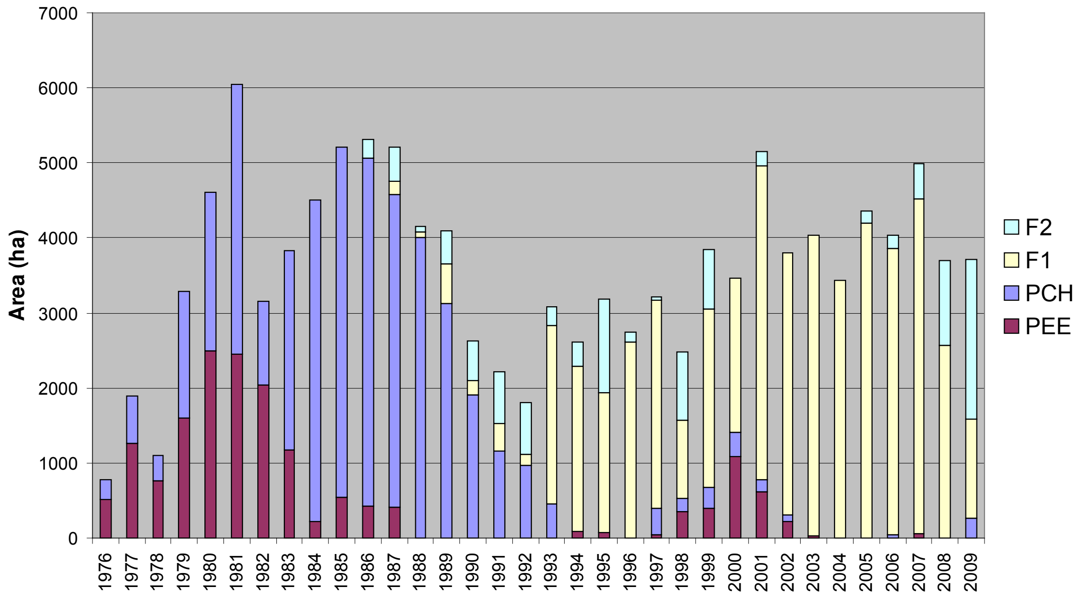


Figure 2. Area planted by planting year by taxa for FPQ estate in south-east Queensland (Beerburrum and Fraser Coast) as at 30 June 2009.

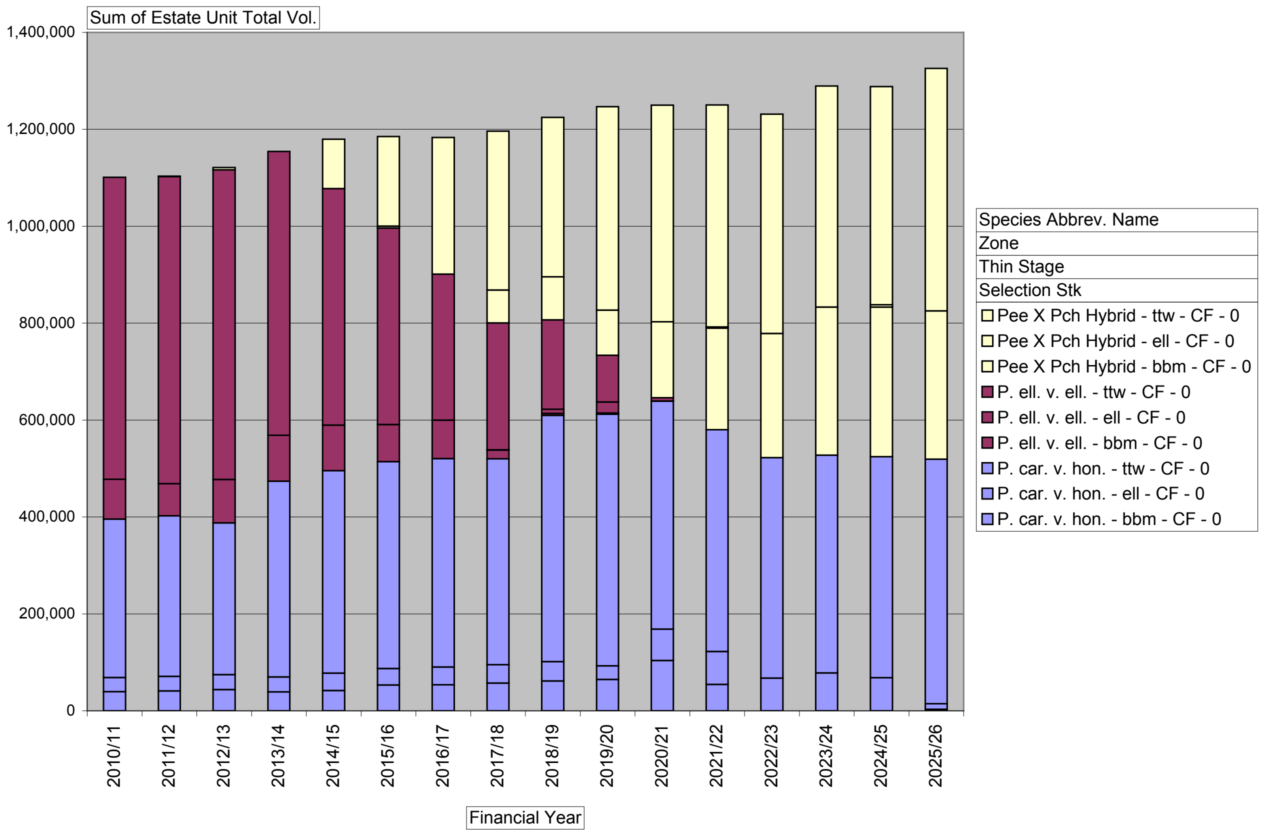


Figure 3. Composition and volume (m^3) of final crop resource becoming available for harvest in south-east Queensland (Beerburrum and Fraser Coast) during next 15 years

The growth, branching habit and wood properties of sub-tropical pines are very different to radiata pine. Appendix 1 contains a brief wood properties comparison of Queensland-grown Caribbean pine with "southern-grown" *Pinus radiata* , including density studies from New Zealand and NSW. Sub-tropical pines naturally shed most of their lower branches producing generally fine and light branches in butt logs. Height and diameter growth is generally lower than radiata pine but wood density is significantly greater in the mature wood and generally above the limiting threshold for structural pine grades, even in the juvenile wood of some trees. In addition, sub-tropical pines produce very little heartwood and therefore heartwood percentage is of little interest as it has good durability and termite resistance so heartwood does not limit its utilisation in above ground situations.

FWPA Project PNC057.0809 (the Project) was developed to support improved management and deployment of sub-tropical pines (slash pine, Caribbean pine and hybrids between these species) for solid wood products based on non-destructive sampling and analysis of growth and wood property data across a broad series of genetics and silviculture trials covering a wide range of ages and locations.

The overall objective is to explore ways of increasing plantation profitability while maintaining or enhancing future volume production and wood quality. The Project explores differences between taxa, within taxa (families versus clones) and impacts of site and silviculture (weed control and fertiliser effects).

Key questions addressed by the Project include:

1. Are growth rates and wood properties of sub-tropical pine taxa significantly different within and between geographic locations?
2. How do hybrid pine growth rate and wood properties vary within and between families and across different sites?
3. Do different deployment strategies (hybrid pine seedlings versus family cuttings versus clones) result in significant differences in growth rate and wood properties? If so, on what basis should hybrid families be characterised as being (a) suitable for direct family forestry deployment (b) better suited for clonal testing and selection or (c) both?
4. How do weed control, genetics and nutrition impact on hybrid pine growth rate and wood properties, separately and in combination?

Expected Outputs from the Project include:

1. Improve the understanding of long-term growth trends and wood properties of major sub-tropical pine taxa to inform the economic analysis of comparisons made by forest growers between a range of plantation management, harvesting and deployment alternatives;
2. Identify superior hybrid pine families and clones for operational use that take account of growth and commercially important wood properties; and
3. Identify the effects of weed competition, fertiliser and genetics on growth and wood properties and utilise these to modify silvicultural regimes to reflect their economic significance to plantation returns.

To address the key questions, the Project relied on non-destructive sampling and analysis of various growth and wood property data across a series of genetics and silviculture trials covering a wide range of ages and locations as indicated in Appendix 2. The trial series are briefly described below, arranged under the key questions each trial was analysed to address:

Question 1. Taxa comparison

- Thinnings age taxa trial (674 TBS)
- Clearfall age taxa trial (464 TBS)

Questions 2 and 3. Clonal and family comparisons

- Hybrid pine clonal trial (89 PPG)
- Hybrid pine family trial (749 TBS)

Question 4. Effects of weed control, nutrition and genetics

- Hybrid pine taxa x silviculture trial (350 GYM)

The following chapters provide summaries for each trial, including results of assessments arising from this Project and their interpretation. Individual milestone reports (available on request from FWPA) should be consulted for further details regarding materials and methods, results and for more in-depth discussion on each topic.

The final chapter brings together relevant findings from the various trials in the context of the Project's key questions and Expected Outputs. A list of recommendations is also presented for further consideration by FWPA, FPQ and other growers.

Thinnings age taxa trial series (674 TBS)

Methods - Thinnings age taxa trial series (674 TBS)

Genetic material: Experiment 674 TBS was established to estimate genetic parameters for *Pinus elliottii* var. *elliottii* (PEE), *Pinus caribaea* var. *hondurensis* (PCH), and their various hybrids. The PEE and PCH each consists of 36 families based on 12 parents generating 6 × 6 = 36 control crosses. The experiment incorporates an F_1 hybrid derived from crossing the 12 PEE parents with the 12 PCH parents, an F_2 hybrid, a PEE × F_1 backcross (BCE), and an F_1 × PCH (BCH) backcross (Table 2). Many of the parents used in the PEE and PCH taxa were also used in the BCE and BCH taxa. Unfortunately it was neither practical nor possible to also use the common parents in the PEE × PCH F_2 hybrid. For the purposes of this Project the family structure was ignored and only whole-of-taxon comparisons for various growth and wood property parameters were made.

Table 2. Mating design for populations in the main trial of Experiment 674 TBS

Taxon number	Taxon name	No. of parents	Mating design	No. of families
1	PEE	12	6 × 6 factorial	36
2	PCH	12	6 × 6 factorial	36
3	F_1	12 PEE + 12 PCH	12 × 12 factorial	144
4	F_2	12 F_1	6 × 6 factorial	36
6	BCE	6 F_1 + 6 PEE	6 × 6 factorial	36
7	BCH	6 F_1 + 6 PCH	6 × 6 factorial	36

Site location and trial design: The design of the main trial is best considered as a randomized complete block design with six taxa in each replicate, with one taxon (F_1 hybrids) having 144 families and the other taxa having only 36 families. The experiment was planted in 1987 at one central Queensland coastal site and three south-east Queensland sites. Site details are presented in Table 3.

Measurements and assessments: The most recent growth assessment at each site (survival, total height, DBHOB[2]) was made at about age 20 years. Wood property sampling (acoustic velocity, basic density and spiral grain) was restricted to two sites as per the summary in Table 4.

[2] Diameter at breast height over bark

Table 3. Site and location details of thinnings age taxa trial (Experiment 674 TBS)

Experiment Number	**674.2a**	**674.2b**	**674.2c**	**674.2d**
Location	Byfield	Tuan	Toolara	Beerburrum
Compartment	10 Brampton	26B Boonooroo	110 South Dempster	203A & 204 Blue Gum
Latitude Longitude	22° 50´S 150°45´E	25° 43´S 152°50´E	26° 05´S 152°50´E	26° 05´S 152°58´E
Elevation and site type	50 m Almost level	14 m Almost level	60 m Undulating slopes to 5°	30 m Mostly level, slopes 1 - 4°
Average Rainfall (mm) to 1987	1,625	1,337	1,369	1,534
Soil Type	Grey silty loam	Gleyed podzolic – lateritic podzolic	Yellow to red earth and variable krasnozems	Humic latosol
Indicative PCH site index[3]	23 m	27 m	29 m	29 m
Site preparation	Overall plough then mound	Strip plough then mound	Small strip mounds	Strip mound
Planted	Feb-Mar'87	April-May'87	May'87	May-June'87
Spacing (row × tree, m)	5 × 3.0 667 sph	4.5 × 2.4 926 sph	4.5 × 2.4 926 sph	4 × 2.7 926 sph

[3] Predominant height is average height of tallest 50 stems per hectare. Site Index is predominant height at age 25 years.

Table 4. Number of core samples analysed for basic density (BD) and spiral grain and trees assessed for acoustic velocity in thinning age Experiment 674 TBS 2B (Tuan) and 2D (Beerburrum).

Population	Number of core samples extracted and analysed for basic density		Number of core samples analysed for spiral grain		Numbers of trees assessed for acoustic velocity	
	2B Boonooroo	2D Bluegum	2B Boonooroo	2D Bluegum	2B Boonooroo	2D Bluegum
PEE × PCH - F_1	143	141	78	76	346	329
PEE × PCH - F_2	109	141	61	81	287	326
PCH	119	149	67	85	306	334
PEE	130	147	76	79	290	331
BCH	-	-	-	-	217	211
BCE	-	-	-	-	221	242

Results - Thinnings age taxa trial series (674 TBS)

Preliminary notes on assessments, analysis and presentation of results

Volume: All volume data refer to total under-bark stem volume above 15cm stumps.

Percent coefficient of variation: Percent coefficient of variation (%CV) is a measure of the relative variability of a stand, and is computed by dividing the standard deviation by the mean, and then multiplying by 100 to express the result as a percentage. Variability has two aspects, viz. how variable are the trees for the given age, and how variable are the trees for their given average size. Only the former aspect of variability is discussed in this report. Scale is also a critical aspect of variability. Thus for some purposes variability within a fraction of a hectare might be important, but for other purposes total variability within a compartment might be important. The %CV's presented here are averages of within-plot %CV's. Thus they are measures of local variability at the fraction of a hectare level and therefore do not necessarily reflect total variability over a whole compartment.

Analysis: FPQ manages some of its plantations using commercial thinnings down to about 400 stems/ha at about age 18 years. As a guide to a generic post-thinning stand, the biggest 400 stems/ha based on DBH at the most recent measure were identified and data for this select fraction were also analysed.

Presentation of results: Only results for the most recent measure at about age 20 years are presented, and bar charts are used with the sites (674.2A, 674.2B, 674.2C and 674.2D) presented in each figure from left to right. The 5% least significant difference (LSD) for a site has been positioned to the left of all of the bars for that site. Two taxa at a site can be regarded as significantly different if their difference exceeds the 5% LSD.

Results – thinning age taxa trials

Stocking rate: PCH had a significantly higher stocking rate than at least one of the F_1 or F_2 hybrids at three of the sites, and is significantly higher than PEE at two of the sites.

Average stem volume: In Figure 4a PEE consistently has the smallest average stem volume (ASV), BCE consistently has the second smallest ASV, and BCH consistently has the largest ASV. Almost all of the taxon comparisons implied in the previous sentence are statistically significant. PCH, F_1 and F_2 are all quite similar for ASV. The *status quo* is maintained for the select fraction in Figure 4b.

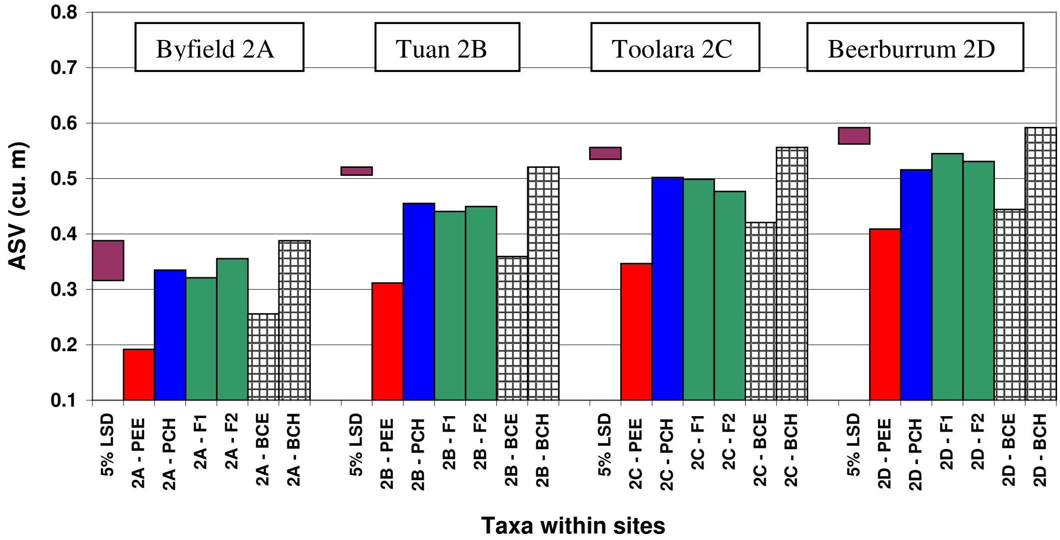


Figure 4a. Average stem volume (underbark, total above 15cm stumps) of live useful stems for each combination of taxon within site in Experiment 674 TBS

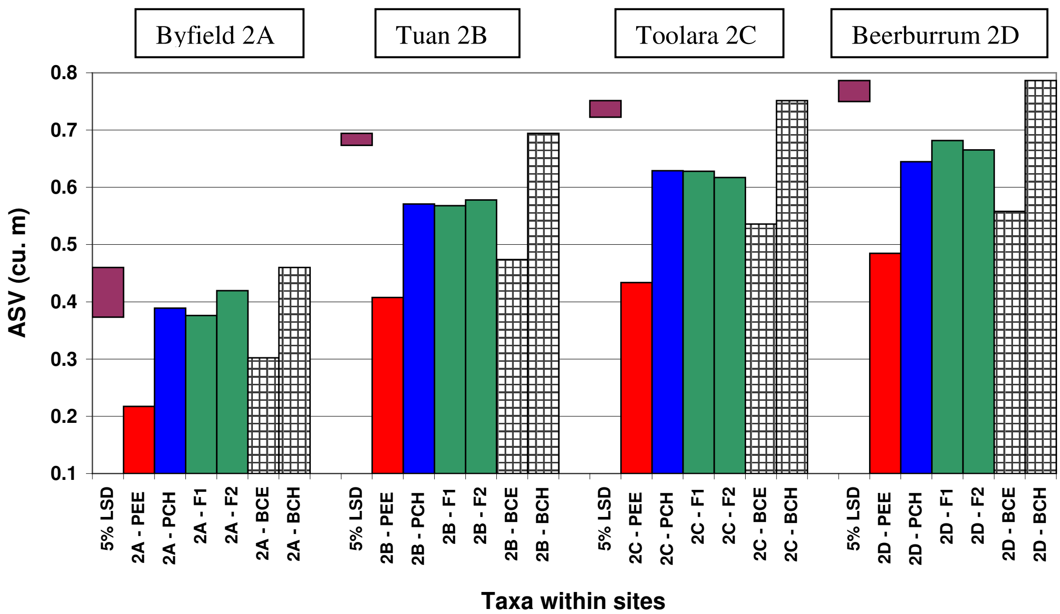


Figure 4b. Average stem volume (underbark, total above 15cm stumps) of the biggest 400 stems/ha for each combination of taxon within site in Experiment 674 TBS

%CV for stem volume: BCH is the most variable taxon for stem volume in Figure 5a, spectacularly so in 674.2C and 674.2D, and PCH has relatively good, low overall variability. PEE seems to have unusually high variability in 674.2B and unusually low variability in 674.2D. In 674.2B the F_1 and F_2 have variability intermediate to their PEE and PCH parents, but at the other three sites these two hybrid taxa are more variable than their parental taxa although not always significantly. For the select fraction in Figure 5b differences among the taxa are not as extreme as for the whole plots. PCH still has overall low variability, and PEE still seems to have unusually high variability in 674.2B and unusually low variability in 674.2D.

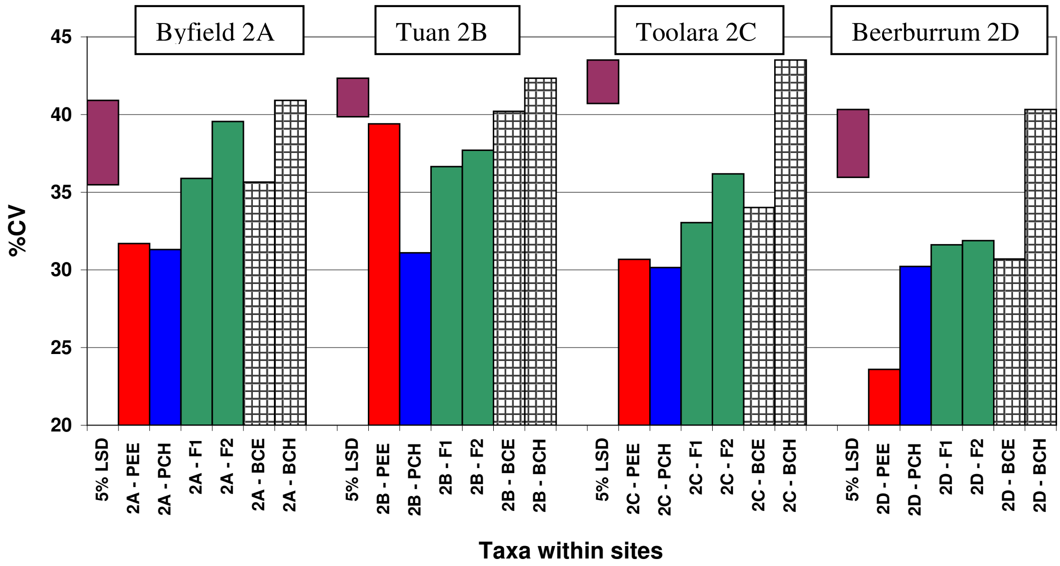


Figure 5a. Percent coefficient of variation for stem volume of live useful stems for each combination of taxon within site in Experiment 674 TBS.

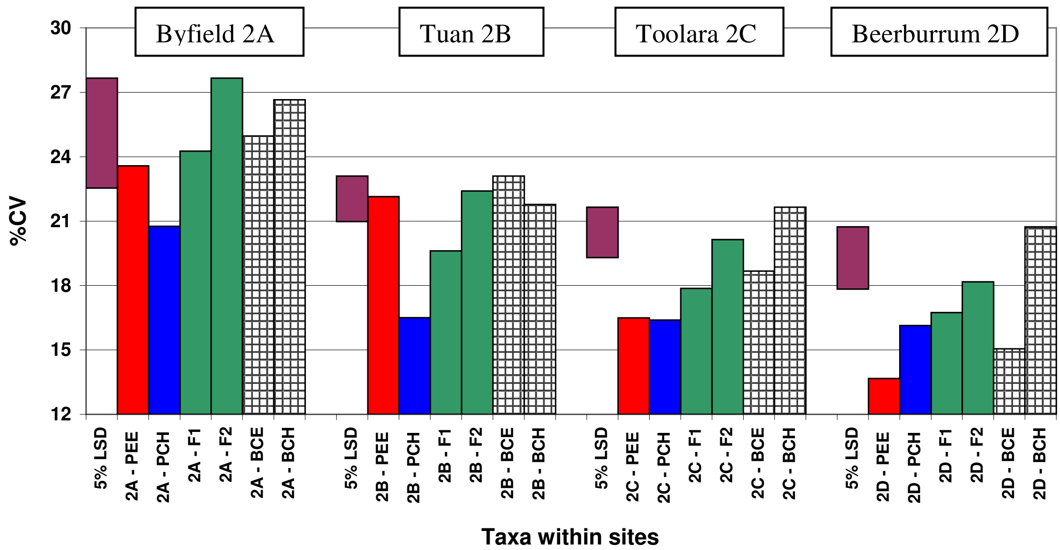


Figure 5b. Percent coefficient of variation for stem volume of the biggest 400 stems/ha for each combination of taxon within site in Experiment 674 TBS.

Standing volume: Although not always statistically significant BCH has the best standing volume at all four sites according to Figure 6a, despite it never having the highest stocking rate. In 674.2B and 674.2C PCH is statistically superior to the F_1 and

F_2, but these three taxa are very similar at the other two sites. With regard to the select fraction in Figure 6b BCH is simply outstanding at the three southern sites and outperforms all other taxa by about 50 m^3 ha^{-1} or more. BCH is still superior at the northern 674.2A site. Within each site PCH, F_1 and F_2 are all fairly similar for standing volumes of the select fraction.

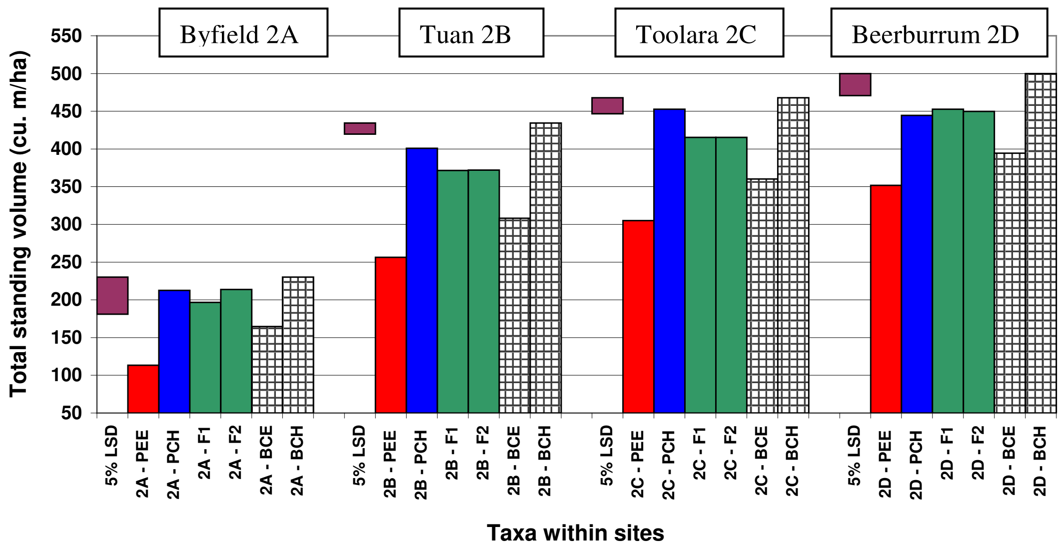


Figure 6a. Estimated total standing volume per hectare (underbark, above 15cm stumps) of live useful stems for each combination of taxon within site in Experiment 674 TBS.

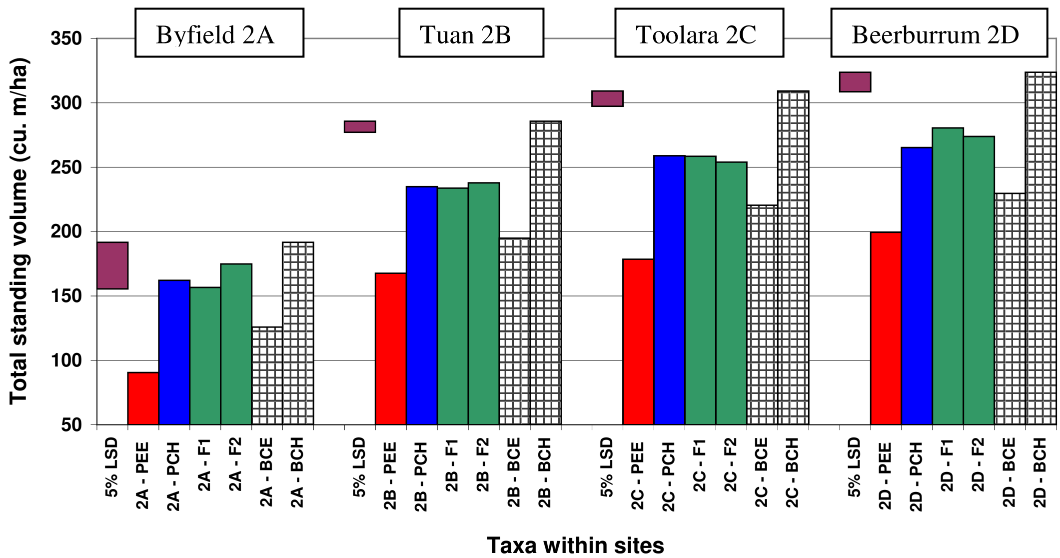


Figure 6b. Estimated total standing volume per hectare (underbark, above 15cm stumps) of the biggest 400 stems/ha for each combination of taxon within site in Experiment 674 TBS.

Basic density: Basic density results for resin-extracted increment core samples from Experiment 674 TBS for the basal area weighted means of juvenile wood, outer wood and whole core are charted in Figure 7. Densities are consistent with past observations (Harding 2009), viz. PEE having superior density, PCH having inferior density and the hybrid being approximately intermediate.

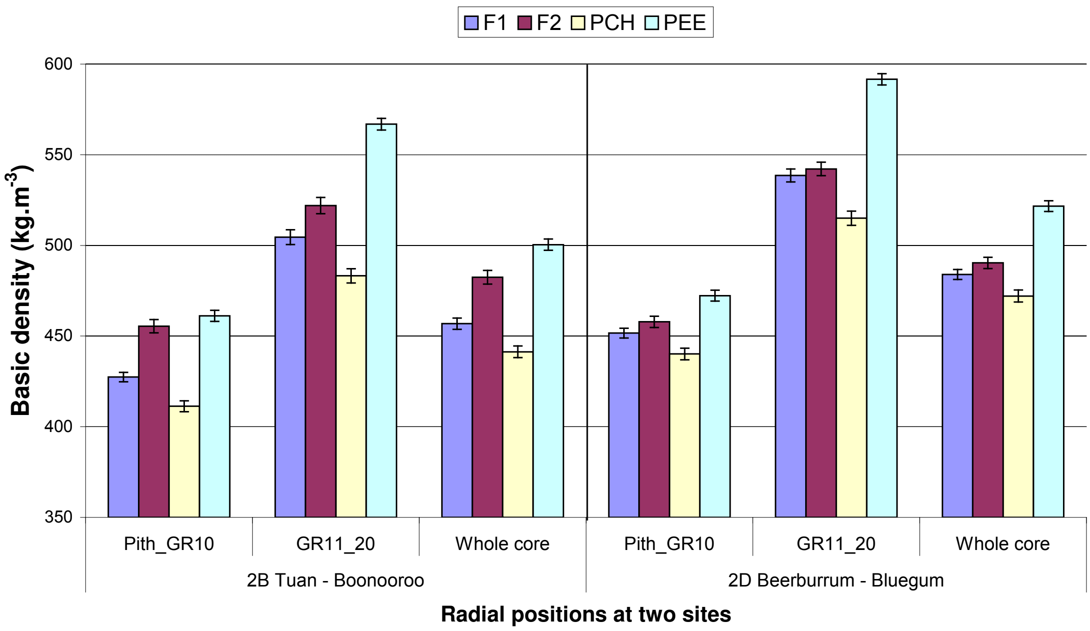


Figure 7. Average resin-extracted basic density of basal area weighted inner wood (Pith_GR10), outer wood (GR11-20) and whole core samples (with standard error bars) for four taxa planted at two sites as part of Experiment 674 TBS.

The radial basic density trends plotted in Figure 8 are similar across sites but with a slightly higher range of values and separation of trend lines at the Tuan site. The obvious difference between the taxa is the increasingly higher density trend of PEE with age over the other taxa. PEE mature wood produces a higher proportion of high density latewood than the other taxa; about twice as much as PCH.

A consistent and clear trend from Figure 8 is that from the outer juvenile core (growth rings 6-10) and into the mature wood, PEE has significantly higher density than PCH with the hybrid taxa being intermediate. Depending on site, the F_2 hybrid may be either very similar, or a little higher, in density than the F_1 hybrid. However, it should be recognised that such comparisons are confounded by genetics and the historic degree of selection pressure exercised on the taxa, which consequently may be biased by growth rate differences

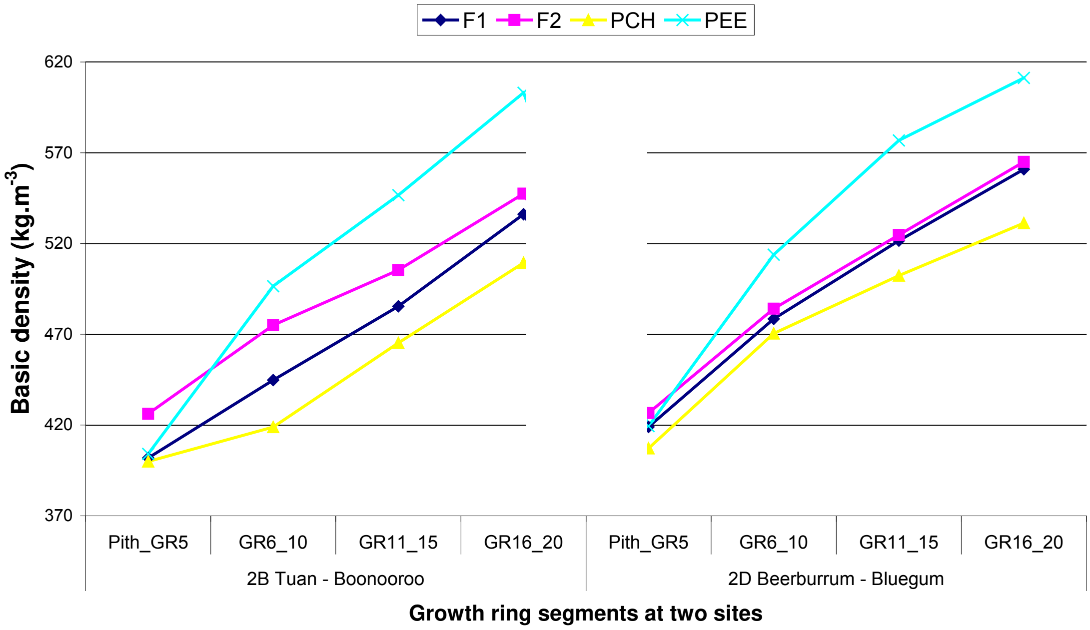


Figure 8. Average resin-extracted basic density of radial 5-growth ring segments for four taxa in two sites in Experiment 674 TBS.

The average standing tree acoustic velocity values for the six key taxa of interest are charted in Figure 9.

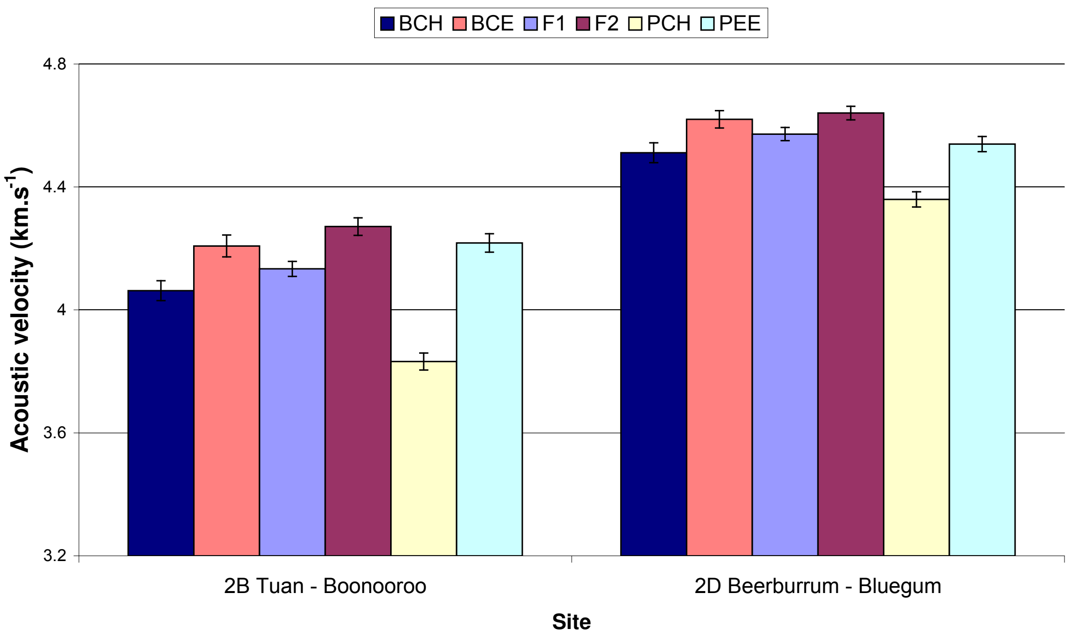


Figure 9 Mean standing tree acoustic velocities of six taxa on two sites sampled in Experiment 674 TBS (standard error bars included) - assessed with a FibreGen ST300 tool on all surviving trees in the experiment.

The differences among taxa are more pronounced at the Tuan site although the rankings are very similar at both sites. The F_2 hybrid, PEE and BCE are superior at both sites and the PCH is inferior to all the other taxa at both sites. The BCH is clearly superior to the pure PCH and is not largely different to the other taxa demonstrating the very positive effect on velocity of the PEE component in this backcross, which has implications for wood stiffness.

The mean predicted stiffness comparisons charted in Figure 10 suggest that the stiffness of the hybrids is closer to that of PEE than to PCH which is > 1000 MPa or about 10 to 20% lower in stiffness than the other taxa at both sites. The F_2 hybrid predicted stiffness is not significantly different from PEE at either site and both F_1 and F_2 hybrids are significantly different from PCH at both sites. If this finding is replicated elsewhere it is a very positive finding for the hybrids, which have been the dominant taxon planted for the last decade or more in south-east and central coastal Queensland where they have overtaken PCH as the preferred taxon to replace PEE in the planting program (Refer Figure 2).

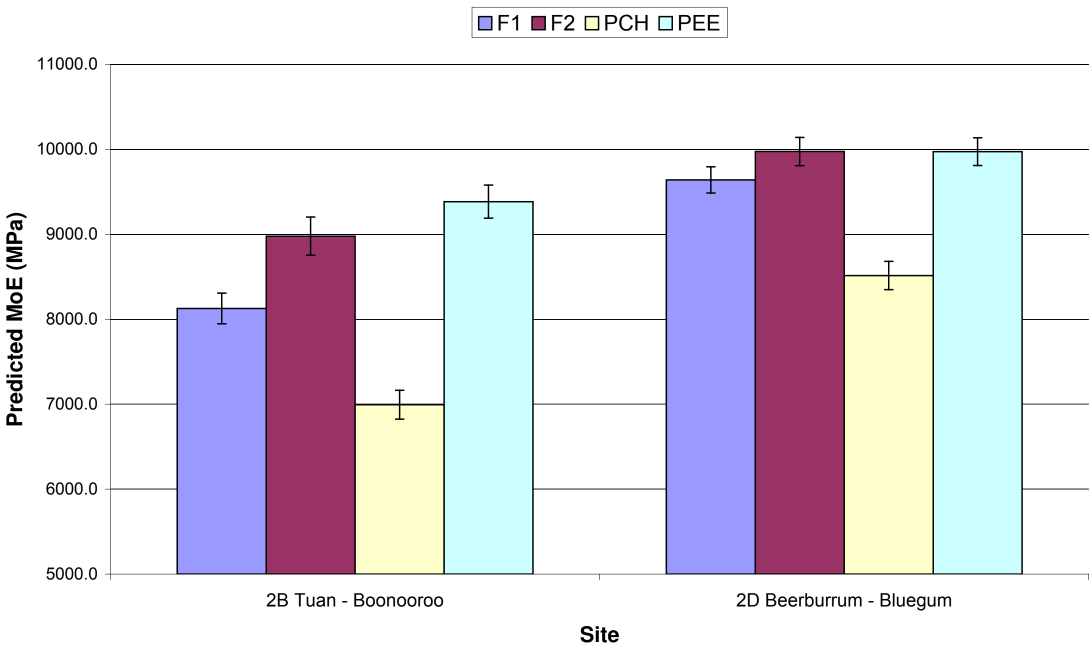


Figure 10. Mean estimated MoE of selected trees of four taxa on two sites sampled in Experiment 674 (standard error bars included) assessed with an ST300 tool (the same trees as used for basic density assessment).

Spiral grain: Spiral grain readings measured on the latewood – earlywood interface of growth rings 3, 4 and 5 are charted in Figure 11. The site × taxa interactions for spiral grain are very striking. Nester (2009a) established that Beerburrum was the faster growing site of these two sites in an analysis of all trees measured. As the sub-sample of trees used for the wood study were selected to represent the DBHOB distributions at these two sites, it is reasonable to conclude that within a taxon fast average growth is accompanied by high spiral grain. The comparison across taxa is also interesting as in wood quality terms it is the reverse of the wood density trend with PEE having the highest or least desirable grain angle values and PCH the lowest with the hybrids being intermediate or similar to PCH.

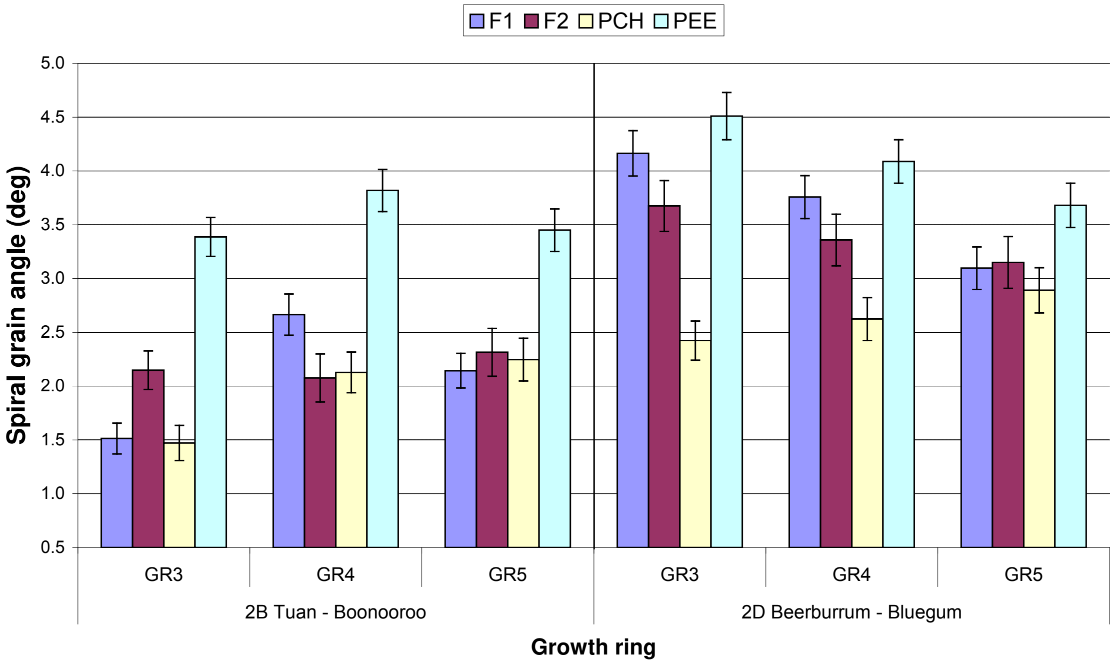


Figure 11. Average spiral grain at growth rings 3, 4 and 5 (standard error bars included) across four taxa grown on two sites in Experiment 674 TBS.

Discussion – Thinnings age trials - 674 TBS

The highly significant differences between PEE and PCH stem volume, and the similarity between PCH and both F_1 and F_2 hybrid stem volume, are consistent with previous observations of these taxa in plantations across south-east Queensland. The increased within-plot variability of the F_1 and F_2 hybrids relative to the parental species found in this study also corroborates field observations of the taxa at the within-stand level.

The significantly higher stem volume (biggest 400 stems/ha) of the F_1 hybrid backcrossed to PCH at three of four sites tested, relative to all competing taxa, is particularly striking. The strong performance of this backcross lends support to the ongoing advanced generation hybrid breeding strategy at FPQ, where recombination and selection of slash and Caribbean pine alleles in a synthetic hybrid population is over time expected to produce genotypes that combine the growth rate of the backcross with the high wood stiffness of slash pine.

Some of FPQ's investment decisions relating to productivity and profitability use PCH as a benchmark and consider percent volume advantages (%Adv) of various genotypes with respect to PCH. %Adv is calculated as follows:

$$\%\text{Adv} = \frac{(Taxon\ volume - PCH\ volume)}{PCH\ volume} \times 100\,.$$

Even though volume advantage is a simple concept, many subtleties are involved in its estimation and use. In an ideal experimental setting all taxa would have identical management regimes and identical stocking histories, and therefore it would be irrelevant as to whether average stem volume or standing volume per hectare was used in estimating %Adv. In Table 5 both volumes are used for estimating the volume advantages for these particular sites. The volume advantages based on the whole plots provide "generic" advantages applicable to unthinned stands. Of course if one is considering just a fixed number of stems in a select fraction it is irrelevant as to whether average stem volume or standing volume per hectare is used in estimating %Adv. The %Adv's for the biggest 400 stems/ha give some idea of volume advantage just after a commercial thinning.

When considering whole (pre-thinned/unthinned) stands the %Adv's based on volume per hectare, about −5 % and −3 % on average respectively, tend to present the F_1 and F_2 as being poor relative to the PCH, whereas calculations based on average stem volumes indicate that the F_1 and F_2 have about 0 % volume advantage on average.

The volume advantages for the select fraction are very similar to volume advantages for the whole stand when based on stem volumes, except for BCH whose %Adv becomes considerably more impressive when the select fraction is considered. The volume advantages for the select fraction will depend on the number of stems per hectare incorporated in the select fraction, as well as the thinning prescription.

Examination of Table 5 suggests that the taxa have relatively stable volume advantages with respect to PCH across all sites. With regard to overall volume growth the taxa can be ranked as follows: PEE very poor; BCE poor; PCH and F_1 and F_2 all very similar; BCH outstanding.

Table 5. Volumes of PCH at the most recent measure of each site in Experiment 674 TBS, and corresponding percent volume advantages of other taxa relative to the PCH benchmark. PEE, PCH and their hybrids are shown in red, blue and green font respectively. Refer to the text for further details.

Stand component	Volume variable	Taxa	674.2A Byfield 10/2006 19.7 yr	674.2B Boonooroo 07/2007 20.3 yr	674.2C Toolara 05/2007 20.1 yr	674.2D Beerburrum 06/2007 20.4 yr	Average across all sites
Whole	Volume per hectare	PCH	213	401	453	444	378
Whole	Volume per hectare	PEE	−47	−36	−33	−21	−34
Whole	Volume per hectare	F_1	−7.5	−7.3	−8.2	1.9	−5.3
Whole	Volume per hectare	F_2	0.5	−7.2	−8.3	1.2	−3.4
Whole	Volume per hectare	BCE	−23	−23	−20	−11	−19
Whole	Volume per hectare	BCH	8.3	8.4	3.3	13	8.1
Whole	Average stem volume	PCH	0.33	0.46	0.50	0.52	0.45
Whole	Average stem volume	PEE	−43	−32	−31	−21	−31
Whole	Average stem volume	F_1	−4.1	−3.2	−0.7	5.7	−0.6
Whole	Average stem volume	F_2	6.2	−1.2	−5.0	3.0	0.7
Whole	Average stem volume	BCE	−24	−21	−16	−14	−19
Whole	Average stem volume	BCH	16	14	11	15	14
Biggest 400 stems per hectare	Average stem volume	PCH	0.39	0.57	0.63	0.64	0.56
Biggest 400 stems per hectare	Average stem volume	PEE	−44	−29	−31	−25	−32
Biggest 400 stems per hectare	Average stem volume	F_1	−3.3	−0.5	−0.2	5.7	0.4
Biggest 400 stems per hectare	Average stem volume	F_2	7.9	1.2	−1.9	3.2	2.6
Biggest 400 stems per hectare	Average stem volume	BCE	−22	−17	−15	−13	−17
Biggest 400 stems per hectare	Average stem volume	BCH	18	22	19	22	20

While the choice of taxa for planting in south-east and central Queensland is primarily determined by the various volume comparisons as computed in Table 5, stem form, branching, stem defect and wood quality traits are also factors in this decision.

Though some of the hybrid populations in Table 5 by some measures incur a slight stem volume penalty relative to PCH, the addition of improved stem form, wood quality and windfirmness in the hybrid affirms the current policy of planting the hybrid on all sites in south-east Queensland, and on wet sites in central Queensland.

Clearfall age taxa trial series (464 TBS)

Methods - Clearfall age taxa trial series (464 TBS)

Experiment 464 TBS was established on three swampy sites in 1976 with the objective of comparing the growth of various hybrids and their parental taxa on mounded swamp sites; and investigating population by environment interactions by comparing the relative performances of populations on the three sites and under two fertiliser regimes (low and moderate rates). The main parental taxa were PEE, PCH, *Pinus caribaea* var. *bahamensis* (PCB) and *Pinus caribaea* var. *caribaea* (PCC). A hybrid with *Pinus elliottii* var. *densa* (PED) was also tested.

Genetic material: A maximum of 14 populations were tested at each site. (Refer Table 6). Mostly the populations are either pure taxa or hybrids with PEE, with all populations involving PEE being based on the same 10 PEE female parents.

Site location and trial design: The three Queensland sites of this experiment, two in south-east Queensland and one in central Queensland (Byfield), are briefly described in Table 7.

The two fertiliser treatments were called “moderate” and “low” and involved nitrogen (N), phosphorus (P), potassium (K) supplied as Q5 (N:P:K was 5.1:6.3:3.9) and various trace elements magnesium, iron, manganese, copper, zinc, molybdenum, boron and cobalt supplied as Essminel. The low rate was nominally half of the moderate rate. Fertiliser was applied as split dressings at ages five months and 1.3 years. The moderate rate was approximately 40 kg ha^{-1} N, 48 kg ha^{-1} P and 35 kg ha^{-1} K.

The experimental sites were mounded and each was planted with tubed stock in April 1976 at a nominal 3 m × 3 m spacing, i.e. at 1,111 stems/ha. The Byfield site was thinned to about 275 stems/ha at age 22 years, the Tuan site was pre-commercially thinned to 500 stems/ha at about age 10 years, and the Beerburrum site was essentially unthinned.

All sites suffered extended drought periods. The Byfield site was damaged by three cyclones, and the Tuan site was subjected to damage from hail, salt and flooding.

Measurements and assessments: Growth measures of all three sites were completed in September 2007, age 31 years.

Acoustic velocity and wood core sampling (Plates 1 and 2) was restricted to the two south-east Queensland sites as detailed in Table 8.

Table 6. All populations which are tested in Experiment 464 TBS

Pop. number	Population name	Population details
1	PEE × PCH F_1 hybrid (Byf)	Ten families of PEE × PCH F_1 hybrid seedlings. In particular, ten select PEE parents (five selected on Beerburrum ridge sites, and five on Beerburrum swamp sites) were polycrossed with a 10-parent pollen mix from intensively selected local plus trees of PCH at Byfield. Family identities have been preserved.
2	PEE × PCH F_1 hybrid (Bbm)	Ten families of PEE × PCH F_1 hybrid seedlings. In particular, the same ten select PEE parents (five selected on Beerburrum ridge sites, and five on Beerburrum swamp sites) were polycrossed with a 9-parent pollen mix from intensively selected local plus trees of PCH at Beerburrum. Family identities have been preserved.
3	PEE × PCC F_1	The same ten select PEE parents (five selected on Beerburrum ridge sites, and five on Beerburrum swamp sites) were polycrossed with a low selection intensity 9-tree pollen mix of PCC. Family identities have been preserved.
4	PEE × PCB F_1	The same ten select PEE parents (five selected on Beerburrum ridge sites, and five on Beerburrum swamp sites) were polycrossed with a low selection intensity 9-tree pollen mix of PCB. Family identities have been preserved.
5	BCE	PEE × (PEE × PCH) backcross to the same ten select PEE parents (five selected on Beerburrum ridge sites, and five on Beerburrum swamp sites). Family identities have been preserved.
6	PEE	The same ten select PEE parents (five selected on Beerburrum ridge sites, and five on Beerburrum swamp sites). The first five families were wind-pollinated, and the second five were polycrossed using pollen mixes from selected local plus trees. Family identities have been preserved.
7	PCH (Byf)	A bulk of open pollinated and single cross families of ten intensively selected Byfield PCH plus trees.
8	PCH (Bbm)	A bulk of open pollinated families of seven intensively selected Beerburrum PCH plus trees.
9	PCC	From the "poor" Byfield clone bank, 67B. Batch R211P. Pollen from these clones was used in population number 3.
10	PCB	Open pollinated bulk from crop trees. Batches R215R and R246R.
11	F_2	(F1 PEE × PCH) × (F1 PEE × PCH). A bulk of open pollinated families from nine F1 clones in the mini-orchard, Experiment 509 TBS. Some of the genetic make-up is in common with population number 5.
12	PCH × PCB + PCC × PCB	Four PCH × PCB families and two PCC × PCB families with identities preserved.
13	PED × PCC + PCC × PED	Polycross families of local PCC trees with pollen mix from two *Pinus elliottii* var. *densa* (PED) trees, and a bulk from two PED trees with a pollen mix from five PCC trees. All trees of relatively low selection intensity with family identities preserved.
14	PEE × PCH F1 hybrid (Late)	Pollen from late flowering PCH.

Table 7. Description of the three Queensland sites for Experiment 464 TBS

Experiment number	464.2A	464.2B	464.2C
Location	Byfield	Tuan	Beerburrum
Abbreviation	Byf	Tuan	Bbm
General location	Central coastal Queensland	South-east Queensland	South-east Queensland
State Forest number	865	915	611
Compartment and Logging Area	1 Corio	53 Melaleuca (formerly 64 Green Ridge)	49B Tripconys (formerly 9B Husseys)
Latitude	22° 50´ S	25° 40´ S	26° 56´ S
Longitude	150° 40´ E	152° 46´ E	153° 01´ E
Height (m) above sea level	50	25	20
Soil	Ground-water podzol with immature coffee rock formation between a thin silty surface and a yellow sandy clay sub-soil.	Gleyed podzolic often with gravel or dense concretions in the profile – a silty swamp soil. Drainage is very poor both internally and laterally.	Low humic gley (loamy sand A horizon and a clay B horizon) – a sandy swamp soil. Internal and lateral drainage is better than the other sites in Experiment 464.
Slope	Very slight slope	Very slight slope	Very slight slope
Average annual rainfall (mm)	1,625	1,338	1,766
PCH SI[4] (m)	24	26	29

[4] Site index (SI) is a measure of site quality and is the average height of the tallest 50 trees/ha at age 25 years.

Plate 1. Measuring standing tree acoustic velocity using a FibreGen ® ST300 tool.

Plate 2. Wood core sampling in Experiment 464 TBS

Table 8. Number of core samples analysed and trees assessed for acoustic velocity in experiment 464 TBS (clearfall age trial).

Population	Number of core samples extracted and analysed		Numbers of trees tested for acoustic velocities	
	2B Tuan	2C Beerburrum	2B Tuan	2C Beerburrum
PCH Bbm	20	19	106	20
PCH Byf	20	20	108	20
PCH × PCB + PCC × PCB	20	18	80	21
PEE	20	20	129	20
PEE × PCH F_1 hybrid (Bbm)	20	20	138	21
PEE × PCH F_1 hybrid (Byf)	20	20	144	20
PEE × PCH F_2 hybrid	20	20	135	21
PEE × PCC F_1	-	-	-	20
PEE × PCB F_1	-	-	-	21
BCE	-	-	-	21
PCC	-	-	-	20
PCB	-	-	-	21
PED × PCC + PCC × PED	-	-	-	20

Results - Clearfall age taxa trial series (464 TBS)

All sites suffered extended drought periods. The Byfield site was damaged by three cyclones, and the Tuan site was subjected to damage from hail, salt and flooding.

Percent survival: Percent survival (excludes trees removed as thinnings) of original stems at the first and last measure dropped by only 6% between the first and last measures at the Byfield and Tuan sites but survival at the unthinned Beerburrum site dropped by 19%, including a 9% drop between ages 22 yr and 31 yr. (Refer Nester 2009b for details).

Stocking rate: In Table 9 the final stocking rates for Beerburrum mostly reflect survival rates, but the final stocking rates for Byfield might reflect various susceptibilities to cyclonic wind damage or reflect (unknown) thinning prescriptions or reflect a combination of both.

Tuan has the smallest range in final stocking rates, viz. from about 380 stems/ha for BCE through to about 480 stems/ha for PEE × PCH F1 hybrid (Byf).

Table 9. Stocking rate of live useful stems at the 2007 measure of each site in Expt 464 TBS. Results from the statistical analysis of population main effects (averaged over fertilisers) are summarized in the light grey-shaded cells, and population × fertiliser interactions are summarized in the dark grey-shaded cells. (LSD = least significant difference).

Population	2A Byf	2B Tuan	2C Bbm
	31.4 yr	31.4 yr	31.5 yr
PEE × PCH F1 hybrid (Byf)	326	482	831
PEE × PCH F1 hybrid (Bbm)	329	472	819
PEE × PCC F1	351	426	912
PEE × PCB F1	268	471	949
BCE	276	378	895
PEE	239	416	880
PCH (Byf)	255	413	905
PCH (Bbm)	268	406	871
PCC	310	431	951
PCB	165	455	940
F2	250	466	849
PCH × PCB + PCC × PCB	203	463	873
PED × PCC + PCC × PED			939
Grand mean	270	440	893
Significance	***	NS	NS
5% LSD	56.7	79.9	99
F Probability	0.0000	0.2186	0.1290
Interaction F Probability	0.291	0.227	0.737
Interaction significance	NS	NS	NS

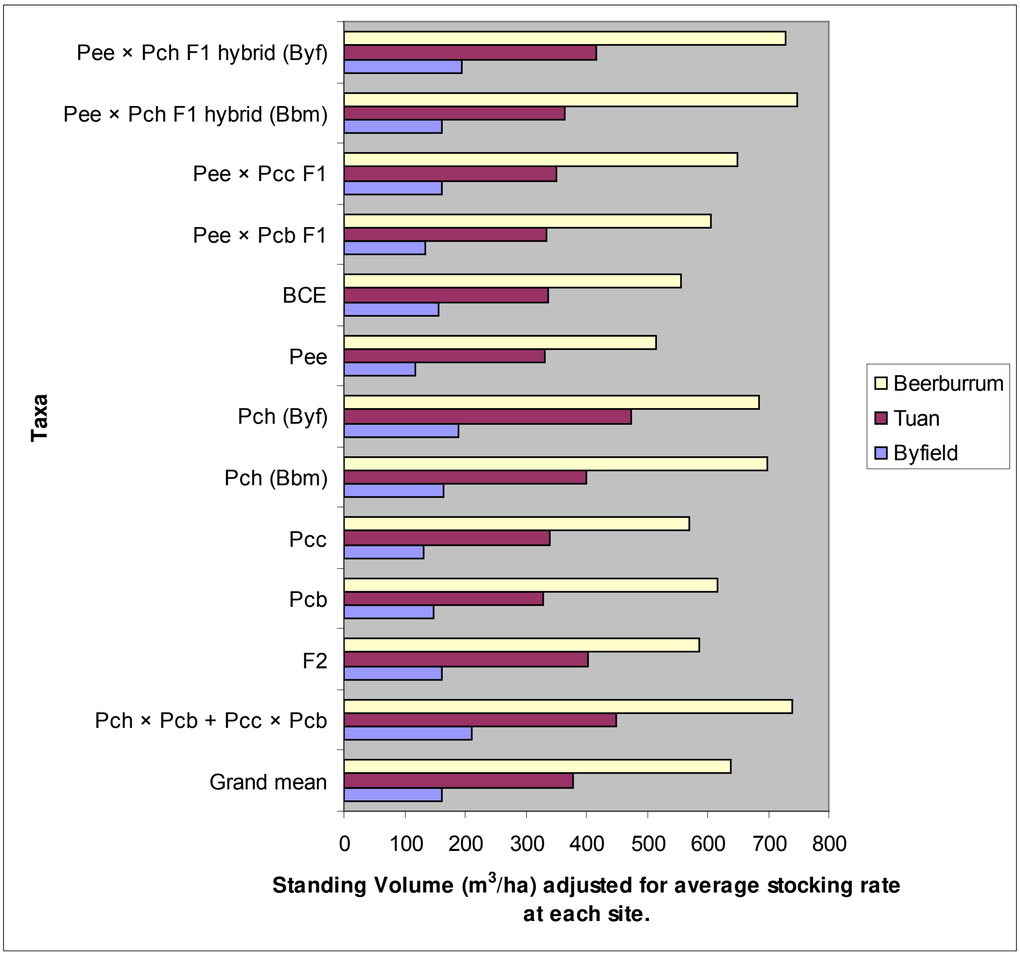


Figure 12: Standing volume (m^3/ha) adjusted for average stocking rate at each site (Beerburrum: 893 stems per ha, Tuan: 440 sph and Byfield 270 sph).

Standing volume: With regard to the standing volumes in Table 10 and Figure 12, PEE was the only population which was in the bottom three at all three sites, whether considering observed volumes or adjusted volumes. No population was correspondingly in the top three at all three sites. However PEE × PCH F_1 hybrid (Byf) and the PCH × PCB + PCC × PCB mixture were in the top three for adjusted volume at all three sites, although they were in the top three for observed volumes at only two of the sites.

After adjusting for stocking rates, increased fertiliser boosted adjusted standing volume by about 40 m^3ha^{-1} at Byfield, by about 30 m^3ha^{-1} at Tuan and by about 70 m^3ha^{-1} at Beerburrum.

Table 10. Standing volume (m^3ha^{-1}, estimated total underbark volume above 15cm stumps) of live useful stems at the 2007 measure of each site in Experiment 464 TBS. The last three columns refer to analyses of covariance separately adjusting final standing volume for each population at each site to the final overall average stocking rate specific to that site. PEE, PCH and their hybrids are shown in red, blue and green font respectively. Within a column (site) the three "best" populations are shaded lavender and the three "worst" populations are shaded tan.

Population		Byf	Tuan	Bbm	Adjusted for stocking rate		
		31.4 yr	31.4 yr	31.5 yr	Byf	Tuan	Bbm
PEE × PCH F_1 hybrid (Byf)		229	457	675	195	417	730
PEE × PCH F_1 hybrid (Bbm)		199	395	684	163	364	749
PEE × PCC F_1		210	337	665	161	350	649
PEE × PCB F_1		133	363	654	134	333	605
BCE		161	276	556	157	336	555
PEE		100	308	504	119	332	516
PCH (Byf)		179	448	694	188	474	684
PCH (Bbm)		163	366	679	164	399	699
PCC		157	330	619	132	339	569
PCB		85	344	656	149	330	616
F_2		150	429	547	162	404	586
PCH × PCB + PCC × PCB		171	470	722	212	448	740
PED × PCC + PCC × PED				635			595
Grand mean		161	377	638	161	377	638
Sub-population		Byf	Tuan	Bbm			
PCH × PCB		267	564	706			
PCC × PCB		108	413	815			
PCB × PCH		122	356	520			
PED × PCC				661			
PCC × PED				451			
PEE × PCH F_1 hybrid (Late)				498			

Population × fertiliser interactions: Apart from presence of foxtails at Byfield there was not much evidence of population × fertiliser interactions.

Population × site interactions: Overall there is a strong population × site interaction for survival, fairly weak population × site interactions for growth rate and productivity, a moderate population × site interaction for straightness, and probably a strong population × site interaction for forks.

Survival: Post-establishment survival was good at the thinned Byfield and Tuan sites but poor at the unthinned Beerburrum site. Perhaps the Beerburrum site simply could not sustain such relatively high stocking rates during the extended drought periods. Survival for FPQ's favoured PEE × PCH F_1 hybrid was very poor at this Beerburrum site—having about 90% survival at age 5, 80% survival at age 20 and 70% survival at age 30 years. This suggests that FPQ should be wary of implementing direct regimes of high stocking rate using this hybrid on sites likely to be subjected to extended drought periods. Unfortunately it seems impossible to ascertain what should constitute a "high stocking rate". If the site had been planted at about 800 stems/ha instead of about 1,100 stems/ha then perhaps survival might have remained relatively good despite not being thinned. At the very least FPQ needs to remain vigilant concerning this matter.

Qualitative ratings of taxa: The relative performances of the populations and sub-populations at each site separately were merged to generate a single qualitative rating for performance across all three sites. (Table 11).

It must be emphasised that Table 6 is based solely on Experiment 464 TBS, and so refers to just one (poorly-drained) site type subjected to extended drought periods. Furthermore the tested genotypes are possibly unrepresentative of the taxa, nor sufficiently selected to represent the full potential of any of the taxa on these kinds of sites under the prevailing conditions.

Table 11. Qualitative ratings[5] for various taxa and hybrids for some important criteria.

Population	%Surv	Growth	Strness	Ramicorns	Forks	Windfirmness
PCB	Moderate	Moderate	Poor	Moderate	Good	Poor
PCC	Good	Poor	Good	Good	Good	Moderate
PCH	Moderate	Good	Poor	Good	Good	Poor
PEE	Moderate	Poor	Moderate	Poor	Good	Good
PCH × PCB	Moderate	Good	Poor	Good	Moderate	Poor
PCC × PCB	Good	Good	Moderate	Good	Good	Poor
PEE × PCB	Good	Poor	Moderate	Poor	Poor	Good
PEE × PCC	Poor	Moderate	Good	Moderate	Good	Good
PEE × PCH	Moderate	Moderate	Good	Moderate	Moderate	Good
PED × PCC	Good	Moderate	Moderate	Moderate	Poor	Poor
BCE	Moderate	Poor	Moderate	Poor	Poor	Good

Basic density: A comparison of the average resin-extracted and basal area weighted basic density of inner wood (Pith-GR15), outer wood (GR16-30) and whole core samples across various taxa in two sites in Experiment 464 TBS is charted in Figure 13. The taxa comparisons are similar within site to those observed in Experiment 674 TBS for the same taxa. PEE is denser than PCH with hybrids intermediate between the parental averages. However the wood densities recorded at these two sites follow the usual latitudinal trend with higher values recorded at Tuan than at Beerburrum, in contrast to the results found in Experiment 674 TBS.

[5] Refer Nester (2009b) (pages 56 – 62) for full details of ranking system used

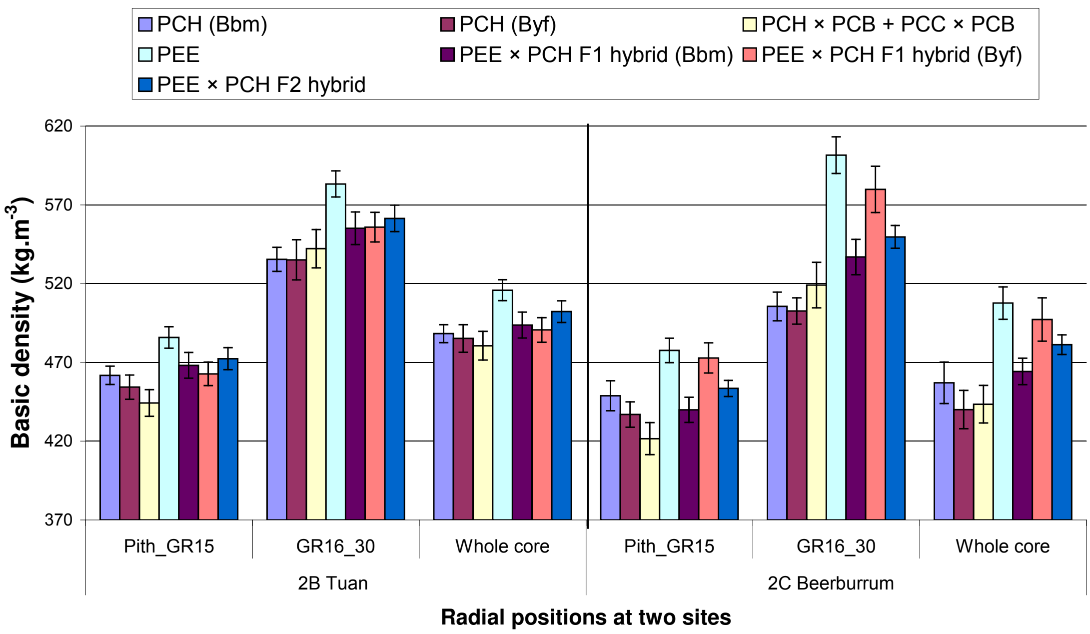


Figure 13. Average resin-extracted basic density of basal area weighted inner wood (Pith_GR15), outer wood (GR16_30) and whole core samples (with standard error bars) across various taxa in two sites in Experiment 464 TBS.

<u>Radial variation in basic density:</u> The average resin-extracted basic density trends for pith to bark 5-ring segments are graphed in Figure 14. The comparison of density trends in Figure 14 suggests that most of the taxa achieved a mature density level by the 11-15 growth ring segment when grown at Beerburrum whereas this mature density plateau was not achieved at Tuan until the 16-20 growth ring segment or about five years later.

The average predominant height for Beerburrum was 30.6m compared to 28.5m for Tuan when averaged over all taxa (Nester 2009b). Nester (pers. comm.) suggests that the higher predominant height for Beerburrum may in part be attributed to its higher stocking rate and this higher unthinned stocking rate may have induced wood density at breast height to peak at an earlier age. This would also be consistent with widely spaced trees maintaining greater crown depth for longer than do closely spaced trees, which in turn relates to the theory that mature wood forms in the base of the stem beneath the lowest green branch.

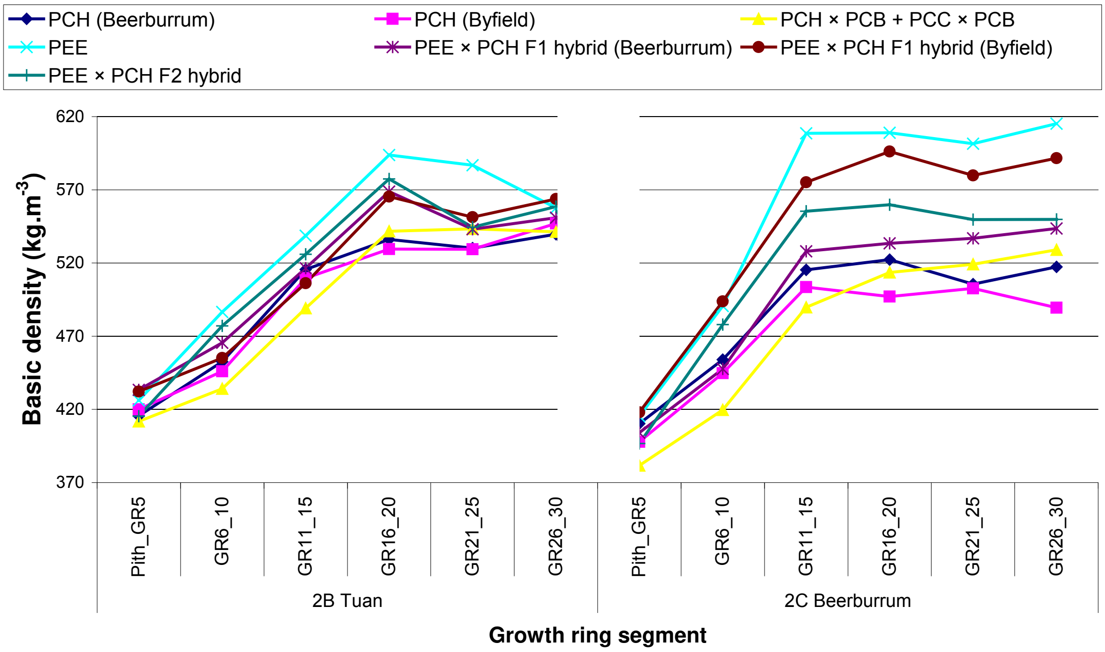


Figure 14. Average resin-extracted basic density of radial 5-growth ring segments by taxa and site in Experiment 464 TBS.

It is also clear in Figure 14 that the expression of wood density differences among the taxa was more pronounced at Beerburrum than at Tuan, although these differences are not statistically significant in the inner five growth rings (pith to growth ring 5; data not shown) at either site. However, given the earlier maturity and higher density values for the PEE and the hybrids at Beerburrum it would be interesting to test whether these density trends along with the better growth at Beerburrum significantly enhanced the graded recovery of these taxa compared to that from the Tuan site. If the latter was confirmed one would need to consider if higher stockings on more productive sites could be used to optimise a grade recovery and stand value proposition, given that average piece size would be reduced and therefore handling and processing costs increased.

Standing tree acoustic velocity and predicted Modulus of Elasticity

Mean standing tree acoustic velocities obtained with a FibreGen® ST300 tool for the trees sampled within each family for basic density in Experiment 464 TBS were used to predict modulus of elasticity (MoE) as presented in Figure 15. Estimates of standing tree stiffness were calculated using the product of acoustic velocity squared and weighted whole core basic density:

$$MoE = v^2 \times BD$$

Traditionally, acoustic dynamic stiffness has been calculated using green density (Mora *et al.* 2009) but green densities were not estimated in this study. The relative differences between taxa in percentage terms should differ little using different density estimates such as basic, air-dry or green. However, it should be emphasised that these estimates are not directly comparable to those based on other estimates such as sawmill air-dry quality assurance test averages conducted on dry boards tested at 12% moisture content. Using basic density will bias estimates downwards from dynamic MoEs estimated using green density or air-dry density. Mora *et al.* (2009)

note the bias inherent in standing tree versus log or SilviScan estimates of dynamic MoE and the need to establish relationships between them to allow values to be converted.

PEE, PEE × PCH and PCH ranked in the same descending order for mean wood MoE at the two sites. However, at the Beerburrum site the taxa means were far more widely dispersed than at the Tuan site. Also at Beerburrum, slash pine had higher MoE than at Tuan while the other taxa had lower MoE, though most of these differences were not statistically significant.

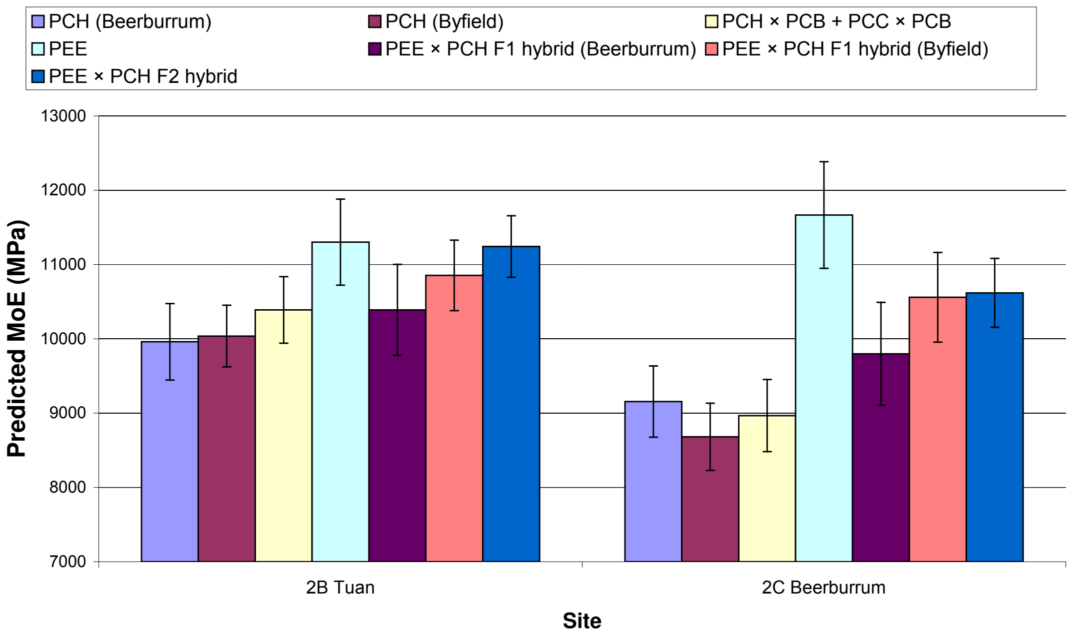


Figure 15. Mean estimated MoE of selected trees of various taxa on two sites sampled in Experiment 464 TBS (standard error bars included) assessed with an ST300 tool (estimates based on the same trees as used for basic density assessment).

The mean acoustic velocity values for the main taxa of interest, as well as several other taxa sampled at the Beerburrum site only, are charted in Figure 16. It is clear from this chart that all taxa that include PEE in their pedigree – whether at the species level or in hybrid or backcross taxa – have higher velocities (and therefore predicted wood stiffness) than the Caribbean pine varietal taxa or PCH and PCB interspecific and varietal crosses. At the varietal level both PCB and PCC had slightly higher velocities than PCH although their distributions overlap.

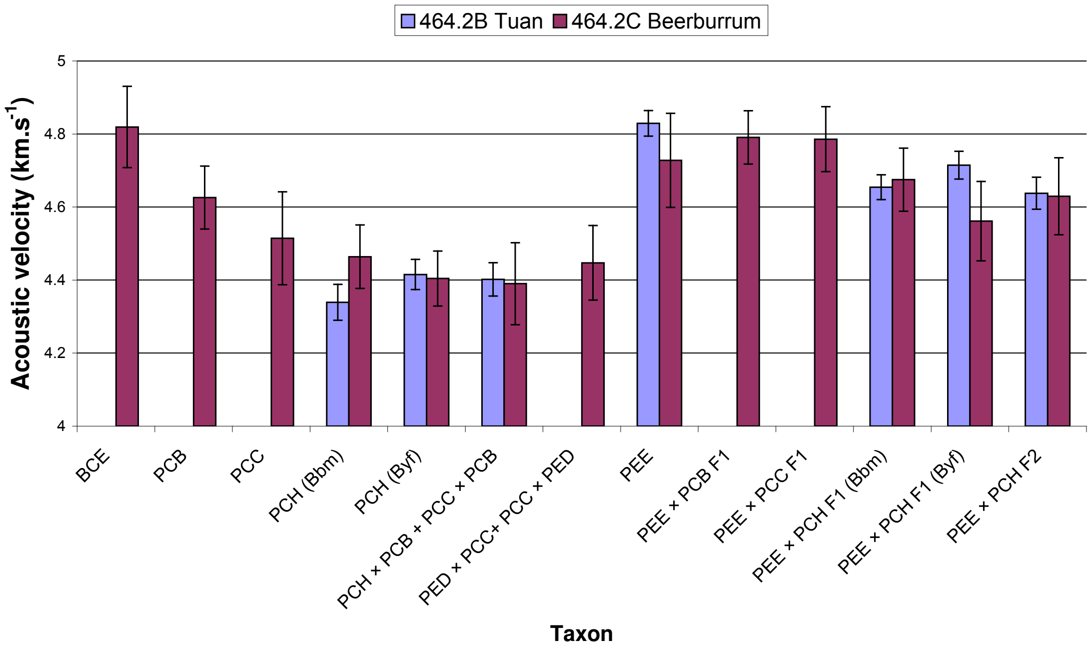


Figure 16. Mean standing tree acoustic velocities among taxa on two sites sampled in Experiment 464 (standard error bars included); assessed with an ST300 tool.

Discussion – Clearfall age trial - 464 TBS

Overall, the experiment provides an endorsement of FPQ's current practice of planting the PEE × PCH hybrid on the mounded swamp sites that this experiment was designed to examine. The experiment provided a good test of the taxa, with sites suffering various levels of damage from hail, drought, flood, cyclone and salt, though fire was fortunately excluded. Drought and flood are tough extremes for any tree to tolerate, and three cyclones are a good test of windfirmness. However, it should be emphasised that these results on swamp sites do not necessarily apply to well-drained sites.

While PEE × PCH was the best overall performer across sites taking a number of growth and defect parameters into account, the results also indicated that it might experience some moderate stock losses during extended drought periods if high stocking direct regimes are attempted. The hybrid suffered 30% stocking losses at the unthinned Beerburrum site when planted at about 1,100 stems/ha. Though this result provides useful information on the upper limits for stocking at similar sites, it is unlikely to impact on the choice of taxon for replanting as PEE × PCH is planted at less than 900 stems per hectare in Queensland.

Notably, population × site interactions for growth traits were low, even though there were some rank changes of taxa between sites. However, there were strong population × site interactions for survival, strong interactions for "foxtails" and possibly other defect parameters such as straightness and presence of forks. The moderate fertiliser rate boosted standing volume by about 30+ m^3ha^{-1}, but other than foxtails at Byfield there was little evidence of a population × fertiliser interaction.

A possible shortcoming of the experiment is that there were no extended wet periods during and after planting, so it may not reflect the effects of wind damage and waterlogging that often occur at young ages during normal wet seasons. However, the climate change prediction for south-east Queensland includes increased severity of storms but an overall reduction in rainfall. Thus this experiment might actually be a good model for "swampy' sites of the future in south-east Queensland. Again PEE × PCH seems to be a good all-round performer for such sites.

The PEE × PCB and PCC × PCB taxa had exceptionally good survival rates. It is possible that good survival on these swampy sites when subjected to extended drought periods (by coastal Queensland standards) reflects a general drought tolerance which is transferable to other sites and soils.

Of the alternative taxa evaluated in this study, the PCC × PCB hybrid possibly provides the easiest method of boosting overall productivity on swampy sites in south-east Queensland, partly because of its improved survival rate. However, this taxon would be extremely prone to damage in severe windstorms. A further option not evaluated in this trial, though its parental varieties PCC and PCH were tested, is the PCC × PCH (*Pinus caribaea* var. *caribaea* x *Pinus caribaea* var. *hondurensis*) inter-variety hybrid. This hybrid is showing strong promise in other trials currently up to 22 years old, and appears to combine the best qualities of the parent species listed in Table 10: primarily, the fast growth of PCH with the improved windfirmness and straightness of PCC. Field observations suggest the hybrid equals or surpasses the better parent in all three traits. Further analysis of taxa trials containing PCC × PCH, and a comparison of its wood quality with PCH, will be high priorities for further study.

Plate 3. PCH plot in Experiment 464 TBS at Tuan.

Discussion of wood properties for thinnings and clearfall age trials - 674 TBS and 464 TBS

The rankings of the taxa for wood density, MoE and spiral grain were broadly consistent across the four sites studied in these two experiments, with PEE consistently superior to PCH in density and MoE, yet consistently inferior for spiral grain (studied at two sites). Both the wood density and spiral grain of the PEE × PCH hybrid were consistently intermediate between the two parental species at all ages and sites. This is consistent with previous results found by Kain (2003) in 674 TBS.

With regard to MoE (predicted from acoustic velocity and basic density), PEE × PCH tended to be much more similar to PEE than to PCH, which was around 10 to 20% lower than the other taxa at both sites. In the thinning age experiment (674 TBS), PEE × PCH notably had very similar or equivalent estimated MoE to PEE. In the clearfall age experiment (464 TBS), the MoE of the hybrid was also more similar to PEE than to PCH. If these findings, particularly those in the thinnings experiment, are replicated more generally it would be very positive as the hybrids have been the dominant taxon planted for the last decade or more in southeast and central coastal Queensland where they supplanted PCH as the preferred taxon to replace PEE in the planting program.

The ranking of sites and regions for wood properties are less consistent between these two studies. For example, in 674 TBS wood density at Tuan was lower than at Beerburrum, but higher in 464 TBS, with the latter reflecting the more usual ranking of these locations. The reasons for these site differences need to be understood before it can be speculated whether they offer any practical opportunities to exploit with strategic taxon deployment and management. Further studies of edaphic characteristics or other specific features of the four sites would be needed to uncover any possible reasons for the reversal of rankings.

The generally (though usually not significantly) higher MoE and wood density of the F_2 hybrid than the F_1 hybrid found in both experiments has also been found in other studies (e.g. in Experiment 195 MBR; Harding *et al.* 2009a) and is likely to be due to the effect of sampling different sets of parents. However, it is also worth noting that the parents of the F_1 hybrid population had undergone an additional cycle of selection for growth and form traits relative to those of the F_2 hybrid. This selection could potentially have induced a correlated genetic decrease in MoE and wood density due to the weak to moderate adverse genetic relationship between growth and wood density in PCH and to a lesser extent in the hybrid (Kain 2003).

A consistent and clear trend in both the experiments sampled in this study is that slash pine mature wood tends to increase in density at a faster rate than PCH and the hybrid taxa. However, targeted sawing and grade recovery studies will be essential to establish the impact on structural stress grade distribution of these differences in wood density and standing tree stiffness. It is also clear that site differences impact the expression of wood density differences among the taxa. In these experiments separation in density trends was more pronounced at Tuan in Experiment 674 TBS and at Beerburrum in Experiment 464 TBS. For Experiment 464 TBS the earlier maturity and higher density values for the PEE and the hybrids at Beerburrum may translate into higher grade recovery. It would be interesting to test whether these density trends along with the better growth at Beerburrum significantly enhanced the graded recovery of these taxa compared to Tuan. If the latter was confirmed one would need to consider if higher stockings on more productive sites could be used to optimise a grade recovery and stand value proposition, given that average piece size would be reduced and therefore handling and processing costs increased.

Conclusions - Thinnings and clearfall age taxa trials -674 TBS and 464 TBS

The following overall conclusions can be drawn from the taxa comparison studies:

1. Caribbean pine (PCH) and the slash x Caribbean pine hybrid (PEE × PCH) have similar stem volume on average across a range of sites, far surpassing that of slash pine (PEE);
2. Outerwood MoE of the PEE × PCH hybrid (predicted using acoustic methods) was more similar to the stiffer parent, slash pine, than to Caribbean pine on three of the four sites examined;
3. The superiority of slash pine wood density over Caribbean pine and the PEE × PCH hybrid began to emerge only after the first five growth rings, and was greatest in the outerwood after rings 16-20, while the hybrid remained intermediate between the parental species;
4. Slash pine had significantly higher spiral grain than Caribbean pine at both Tuan and Beerburrum, and significantly higher than the PEE × PCH hybrid at one site. Spiral grain in the PEE × PCH hybrid varied greatly between the two sites;
5. The F_2 hybrid had higher basic density, acoustic velocity and predicted MoE than the F_1 hybrid on all sites examined, though the difference was rarely significant and most likely a genetic sampling effect;
6. Relative rankings of PEE, PCH and PEE x PCH in all wood properties were very consistent across sites, though the *differences* between the taxa were much greater on some sites than others. No relationship to trends in latitude or other known site characteristics could be identified;
7. Relative rankings of the Tuan and Beerburrum regions for wood density were reversed in these two experiments. Further investigation of the characteristics of the four sites may help elucidate the causes of this site-related variation in wood properties and that described in point 6.

Hybrid pine (Series IV) clonal trial series (89 PPG)

Methods - Hybrid pine (Series IV) clonal trial series (89 PPG)

Genetic material: The hybrid families in this trial were generated specifically for the purpose of inclusion in clonal tests. Parents were selected on the basis of their genetic merit (i.e. breeding values) as determined by an evaluation of all hybrid progeny test data (over 85,000 trees) for volume and stem straightness, resulting in a substantial improvement in the genetic merit of the families tested.

Resources available allowed field testing of approximately 2,000 clones. The Series IV clonal testing program evaluated an average of 125 clones per family. Full details of the families included in the Series IV tests are given in Table 12. In addition, the trials also included the best Series I clone (c545), six elite Series II clones, one F_1 hybrid family (2ee1-102 × 2ch4-098)[6], and two seedling controls (PEE × PCH F_2 hybrid and PCH seedlots collected in clonal seed orchards).

Table 12. Families and number of clones per family included in Series IV tests (Experiment 89 PPG)

Family	Hybrid	No. Clones
1ee1-053 × 1ch4-097	F_1	2†
1ee1-161 × 1ch4-097	F_1	60
1ee1-161 × 1ch4-140	F_1	36
1ee1-161 × 2ch4-151‡	F_1	138
1ee2-044 × 1ch4-115	F_1	4†
1ee2-044 × 2ch4-219	F_1	2†
1ee2-056 × 1ch4-087	F_1	142
1ee2-056 × 1ch4-115	F_1	106
2ee1-095 × 2ch4-151‡	F_1	44
2ee1-095 × 2ch4-219‡	F_1	21
2ee1-102 × 2ch4-098‡	F_1	148
2ee1-166 × 2ch4-151	F_1	68
2ee1-166 × 2ch4-210‡	F_1	86
2ee1-166 × 2ch4-219	F_1	91
2ee1-170 x 1ch4-087	F_1	150
2ee1-170 × 1ch6-029‡	F_1	172
eh0097 × eh0042	F_2	141
eh0105 × eh0042‡	F_2	143
eh0106 × eh0042	F_2	149
eh0107 × eh0083‡	F_2	147
eh0107 × eh0107	F_2	138

† These three families were not included in calculations of the number of families or the number of clones per family reported in the text.
‡ Eight families sampled for measurement of acoustic velocity using an ST300 – see materials and methods in Dieters (2009a).

[6] This is the same family from which c545 and many Series II clones were selected, and which was also included in the Series IV tests (see Table 11).

Experimental Design: Each clone[7] is represented by three ramets on each site, tested on up to seven sites in Queensland and two sites in northern NSW (Table 13). A resolvable incomplete block design was used for each test site, with 24-tree incomplete blocks (3 rows × 8 trees) and three replicates. Single-tree plots were used for each clone (or entry), so that each replicate included only one tree of each clone.

Measurements and Assessments:

Growth and form: All surviving trees were measured at approximately two and four years after planting for diameter at breast height over bark and total tree height. At four years of age all trees were assessed for stem straightness, presence/absence of double leaders and ramicorn branches, branch angle and branch diameter. In addition, based on comments recorded against each tree during the measurement, codes were also created for wind-firmness and for foxtails. Diameter and height data were used to estimate the conical volume of each tree (dm^3).

Acoustic velocity: At age five years the controls plus a subset of the clones were selected for evaluation of acoustic velocity using a FibreGen ® ST300 tool in two tests located at Tuan (89c and 89d) on contrasting poorly-drained (Boonooroo) and well-drained (Cowra) sites respectively. The sampling strategy for acoustic velocity used growth data to rank the families, and then selected eight families that spanned the range (refer to the footnote to Table 12). From each of these 8 families, 20 clones were randomly selected for sampling and three ramets per clone (at each site) were assessed. In addition, all 161 of the most promising clones were also added to the list to be assessed with the ST300. Acoustic velocity was assessed on two sides of each tree, with each reading being calculated from eight 'hits' – the two highest and two lowest were discarded and an average recorded from the other four hits on each side of each tree. Acoustic velocity recordings were divided by 100,000 to express in km/sec and then squared; the modulus of elasticity (MOE) is directly proportional to the square of acoustic velocity.

[7] A smaller number of Series IV clones were tested on the NSW sites (1,335 and 567) compared to 1,600 to 1,950 on SEQ sites and 1,478 at Byfield

Table 13. Site and location details of Series IV clonal tests (Experiment 89 PPG)

Experiment Number	**89a**	**89b**	**89c and 89d**	**89e and 89f**	**89g**	**89h**	**89i**
Location Compartment	Byfield 201 Waterpark	Wongi 207 Richmond	Tuan 221 Boonooroo and 201 Cowra	Toolara 23 Sugarloaf and 208A Round	Beerburrum 221 Woodford	Whiporie 196 & 198 SF 928	Barragunda 6 Carwong SF 345
Latitude	22° 53´ S	25° 24´ S	25° 39´ S	26° 08´ S	26° 56´ S	29° 15´ S	29° 02´ S
Longitude	150° 40´E	152° 36´E	152° 48´E	152° 57´E	152° 50´E	153° 02´E	152° 57´E
Elevation	38m	45m	15m	E = 65m, F = 85	150m	60m	50m
Soil Type	Grey earth, podzol & siliceous sands	Not recorded	C = Grey earth D = Podzol and grey podzolic	E = Red podzolic, G/Y earth F= Yellow earth	Yellow podzolic, yellow earth, grey earth	Not described	Not described
Planted	10/2003	9/2003	8/2003	E= 9/2003, F = 10/2003	9/2003	2/2004	2/204
Spacing (row × tree, m)	5 × 2.4	6 × 2	C = 6 × 2, D = 5 × 2.4	5 × 2.4	4.5 × 2.6	4.2 × 2.5	4.2 × 2.5
Nearest Rainfall Data	Byfield Childs Rd Station	Maryborough Station	Tuan Creek Forest Station	Toolara Forestry Station	Beerburrum Forest Station	Casino, NSW	Casino, NSW
Mean annual rainfall (mm)	1661	1152	1251	1282	1384	1,029	1,029
10^{th} percentile	1176	751	801	894	908		
90^{th} percentile	2289	1547	1777	1827	1893		

Wood property assessments: Sampling of clones for the collection of cores[8] to determine wood properties was restricted to clones that were most promising for deployment. Sampling was restricted to the two sites where acoustic velocity was assessed. A total of 29 clones were selected based on their overall performance for growth, form and acoustic velocity traits, with a variable number of trees per clone (6, 5 if poor survival) depending on survival and initial replication. Consequently only a relatively few clones were core sampled in each family, and only 7 of the 21 families were sampled. Families and clones that were wood sampled are representative of those available for operational use.

The average angle of spiral grain was assessed by opening bark windows on directly opposite sides of each sampled tree, highlighting the grain direction by using a scribing tool with a freely pivoting handle and measuring the grain angle with a Spiralite digital display levelling tool.

Traits for which data from the increment cores were available for analysis were:

- Un-extracted[9] basic density – area weighted average
- Average spiral grain angle
- Predicted modulus of elasticity (MoE) based on the product of average basic density and velocity-squared

Results - Hybrid pine (Series IV) clonal trial series (89 PPG)

Mean performance of the clones across the seven trials in Queensland indicate that all tests were developing normally (height growth of approximately 1.5m/year), with a similar level of key growth and form traits (Table 14). There was however a substantial range in the growth rates – the fastest growing site (89e) had more than double the volume of the slowest growing site (89c). Further, it can be noted that the fastest growing site also had the highest incidence of double leaders, ramicorn branches and foxtails (Table 14). Selection against these traits may therefore be most important on the highest productivity sites. Differences in acoustic velocity between the two sites assessed were however relatively small (Table 14). Unfortunately, the fastest growing site (89e) was not assessed for acoustic velocity.

A comparison of the average stem volume at age 4 years of outcrossed[10] clones that are common to all sites (including the two NSW sites) with F2 seedling controls is presented in Figure 17.

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[8] Bark to bark diametral 12mm increment core removed from middle of nearest inter-whorl below breast height at approximately 1.1 to 1.2m.

[9] The young age (5 years) at sampling in 89PPG means that resin defects (resin streaks and shakes) and heartwood formation were not present so increment core samples were not resin–extracted as a cost-saving measure and as variation in background sapwood resin levels (3-4 % by weight) should be small. In contrast, wood core samples from older trials were unavoidably impacted by varying levels of resin flooding associated with streaks and resin shake, which can greatly inflate wood density values. Resin extraction of wood samples from older trees is needed to minimise variation in wood density resulting from the presence of resin flooding from resin defects and from heartwood deposition.

[10] Clones arising from the selfed cross of Series 1 clone c545 are excluded from Appendix 4 data

Table 14. Site means for seven tests established in Queensland.

Site/Trait†	89a	89b	89c	89d	89e	89f	89g
Ht2 (m)	—	4.1	3.2	3.9	4.5	3.6	4.1
Ht4 (m)	6.1	6.1	5.3	7.1	7.5	6.5	6.9
Vol4 (dm^3)	20.2	17.1	13.2	17.1	34.2	23.2	25.3
Str (1-6)	—	4.1	3.3	3.7	3.6	4.3	4.3
DL (%)	—	3.4	2.8	9.8	14.2	6.4	3.5
RM (%)	—	33.6	24.7	35.6	43.7	38.3	21.8
BA (1-9)	—	7.0	7.3	7.4	7.3	6.8	6.8
BD (mm)	—	14.6	14.1	17.1	17.5	13.9	13.5
Fox (%)	—	0.4	0.1	0.7	1.2	0.5	0.5
$Vel1^2$ $(km/sec)^2$	—	—	7.2	7.6	—	—	—
$Vel2^2$ $(km/sec)^2$	—	—	7.2	7.6	—	—	—

† Ht2 = height at 2 years, Ht4 = height at 4 years, Str = straightness, DL = double leaders, RM = ramicorn branches, BA = branch angle, BD = branch diameter, Fox = foxtails, $Vel1^2$ = acoustic velocity squared first side, and $Vel2^2$ = acoustic velocity squared on opposite side of tree.

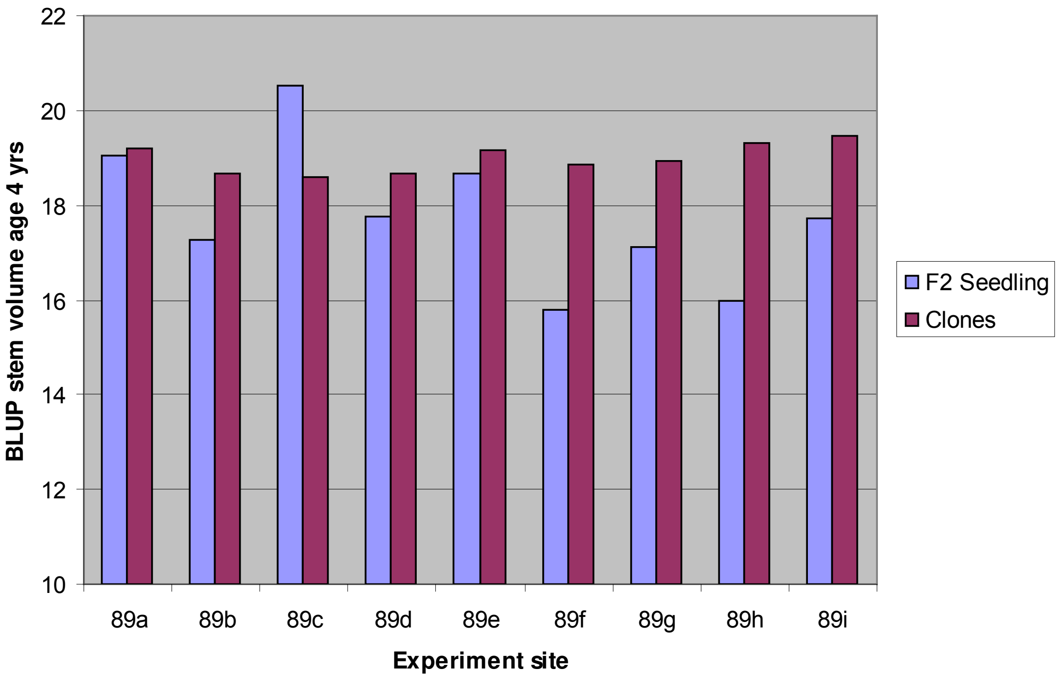


Figure 17: Comparison of mean clone and F2 seedling stem volume at age 4 years for outcrossed hybrid pine clones that are common across 9 tests sites. Sites 89h and 89i are in northern NSW. Refer Table 13 for site details

Broad sense heritability (H^2) indicates the relative importance of variation between clones compared to the total amount of variation measured in each trait at each site. The expression of traits with relatively high H^2 values is largely due to genetic mechanisms, while those with lower H^2 are more influenced by environmental factors. Tree height, branch angle and acoustic velocity were largely controlled by genetic effects with H^2 values typically exceeding 0.5, but traits such as double leaders, ramicorn branching, branch size and fox-tailing were much more influenced by random environmental variation within each site (Table 15). However, for all traits examined there were only relatively low levels of clone × site interactions as indicated by the high type B genetic correlations (Table 15)[11]; for all traits, except foxtails, type B genetic correlations exceeded 0.8 (data not shown). This does not mean that all clones will rank in the same way on all sites, but rather that variation due to re-ranking of clones was relatively unimportant, and that the performance of clones across sites was highly correlated.

Table 15. Broad sense heritability and type B genetic correlations.

	Broad Sense Heritability (H^2)							$r_{B(G)}$ †
Site/Trait‡	**89a**	**89b**	**89c**	**89d**	**89e**	**89f**	**89g**	
Ht2 (m)	—	0.61	0.38	0.54	0.59	0.48	0.42	0.92
Ht4 (m)	0.43	0.70	0.54	0.67	0.69	0.64	0.60	0.93
Vol4 (dm^3)	0.35	0.47	0.34	0.55	0.58	0.49	0.42	0.85
Str (1-6)	—	0.37	0.46	0.40	0.44	0.32	0.34	0.84
DL (%)	—	0.16	0.08	0.14	0.11	0.14	0.13	0.83
RM (%)	—	0.12	0.09	0.16	0.12	0.16	0.09	0.82
BA (1-9)	—	0.55	0.53	0.49	0.53	0.53	0.60	0.96
BD (mm)	—	0.36	0.25	0.38	0.36	0.44	0.41	0.88
Fox (%)	—	0.28	0.00	0.37	0.15	0.34	0.17	0.75
$Vel1^2$ $(km/sec)^2$	—	—	0.74	0.68	—	—	—	0.91
$Vel2^2$ $(km/sec)^2$	—	—	0.72	0.68	—	—	—	0.90

† Type B (total) genetic correlation for same trait measured across all sites.
‡ Traits as described in footnote to Table 7. Further, the heritability of wind-firmness was effectively zero on all sites due to limited variation recorded in this trait. Therefore, this trait has been excluded from any analyses presented.

Examination of the association (correlation) between the BLUP[12]s for each trait in each clone indicates the level of genetic association between traits in this group of clones. Positive correlations indicate that clones with a high value in one trait will tend to have a high value in the second trait. These correlations indicate that the growth traits (volume and height) were very strongly correlated, as were branch diameter and the growth traits, and the two measures of acoustic velocity (Table 16). Stem straightness was however negatively correlated with all other traits measured, while acoustic velocity was positively associated with some traits and negatively associated with others (Table 14).

[11] A type B genetic correlation of 0.67 indicates that variation due to clone × site interactions is half the size of the variation between clones.
[12] Best Linear Unbiased Predictions

Table 16. Correlations among trait BLUPs of all Series IV clones across the seven Queensland test sites.

Trait	Vol4	Ht4	Str	DL	RM	BA	BD	Fox	Vel1^2
Ht4	0.87								
Str	-0.18	-0.27							
DL	0.09	0.11	-0.28						
RM	0.44	0.51	-0.36	0.48					
BA	0.42	0.59	-0.30	0.01	0.14				
BD	0.71	0.78	-0.33	0.18	0.50	0.28			
Fox	0.06	0.14	-0.22	-0.07	0.05	0.11	0.39		
Vel1^2	-0.13	0.22	-0.29	-0.08	0.10	0.20	-0.35	0.52	
Vel2^2	-0.23	0.19	-0.23	-0.14	0.13	0.29	-0.46	0.46	0.98

Note however, that all positive associations are not necessarily favorable, and *vice versa*. For example the strong positive association between branch diameter and both height and volume (Table 16) is unfavorable – faster growing clones also tend to have large branches. Further, we can see that branch diameter is negatively correlated with acoustic velocity, i.e. this is a favourable association as trees with smaller branches will have faster acoustic velocity. The strong positive association between foxtails and acoustic velocity (clones with foxtails have faster acoustic velocity) is unfavorable. This complex pattern of favorable and adverse correlations among the selection traits makes selection of clones that combine all required characteristics problematic, therefore requiring screening of large numbers of clones to find the rare clone that combines all/most of the desired characteristics.

The 161 clones selected in early 2008 by FPQ for evaluation of wood properties came from 18 of the 21 families included in this set of clonal tests (Table 17). One family with 60 clones (1ee1-161 × 1ch4-097) had no clones selected, while three of the families (2ee1-095 × 2ch4-151, 2ee1-095 × 2ch4-219, and 2ee1-102 × 2ch4-098) yielded over 45% (73 clones) of the selected clones (Table 15). Family means and within family standard deviations (Tables 17 and 18) were examined in an attempt to explain why some families yield a large number of clones and others relatively few elite clones. As indicated in the introduction, families with a high level of within family variation may be more likely to yield outstanding individuals. However, when family means are compared for the families with a high level of clonal selection to the family with zero selection, the most striking difference is the mean volume – family 1ee1-161 × 1ch4-097 had the lowest mean volume of all the out-crossed families, only the eh107 selfed family had a lower mean (Table 17).

To understand the possible implications of within family variance, families with similar mean volume, but differences in within family variance should be examined. Two families involving the maternal parent 2ee1-170 have similar mean volumes (15.2 and 15.3) and similar mean straightness (4.2 and 3.9), but differ in within family standard deviation (3.6 and 7.2 for volume) – refer Tables 16 and 17. Further, both of these families are represented by a large number of clones in these tests; 150 and 172 out of which 3 and 10 clones were selected from families 2ee1-170 × 1ch4-087 and 2ee1-170 × 1ch6-029 respectively. Hence in this case we can see that a higher proportion of clones were selected in the family with the highest within family variance for volume, even though its mean straightness was slightly lower.

However, if we examine another pair of families that share a common parent (eh042), similar mean for volumes but differing within family variation (i.e. eh097 × eh042 and eh105 × eh042), we don't see the same trend. Again both families are represented by a large number of clones 141 and 143, out of which 7 and 10 clones were selected in eh097 × eh042 and eh105 × eh042 respectively. However, in this case the highest proportion of clones was selected in the family with the lowest within family standard deviation (Tables 17 and 18).

Table 17. Mean of all clonal BLUPs for families represented by at least 20 clones.

Family	BA	BD	DL	Fox	Ht4	RM	Str	Vel1[2]	Vel2[2]	Vol4	Sel[n†]
1ee1-161 × 1ch4-097	***6.48***	***14.16***	***2.48***	***0.09***	***5.86***	***38.02***	***4.36***			***13.82***	***0.0***
1ee1-161 × 1ch4-140	7.19	15.35	1.88	0.12	5.79	30.85	3.88			19.13	5.6
1ee1-161 × 2ch4-151	6.32	15.89	1.91	0.10	5.62	31.99	4.14	6.18	6.23	18.01	8.0
1ee2-056 × 1ch4-087	7.65	15.96	5.22	0.11	6.00	35.59	3.97			17.64	2.8
1ee2-056 × 1ch4-115	7.47	15.12	12.50	0.13	5.95	40.96	3.57			19.30	1.9
2ee1-095 × 2ch4-151	***7.09***	***16.27***	***2.54***	***0.08***	***6.31***	***34.50***	***4.05***	***6.07***	***6.04***	***24.67***	***47.7***
2ee1-095 × 2ch4-219	***7.29***	***16.84***	***4.58***	***0.07***	***6.90***	***41.36***	***3.72***	***7.02***	***6.97***	***30.35***	***66.7***
2ee1-102 × 2ch4-098	***7.32***	***14.86***	***2.91***	***0.12***	***6.19***	***34.25***	***4.17***	***7.85***	***7.78***	***20.97***	***25.3***
2ee1-166 × 2ch4-151	7.19	15.38	3.87	0.13	6.10	32.63	3.89			18.79	2.9
2ee1-166 × 2ch4-210	7.43	14.87	2.02	0.12	5.96	30.46	3.49	7.05	7.04	18.12	3.5
2ee1-166 × 2ch4-219	7.07	15.48	2.09	0.14	6.44	36.30	3.75			20.90	8.8
2ee1-170 × 1ch4-087	7.04	16.23	1.52	0.09	5.83	27.10	4.18			15.20	2.0
2ee1-170 × 1ch6-029	6.69	14.82	1.72	0.13	5.28	23.27	3.89	6.81	6.87	15.33	5.8
eh097 × eh042	7.64	14.14	5.48	1.45	5.55	30.35	3.35			18.83	5.0
eh105 × eh042	7.46	15.27	3.73	0.43	6.05	32.60	3.62	7.31	7.19	18.64	7.0
eh106 × eh042	7.58	14.24	3.09	0.75	6.03	28.78	3.68			18.47	6.0
eh107 × eh083	7.65	15.50	2.17	1.22	6.25	33.01	3.69	8.03	7.98	19.88	10.2
eh107 × eh107‡	7.52	12.74	5.67	0.09	4.12	28.27	3.39			7.16	0.7

† Proportion (%) of clones selected in each family for further evaluation of wood quality. These clones form the group of 161 most promising clones selected on the basis of 4 year growth and form data.
‡ Only 1 clone (out of 138) was selected in this selfed family.

Table 18. Within family standard deviations among clones for all families represented by at least 20 clones.

Family	BA	BD	DL	Fox	Ht4	RM	Str	Vel1[2]	Vel2[2]	Vol4
1ee1-161 × 1ch4-097	0.420	1.092	3.273	0.042	0.562	9.880	0.278			3.576
1ee1-161 × 1ch4-140	0.341	1.270	2.538	0.065	0.771	10.195	0.372			5.130
1ee1-161 × 2ch4-151	0.420	1.603	2.632	0.059	0.728	10.230	0.367	0.911	0.870	4.913
1ee2-056 × 1ch4-087	0.474	1.712	5.233	0.353	0.586	11.305	0.388			4.077
1ee2-056 × 1ch4-115	0.468	2.087	10.339	0.392	1.097	10.708	0.463			6.867
2ee1-095 × 2ch4-151	***0.383***	***1.275***	***2.701***	***0.044***	***0.374***	***10.566***	***0.323***	***0.811***	***0.827***	***3.994***
2ee1-095 × 2ch4-219	***0.487***	***1.193***	***6.696***	***0.005***	***0.378***	***11.881***	***0.510***	***1.191***	***1.203***	***4.013***
2ee1-102 × 2ch4-098	***0.552***	***1.601***	***3.118***	***0.316***	***0.731***	***10.828***	***0.473***	***1.142***	***1.045***	***4.968***
2ee1-166 × 2ch4-151	0.603	1.560	6.868	0.172	0.466	11.767	0.393			3.564
2ee1-166 × 2ch4-210	0.613	1.344	2.408	0.058	0.604	9.726	0.540	0.992	0.940	4.556
2ee1-166 × 2ch4-219	0.488	1.148	2.461	0.456	0.553	10.112	0.423			4.513
2ee1-170 × 1ch4-087	0.467	1.502	2.290	0.160	0.511	8.338	0.367			3.570
2ee1-170 × 1ch6-029	0.493	2.665	2.690	0.453	1.201	8.668	0.464	0.776	0.814	7.202
eh097 × eh042	0.533	3.330	5.753	4.948	1.816	12.360	0.499			8.403
eh105 × eh042	0.498	1.828	4.677	1.190	0.815	11.322	0.475	1.003	0.950	5.646
eh106 × eh042	0.439	1.572	5.395	3.732	0.705	11.471	0.550			5.191
eh107 × eh083	0.469	2.103	2.674	5.171	0.642	10.822	0.505	1.454	1.521	5.130
eh107 × eh107	0.516	1.626	7.150	0.122	1.056	10.939	0.686			5.431

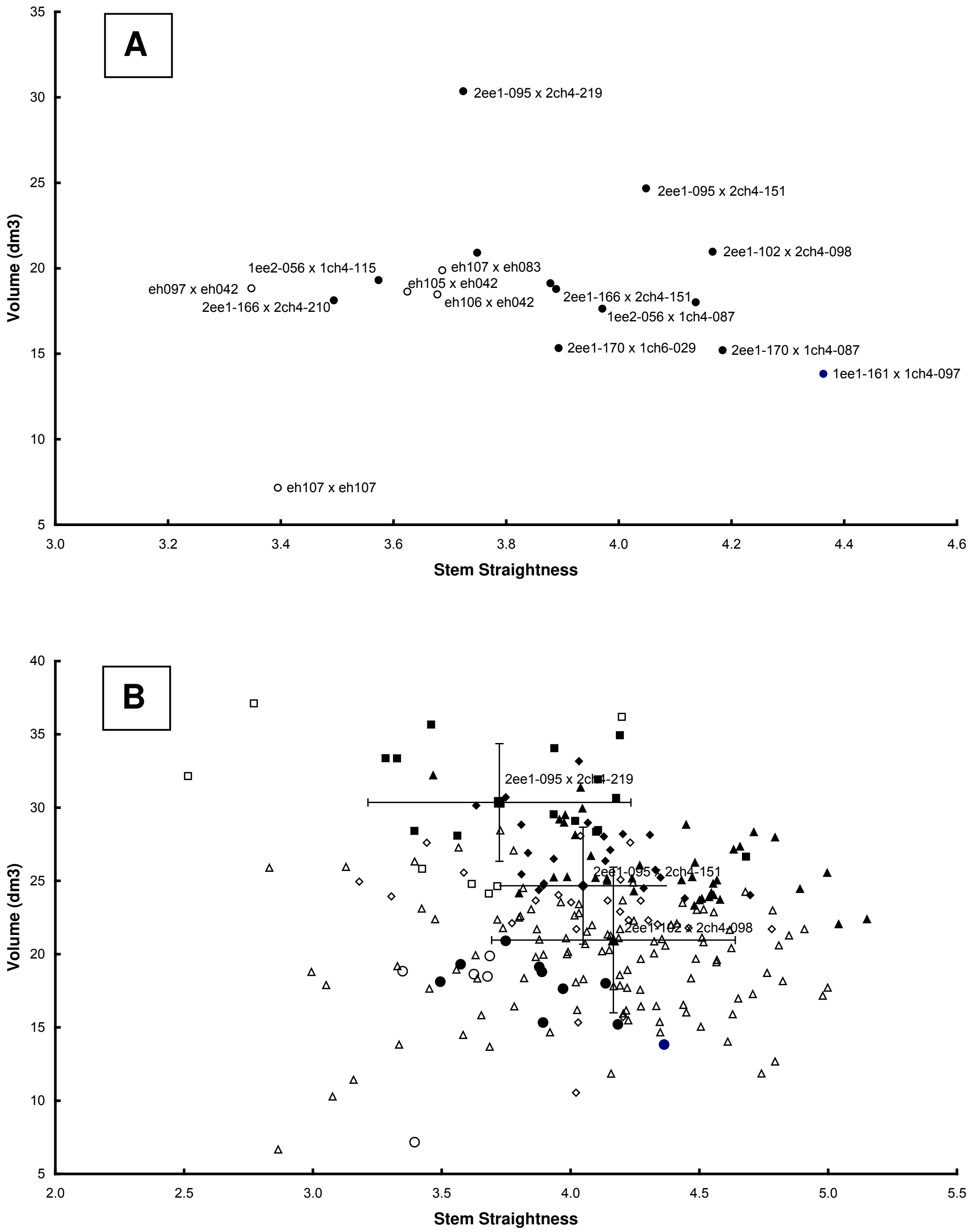


Figure 18. Family mean performance for stem straightness and volume. A. Plot of all families with at least 20 clones included in the tests. B. Plot of top three families – bars indicate the within family standard deviations, symbols indicate clonal means within each of the three families – solid symbols are the selected subset of clones in each family.

From this discussion it is clear that for the group of 161 clones selected by FPQ in early 2008 for evaluation of wood properties, the most important selection criterion was improved volume; reflected in the large proportion of clones from the most vigorous families. The level of within family variation may have an impact on the probability of finding extreme individuals; however, this effect appeared to be secondary to the average performance of the families. From Figure 18 it is clear that the level of variation within families is large, and exceeds the mean differences between families. Nevertheless, the significant 'step-up' in performance from excellent family mean volume can not be readily overcome by within family selection alone.

The issue of tested families versus tested clones for deployment is complex. Certainly, the best families included in this set of tests substantially exceeded (30.4 vs. 18.5 dm^3/tree) the performance of the F_2 hybrid control for volume at four years of age, but differences in acoustic velocity are only small (data not presented). Further, the best two families exceeded the volume production of all Series II clones that had been included as controls, but again when compared in terms of wood properties (i.e. acoustic velocity) and form traits the elite clones were superior to the best families. The results indicate that it is possible to identify hybrid families that have excellent vigour and/or stem straightness; however, clonal selection for form traits and wood properties will yield significant gains. To an extent this reflects the fact that *breeding* has concentrated primarily on growth and stem straightness, with relatively little weight given to wood properties in the past. Nevertheless, this study indicates that it is now possible to assess family performance of key wood properties using acoustic technologies, and that useful variation can be detected (Table 17). However, outside the clonal testing program, there is relatively little information available to rank parents for wood quality. Consequently, a strategy to improve wood quality should use these elite clones as parents – due to the high heritability of wood traits (e.g. acoustic velocity, Table 15). These results suggest that there is every indication that new cycles of testing and selection among hybrid family crosses (i.e. derived from crossing the elite clones) should lead not only to excellent wood quality gains, but quite possibly volume gains as well. Progress may be almost as rapid as could be achieved using clonal selection (although the use of clones in testing may enhance selection efficiency). When the additional costs and complexities of mass-scale clonal propagation are taken into account, the family approach could be seen as a very effective alternative.

The dispersion of clonal means around the family means for volume and straightness (Figure 18) indicates the presence of substantial genetic variability within these families. As well, tree-to-tree variability within families will be larger than indicated in Figure 18, because the points plotted are the clonal means (BLUPs) across the seven sites. Selection of elite clones within the best families will capture more gain, improve stand uniformity, and allow deployment of a better 'package' of traits than can currently be achieved using the best tested families. If *only a single trait* (e.g. volume) is considered, similar gains can be achieved (in this one trait) by deploying the best family as compared to deploying the best clones that have been selected for the *nine growth, form and wood quality traits* examined in this report. However, if we consider genetic gain in all nine traits simultaneously (improvement in the overall value of plantations in terms of growth, form and wood quality) it is not currently possible to identify families that meet all selection criteria. Ultimately, the choice will depend on the relative value of improvements in form and wood quality traits through clonal selection, as well as the additional cost of the clonal program.

Basic density

The average un-extracted basic densities of clones aged 5 years from the two experiments sampled (89c and 89d PPG) are charted in Figures 19 and 20 with additional details including sample size provided in Table 19.

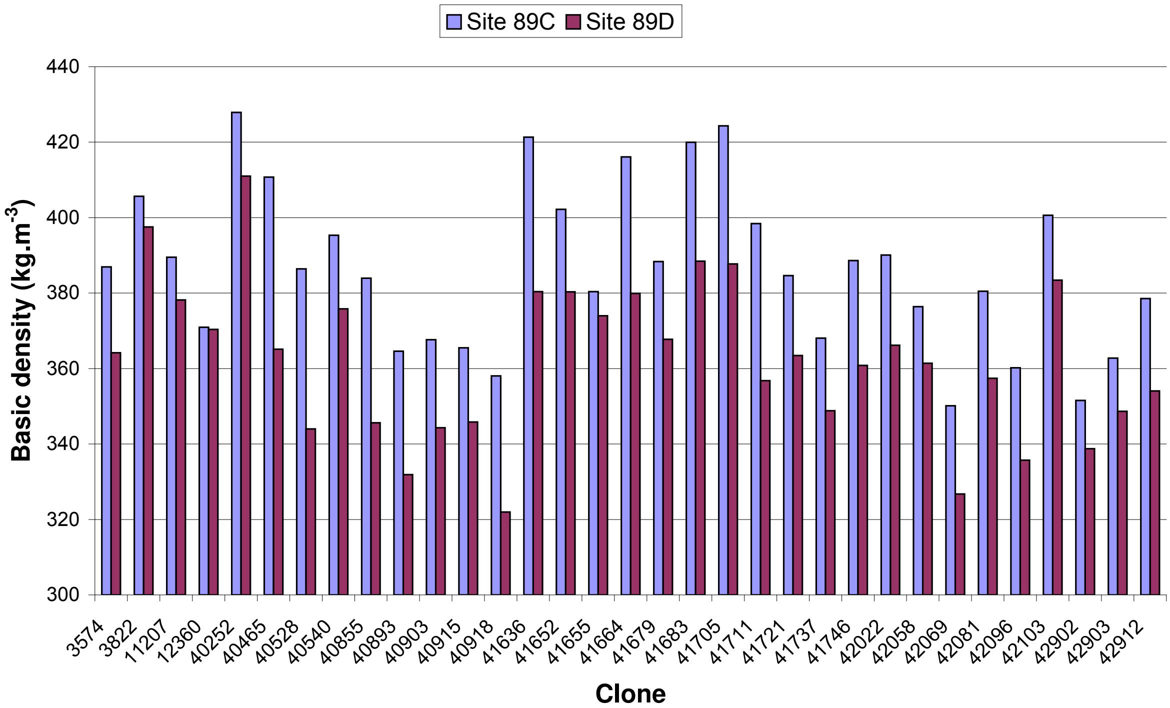


Figure 19. Twelve millimetre increment core average un-extracted basic density comparisons among clones and by site at age 5 years (Experiments 89c and 89d PPG).

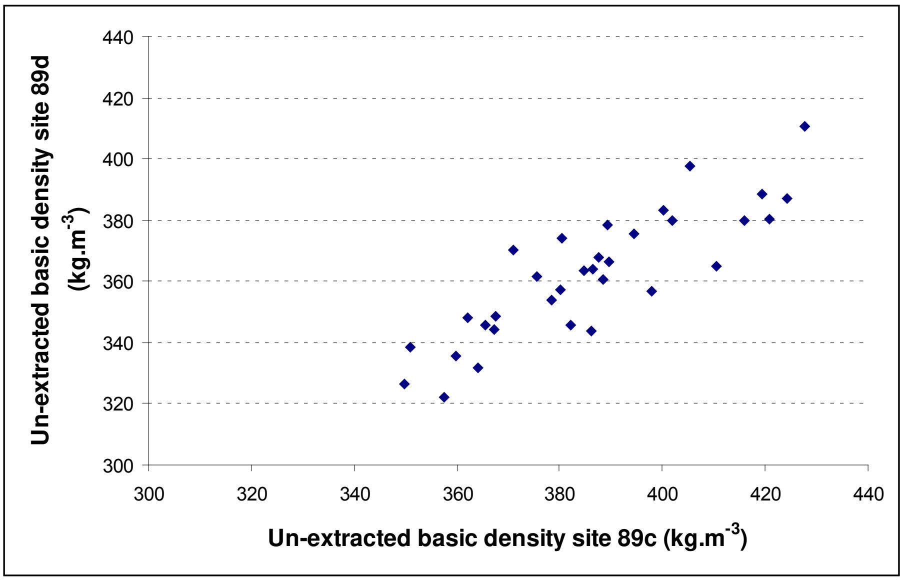


Figure 20. Un-extracted basic density at age 5 years showing relationship between two sites for sampled clones

Table 19. Comparison of average un-extracted basic density (kg/m^3) of clones in Experiments 89c and 89d PPG**.**

Clone	Family	Experiment 89c			Experiment 89d		
		Count	Density ($kg.m^{-3}$)	StDev ($kg.m^{-3}$)	Count	Density ($kg.m^{-3}$)	StDev ($kg.m^{-3}$)
3574	2ee1-102 × 1ch6-029	3	387	3.7	3	364	6.3
3822	2ee1-169 × 2ch4-270	3	406	11.1	3	398	4.8
11207	F_2 CSO	15	389	38.3	3	378	9.6
12360	PCH CSO	2	371	45.2	14	370	34.4
40252	1eh105 × 1eh042	2	428	3.6	3	411	15.3
40465	1eh106 × 1eh042	3	411	21.4	3	365	10.3
40528	1eh106 × 1eh042	3	386	6.7	3	344	5.1
40540	1eh106 × 1eh042	2	395	9.5	3	376	6.6
40855	1eh107 × 1eh083	3	384	11.4	3	346	9.9
40893	1eh107 × 1eh083	3	365	2.4	2	332	0.3
40903	1eh107 × 1eh083	3	368	9.2	3	344	8.3
40915	1eh107 × 1eh083	3	365	11.0	3	346	9.6
40918	1eh107 × 1eh083	3	358	15.2	2	322	8.6
41636	2ee1-102 × 2ch4-098	2	421	0.1	3	380	8.1
41652	2ee1-102 × 2ch4-098	3	402	3.5	3	380	11.5
41655	2ee1-102 × 2ch4-098	2	380	0.3	3	374	8.9
41664	2ee1-102 × 2ch4-098	3	416	4.4	3	380	1.3
41679	2ee1-102 × 2ch4-098	3	388	3.8	3	368	6.2
41683	2ee1-102 × 2ch4-098	3	420	9.1	3	388	9.8
41705	2ee1-102 × 2ch4-098	3	424	9.2	3	388	10.2
41711	2ee1-102 × 2ch4-098	3	398	3.3	3	357	5.8
41721	2ee1-102 × 2ch4-098	3	385	5.4	3	363	7.4
41737	2ee1-102 × 2ch4-098	3	368	17.8	3	349	4.7
41746	2ee1-102 × 2ch4-098	3	389	15.7	3	361	6.5
42022	2ee1-166 × 2ch4-219	3	390	3.6	3	366	8.5
42058	2ee1-166 × 2ch4-219	2	376	13.0	3	361	4.5
42069	2ee1-166 × 2ch4-219	3	350	2.4	3	327	5.8
42081	2ee1-166 × 2ch4-219	3	380	21.4	3	357	5.5
42096	2ee1-166 × 2ch4-219	3	360	10.2	3	336	2.0
42103	2ee1-166 × 2ch4-210	3	401	9.4	3	383	4.9
42902	2ee1-095 × 2ch4-219	3	352	6.7	3	339	7.9
42903	2ee1-095 × 2ch4-219	3	363	2.1	3	349	8.9
42912	2ee1-095 × 2ch4-219	3	379	10.5	3	354	3.9

Standing tree acoustic velocity – Series IV clones

The mean standing tree acoustic velocities of clones by site are compared in Table 20.

Table 20. Comparison of site differences for ST300 average acoustic velocity (AV) by clone with taxon, source and family pedigree provided for the clones sampled for wood properties (density and spiral grain) in Experiments 89c and 89d PPG.

				Site					
				Experiment 89c			Experiment 89d		
Taxon	Source	Family	Clone	Count	Mean AV	StdDev AV	Count	Mean AV	StdDev AV
F_1	Series II	2ee1-102 x 1ch6-029	3574	9	2.88	0.19	9	3.02	0.15
		2ee1-169 x 2ch4-270	3822	9	2.53	0.08	9	2.54	0.15
	Series IV	2ee1-095 x 2ch4-219	42902	3	3.00	0.09	3	2.96	0.19
		2ee1-095 x 2ch4-219	42903	3	2.83	0.17	3	2.95	0.15
		2ee1-102 x 2ch4-098	41636	2	3.02	0.03	3	3.03	0.19
		2ee1-102 x 2ch4-098	41652	3	3.02	0.09	3	3.21	0.06
		2ee1-102 x 2ch4-098	41655	2	2.97	0.02	3	3.13	0.17
		2ee1-102 x 2ch4-098	41664	3	3.00	0.05	3	3.02	0.09
		2ee1-102 x 2ch4-098	41679	3	3.05	0.17	3	2.92	0.10
		2ee1-102 x 2ch4-098	41683	3	2.92	0.05	3	2.89	0.10
		2ee1-102 x 2ch4-104	41687	3	3.40	0.16	2	3.41	0.01
		2ee1-102 x 2ch4-098	41705	3	3.21	0.12	3	3.23	0.06
		2ee1-102 x 2ch4-098	41711	3	2.94	0.22	3	3.02	0.29
		2ee1-102 x 2ch4-098	41721	3	3.14	0.05	3	3.26	0.15
		2ee1-102 x 2ch4-098	41737	3	3.04	0.16	3	2.81	0.10
		2ee1-102 x 2ch4-098	41746	3	3.04	0.42	3	3.29	0.10
		2ee1-166 x 2ch4-210	42103	3	2.92	0.13	3	3.06	0.17
		2ee1-166 x 2ch4-211	42111	3	2.43	0.09	2	2.75	0.02
		2ee1-166 x 2ch4-219	42022	3	3.01	0.08	3	3.19	0.24
		2ee1-166 x 2ch4-219	42058	2	3.29	0.03	3	3.16	0.13
		2ee1-166 x 2ch4-219	42069	3	2.98	0.15	3	3.07	0.07
		2ee1-166 x 2ch4-219	42081	3	2.92	0.34	3	3.16	0.12
		2ee1-166 x 2ch4-219	42096	3	3.04	0.11	3	3.14	0.07
F_1 Total/Mean				78	2.94	0.26	79	3.01	0.25
F_2	Seedling	F_2 CSO	11207	37	2.80	0.38	3	2.78	0.55
	Series IV	eh105 x eh042	40252	2	3.09	0.02	3	3.14	0.06
		eh106 x eh042	40465	3	3.08	0.29	3	3.04	0.09
		eh106 x eh042	40528	3	3.22	0.03	3	3.21	0.25
		eh106 x eh042	40540	2	2.88	0.00	3	3.04	0.10
		eh107 x eh083	40855	3	3.28	0.15	3	3.18	0.21
		eh107 x eh083	40893	3	3.19	0.09	2	2.81	0.00
		eh107 x eh083	40903	3	3.51	0.07	3	3.24	0.18
		eh107 x eh083	40915	3	2.83	0.13	3	3.04	0.09
		eh107 x eh083	40918	3	2.91	0.26	2	3.10	0.15
F_2 Total/Mean				62	2.93	0.37	28	3.06	0.24
PCH	Seedling	PCH CSO	12360	2	2.86	0.19	40	2.81	0.49
Grand Total/Mean				142	2.93	0.31	147	2.97	0.34

Spiral Grain – Series IV clones

Absolute mean spiral grain values for each clone or control lot sampled are listed in Table 21.

Table 21. Comparisons of mean bark window spiral grain in experiment 89 sampled at age 5 years at two sites.

Taxon	Source	Clone	89c Boonooroo	89d Cowra
F_1	Series II	3574	1.0	1.8
		3822	1.8	2.8
	Series IV	42902	2.0	3.0
		42903	4.8	3.1
		42912	1.7	2.3
		41636	1.4	3.5
		41652	1.9	2.4
		41655	0.2	1.3
		41664	2.5	3.8
		41679	3.1	4.4
		41683	2.2	3.8
		41705	1.4	3.2
		41711	2.4	1.4
		41721	2.5	3.4
		41737	0.4	2.1
		41746	2.0	3.4
		42103	0.8	0.9
		42022	2.4	2.1
		42058	2.4	1.6
		42069	1.3	2.0
		42081	1.7	1.1
		42096	1.5	2.7
F_2	Seedling	11207	1.5	1.0
	Series IV	40252	0.3	2.5
		40465	3.7	5.0
		40528	3.4	3.5
		40540	2.9	2.9
		40855	1.4	3.9
		40893	4.4	4.9
		40903	2.9	3.3
		40915	0.3	0.9
		40918	2.5	2.7
PCH	Seedling	12360	1.6	1.8

Discussion - Hybrid pine (Series IV) clonal trial series (89 PPG)

Both the clonal (89 PPG) and family (749 TBS) studies identified large and economically valuable differences between the best and worst clones and families in important wood traits (predicted MoE, acoustic velocity, wood density and spiral grain). The high variability and highly significant differences among genotypes indicate positive prospects for selection at the parental, family and clonal levels. The use of both highly selected Series IV clones and individuals from progeny tests as breeding parents will accelerate the process of genetic improvement of wood properties in the synthetic PEE × PCH hybrid breeding population. This study additionally yielded various genetic parameters relevant to selection and breeding strategy to improve wood quality in PEE × PCH. The implications of these findings, and the outcomes of clonal and family selection, will be discussed individually.

Plate 4. Series IV clones from the Tuan site.

Low genetic correlation between growth and acoustic velocity

A key finding of this study is the low correlation of Series IV clone BLUPs between stem volume and acoustic velocity across the seven test sites (-0.13 and -0.23 for the two measures of velocity). This result is broadly in agreement with previous estimates of low adverse genetic correlations between growth traits and wood density (Kain 2003) and low favourable genetic correlations between growth traits and SilviScan-estimated MoE (Dieters *et al.* 2007) in the PEE × PCH hybrid. These results suggest good prospects for concurrently improving wood stiffness and stem volume in the breeding population. The situation contrasts with that reported by Baltunis *et al.* (2006) for radiata pine, where moderate adverse genetic correlations are found between growth and wood stiffness-related traits (e.g. r_A=-0.54±0.14 between SilviScan-estimated MoE and stem sectional area, Baltunis *et al.* 2006 in Wu *et al.* 2009).

Selection of families with high within-family variability

Families in which a large number of clones were selected had a strong tendency to be those with the highest mean stem volumes, whereas the importance of selecting families with high within-family variability in stem volume was uncertain in these data. It is to be expected that *among-family* variability, rather than within-family variability, would play a greater role in determining selection outcomes in traits with lower heritability such as growth, where the phenotypic value of a single individual is a poorer reflection of genotypic value than in more strongly genetically controlled traits. The benefits of choosing highly variable families for clonal programs may potentially be greater in traits where within-family variation is more highly heritable, such as acoustic velocity and wood stiffness. In this study, clone within family selection achieved substantial genetic gains in wood quality traits. One example is in family 2ee1-102 x 2ch4-098, where clone 41746 had a velocity of 3.29 kms^{-1}, while clone 41737 from the same family had a velocity of 2.81 kms^{-1}. This difference of 0.48 kms^{-1} is likely to translate into a difference in predicted MoE in excess of 2GPa, a highly economically significant difference.

Only one assessment needed for velocity

The very high correlation of BLUPs between acoustic velocity measured on one side of the tree and another (r = 0.98) is a very helpful finding in relation to breeding for improved wood quality. This indicates that future assessments will need only to assess one side of each tree.

Clonal selection

Successful concurrent selection for growth and wood stiffness in the PEE × PCH hybrid, and the emphasis placed on wood stiffness in clonal selection, are illustrated by the 29 selections made from 161 priority clones recommended by Peters and Toon (2009) (Figure 21). These selections typify the approach taken in screening clones for operational deployment from the Series II, III and IV test series. The approach taken has been to identify a priority pool of best growth and form performers whilst also trying to maintain genetic diversity within this pool and then screen these priority clones for wood quality. For the Series II and III trials the larger pool of priority clones was assessed for basic density and then a much smaller group of selects (about 30 clones) assessed for radial spiral grain pattern and analysed with SilviScan for microfibril angle, density and estimated MoE. The adoption of standing tree acoustic velocity tools has enabled a much broader sampling of the Series IV clones to allow the culling of the priority clones to a select pool based on acoustic velocity.

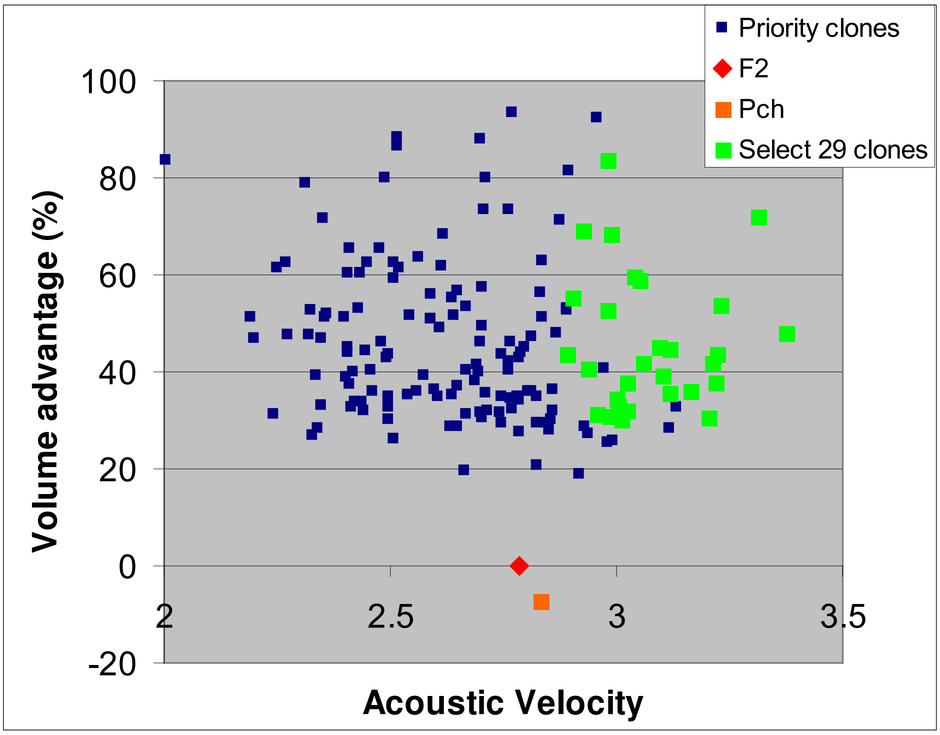


Figure 21: Volume advantage (age 4 years) and standing tree acoustic velocity (age 5 years) for 161 priority clones, including 29 select clones, compared to PCH and F_2 hybrid CSO seedling controls (from Peters and Toon 2009).

Site-related differences

Finally, the impact of site on basic density was very consistent with the poorly-drained Boonooroo site (Experiment 89c) producing higher average density results for all clones (Figure 15) than the well-drained Cowra site (Experiment 89d). These differences in density will almost certainly reflect differences in latewood proportion with a robust relationship between latewood proportion and average density being the norm in these sub-tropical pine plantations (Harding 2009). Environmental factors that limit seasonal growth, particularly moisture availability at the start or the end of the growing season, will impact on latewood proportion and average growth ring density. These consistent patterns of wood density ranking with site differences add weight to the genetic analysis that revealed no significant genotype by environment interaction for wood traits. The standing tree acoustic velocity results (Table 20) were also fairly consistent across sites with most clones at the well-drained Cowra site (89d) having slightly higher velocity than the same clones planted at the poorly-drained Boonooroo site (89c). This is the reverse of the density trend and suggests a difference in stem straightness or microfibril angle positively impacting on acoustic velocity at Cowra as spiral grain also tended to be higher at this site which should negatively impact velocity readings.

Hybrid pine family evaluation trial series (749 TBS)

Methods - Hybrid pine family evaluation trial series (749 TBS)

Genetic material: The 189 F_1 families included in experiment 749 TBS were selected from amongst those that had been accumulated in storage up to 1996. The families form an unbalanced, incomplete factorial mating design, involving a total of 14 PEE maternal parents and 60 PCH paternal parents (average of 13.5 families per PEE parent, and 3.2 families per PCH parent). Not all families were sampled for assessment of wood properties by coring.

Site location and trial design: The F_1 progeny were established in replicated field tests on up to five sites – four in southeast Queensland and one in central Queensland, with each test established using a resolvable, incomplete block design with either five or six replicates. Further details are provided in Table 22.

Table 22. Location and site details of hybrid pine family trial (Experiment 749 TBS)

Trial: Descriptor	Exp 749/2a TBS	Exp 749/2b TBS	Exp 749/2c TBS	Exp 749/2d TBS	Exp 749/2e TBS
Region	Central	Southeast	Southeast	Southeast	Southeast
Locality	Byfield	Tuan	Toolara	Beerburrum	Beerburrum
Compartment	206 Stringybark	228 Magnolia	230 Kelly	201 & 202 Black Swamp	205 Donnybrook
Latitude	22° 51´ S	25° 42´ S	25° 57´ S	26° 56´ S	26° 56´ S
Longitude	150° 39´E	152° 44´E	152° 48´E	153° 00´E	153° 00´E
Planted	12/1997	04/1997	05/1997	04/1997	05/1997
Site type	Poorly-drained‡	Poorly-drained	Poorly-drained	Poorly-drained	Well-drained
Soil Type	Grey Podzolic	Yellow Podzolic	Yellow Podzolic and Yellow Earth	Grey Podzolic	Yellow Podzolic
Spacing - row × tree (m)	5 × 2.4	4.5 × 2.7	4.5 × 2.7	5 × 2.4	5 × 2.4
Nearest Met. Station	Byfield, Childs Rd	Tuan Creek Forest Station	Toolara Forestry Station	Beerburrum Forest Station	Beerburrum Forest Station
Mean annual rainfall (mm)	1661	1251	1282	1384	1384
10^{th} percentile	1176	801	894	908	908
90^{th} percentile	2289	1777	1827	1893	1893

.‡Located on ridge-top, however is nevertheless considered to be a 'poorly drained' site.

Measurements and assessments:

Growth and form: All surviving trees were measured for growth at approximately four, six and ten years after planting – diameter at breast height and total tree height. Conical volumes were calculated for each tree based on the measured diameter and height. Form traits were assessed at four and six years of age – stem straightness (1 = poorest tree on site, 6 = straightest tree on site), and the presence/absence of double leaders and ramicorn branches.

Acoustic velocity: All surviving trees at two of the south-east Queensland sites (experiments 749/2b and 749/2e) were assessed for standing tree acoustic velocity using a FibreGen ® ST300 tool.

Wood coring: The sampling strategy for wood coring is documented in detail by Nester (2009). Of the five tests the Tuan site (749/2b TBS, planted April 1997 on a poorly-drained yellow podzolic soil) was selected for assessment of wood properties using core samples. The original sampling strategy of choosing two families in each combination of three average DBH classes (high, medium, low) by three average acoustic velocity classes (high, medium, low) was applied to a truncated list of families. Any genetic relationships among the families were ignored when selecting the families.

Spiral grain was assessed at the latewood boundary of growth rings 3, 4 and 5, which were split tangentially with a sharp knife.

Results - Hybrid pine family evaluation trial series (749 TBS)

Additive and Dominance Variation: A review of the mean heights and assessments across these five sites (Table 23) indicated that growth at the most northern site (2a at Byfield) was notably less than at the other four sites. However, this was at least partially related to age – this site was planted seven to eight months after the other sites using carry-over stock, and so the 'ten year' measurement was actually conducted at 9.2 years compared to 9.9, 9.9, 10.3 and 10.4 years at the other four sites. Mean stem straightness was very similar across all sites, as a consequence of the relative scale used in the assessment. The proportion of double leaders was generally low (< 6%) except at the 2e site at Beerburrum, while the proportion of ramicorn branching was quite high (>50% of trees affected on three out of four sites) – Table 22. These observed differences may also be related to the varying sample of families tested at each site.

The relative amount of variation in this data due to the average effects of the parents (i.e. their breeding values, or additive genetic effects) in comparison to the deviations due to family effects can be evaluated by comparing estimates of heritability and the proportion of dominance genetic variance (Table 24). The proportion of dominance reported here was calculated by multiplying the estimated variance at the family level (i.e. the SCA variance) by four, and then dividing by the total phenotypic variance. This parameter may additionally include epistatic variance, but for simplicity is referred to as the proportion of dominance variance. While the interpretation of additive and dominance genetic variances is less certain in hybrids than in pure species, these parameters can at least be considered as references to their underlying parental and family variances.

For growth traits (height, diameter and volume) from four to ten years, in this group of PEE × PCH hybrids, 10 to 30 % of the observed variation could be attributed to additive gene effects (Table 24). The proportion of variation due to dominance (i.e. d^2 = 4 × variance between families) was usually of a similar magnitude to the estimated heritability. By contrast, for stem straightness heritability was slightly higher (20 to 30%) and proportion of dominance was relatively small (< 10% – Table 24). Level of genetic control of both double leaders and ramicorn branches in this set of families tended to be low (Table 24).

When examining the impact of site on the estimated additive and dominance effect (Table 25) we can see that quite significant amounts of additive × site variance were present for the growth traits (type B additive genetic correlations ranging from 0.43 to 0.75) but the form traits showed strong additive genetic correlations between sites (> 0.87, Table 25). The dominance (i.e. family deviations) effects were by contrast quite consistent across sites for the growth traits (i.e. $r_{g(D)}$ values greater than 0.65), but dominance correlations were poor for the form traits (Table 25). However, poor correlations of dominance effects in the form traits may reflect the relatively low levels of dominance variance contributing to the expression of these traits (Table 24).

The predicted family effects at each site, with the statistical models used to analyse these data, are a linear combination of the average breeding value of the two parents plus the family deviation. Therefore, from the data presented, we can see that the genetic determinants of variation between families is largely driven by variation amongst the breeding values (i.e. additive effects) of the parents, rather than specific effects of the particular crosses.

For growth traits, in this experiment there were however strong indications of genotype × environment interactions for additive, but not for dominance (family) effects. Therefore, these interactions were examined further using pattern analysis as described in Dieters 2009b – here volume at ten years and stem straightness at six years were selected due to the importance of these traits in selection decisions, and because of their contrasting stability across sites described in the previous paragraph.

Table 23. Trait means (± standard errors) and the number of observations for selected traits at each site of Exp. 749 TBS.

Trial:		Exp 749/2a TBS			Exp 749/2b TBS			Exp 749/2c TBS			Exp 749/2d TBS			Exp 749/2e TBS		
Trait	Age	Mean ± SE		No. Obs.	Mean ± SE		No. Obs.	Mean ± SE		No. Obs.	Mean ± SE		No. Obs.	Mean ± SE		No. Obs.
Height (m)	4	6.38	± 0.14	2601	7.13	± 0.18	3617	7.49	± 0.28	3575	6.68	± 0.36	3983	9.12	± 0.12	3952
Height (m)	6	11.01	± 0.17	2559	10.31	± 0.23	3590	10.41	± 0.26	3554	9.64	± 0.38	3953	12.07	± 0.16	3920
Height (m)	10	13.06	± 0.18	2543	14.15	± 0.27	3557	14.96	± 0.24	3539	14.47	± 0.42	3869	16.64	± 0.17	3845
Straightness (1-6)	6	3.62	± 0.08	2559	3.42	± 0.14	3590	3.38	± 0.11	3554	3.30	± 0.10	3953	3.36	± 0.09	3920
Double Leaders (%)	6	3.41	± 1.07	2557	6.06	± 1.19	3590	5.77	± 1.72	3554	4.93	± 1.27	3953	15.30	± 2.55	3920
Ramicorns (%)	6			0	52.95	± 3.83	3590	41.90	± 3.94	3554	55.86	± 3.98	3953	64.72	± 2.90	3920

Table 24. Narrow sense heritability (i.e. proportion of additive variance, h^2) and proportion of dominance variance (d^2) for each trait as determined in single-site analyses.

Trial:		Exp 749/2a TBS				Exp 749/2b TBS				Exp 749/2c TBS			
Trait	Age	h^2 ± SE		d^2 ± SE		h^2 ± SE		d^2 ± SE		h^2 ± SE		d^2 ± SE	
Diameter (cm)	4	0.10	± 0.04	0.14	± 0.05	0.21	± 0.05	0.14	± 0.04	0.11	± 0.04	0.12	± 0.04
Diameter (cm)	6	0.15	± 0.05	0.15	± 0.06	0.21	± 0.05	0.13	± 0.04	0.08	± 0.03	0.17	± 0.05
Diameter (cm)	10	0.18	± 0.06	0.14	± 0.06	0.22	± 0.05	0.13	± 0.04	0.08	± 0.03	0.19	± 0.05
Height	4	0.10	± 0.04	0.19	± 0.06	0.25	± 0.06	0.21	± 0.05	0.17	± 0.05	0.13	± 0.04
Height	6	0.29	± 0.07	0.20	± 0.06	0.24	± 0.06	0.19	± 0.05	0.20	± 0.05	0.19	± 0.05
Height	10	0.30	± 0.07	0.16	± 0.05	0.24	± 0.06	0.20	± 0.05	0.21	± 0.06	0.23	± 0.06
Volume (dm^3)	4	0.09	± 0.04	0.11	± 0.05	0.22	± 0.02	0.12	± 0.04	0.12	± 0.04	0.09	± 0.03
Volume (dm^3)	6	0.18	± 0.06	0.14	± 0.05	0.21	± 0.05	0.12	± 0.04	0.13	± 0.04	0.13	± 0.04
Volume (dm^3)	10	0.20	± 0.06	0.14	± 0.05	0.21	± 0.05	0.11	± 0.04	0.13	± 0.04	0.15	± 0.04
Straightness (1-6)	4					0.33	± 0.07	0.10	± 0.04	0.22	± 0.05	0.14	± 0.04
Straightness (1-6)	6	0.30	± 0.07	0.08	± 0.04	0.52	± 0.08	0.06	± 0.03	0.31	± 0.06	0.11	± 0.04
Double Leaders (0/1)	4	0.01	± 0.01	0.06	± 0.04	0.06	± 0.02	0.05	± 0.03	0.03	± 0.02	0.08	± 0.03
Double Leaders (0/1)	6	0.06	± 0.04	0.29	± 0.07	0.06	± 0.03	0.08	± 0.04	0.12	± 0.03	0.00	± 0.00
Ramicorns (0/1)	4	0.09	± 0.03	0.00	± 0.03	0.09	± 0.03	0.07	± 0.03	0.05	± 0.02	0.02	± 0.03
Ramicorns (0/1)	6					0.10	± 0.03	0.08	± 0.03	0.15	± 0.03	0.00	± 0.00

Table 23 – Continued.

Trial:		Exp 749/2d TBS				Exp 749/2e TBS			
Trait	Age	h^2 ± SE		d^2 ± SE		h^2 ± SE		d^2 ± SE	
Diameter (cm)	4	0.07	± 0.03	0.12	± 0.03	0.08	± 0.03	0.25	± 0.05
Diameter (cm)	6	0.08	± 0.03	0.09	± 0.03	0.08	± 0.03	0.19	± 0.05
Diameter (cm)	10	0.10	± 0.03	0.10	± 0.03	0.07	± 0.03	0.15	± 0.04
Height	4	0.12	± 0.04	0.12	± 0.04	0.17	± 0.05	0.19	± 0.05
Height	6	0.13	± 0.04	0.14	± 0.04	0.21	± 0.05	0.20	± 0.05
Height	10	0.15	± 0.05	0.17	± 0.04	0.22	± 0.05	0.17	± 0.05
Volume (dm^3)	4	0.05	± 0.02	0.09	± 0.03	0.11	± 0.04	0.21	± 0.05
Volume (dm^3)	6	0.07	± 0.02	0.07	± 0.03	0.12	± 0.04	0.17	± 0.04
Volume (dm^3)	10	0.09	± 0.03	0.08	± 0.03	0.12	± 0.04	0.13	± 0.04
Straightness (1-6)	4					0.25	± 0.05	0.09	± 0.03
Straightness (1-6)	6	0.31	± 0.06	0.12	± 0.04	0.29	± 0.06	0.10	± 0.03
Double Leaders (0/1)	4	0.06	± 0.02	0.02	± 0.02	0.08	± 0.03	0.07	± 0.03
Double Leaders (0/1)	6	0.08	± 0.02	0.01	± 0.02	0.12	± 0.04	0.12	± 0.04
Ramicorns (0/1)	4	0.04	± 0.02	0.02	± 0.03	0.06	± 0.02	0.03	± 0.03
Ramicorns (0/1)	6	0.11	± 0.03	0.01	± 0.02	0.08	± 0.03	0.08	± 0.03

Table 25. Type B genetic correlations of additive and dominance genetic effects across the five test sites in Exp. 749 TBS.

Trait	Age	$r_{B(A)}$		$r_{B(D)}$	
Diameter (cm)	4	0.44	± 0.11	0.78	± 0.08
Diameter (cm)	6	0.43	± 0.11	1.00	± 0.00
Diameter (cm)	10	0.48	± 0.10	1.00	± 0.00
Height	4	0.65	± 0.08	0.65	± 0.08
Height	6	0.74	± 0.06	0.78	± 0.07
Height	10	0.75	± 0.06	0.84	± 0.06
Volume (dm^3)	4	0.52	± 0.09	0.68	± 0.09
Volume (dm^3)	6	0.53	± 0.09	0.92	± 0.09
Volume (dm^3)	10	0.56	± 0.09	0.94	± 0.09
Straightness (1-6)	6	0.89	± 0.03	0.56	± 0.10
Double Leaders (0/1)	4	0.87	± 0.08	0.23	± 0.20
Double Leaders (0/1)	6	0.95	± 0.04	0.34	± 0.13

Within-family variance: One of the often cited advantages of clonal forestry (i.e. the deployment of tested clones) over family forestry (i.e. the deployment of tested families) is the greater level of uniformity from tree to tree that can be expected with clones, although the extent of this advantage diminishes on highly variable sites. However, if elite families can be differentiated in terms of their within family variability, then it may be possible to identify families for: a) reproduction and deployment as tested families with high mean and low within family variance, or b) inclusion in a clonal testing program as tested families with high mean and high within family variance. In the first case this would provide a relatively low cost alternative to clonal forestry coupled with improved tree-to-tree uniformity, and in the second case this would maximize the probability of identifying elite clones from the families screened in a clonal test.

The estimated within family variance (Table 26) for each site was compared to the predicted family performance at each of the five sites using correlation (Table 27). In general it can be seen that the level of within family variance for height was negatively correlated with family performance, i.e. the tallest families tended to have lower within family variance. For volume the correlations were also negative, but not significantly different from zero. For stem straightness, the correlations were negative and not significant on three sites, but positive and significant on the remaining two sites. The reason for this is not clear. These results provide the first indication that it may be possible to identify families that combine high mean performance and low within family variance. Further, as correlations observed (between family performance and variability) for volume and stem straightness were not strong (or positive), it should also be possible to find families which combine high mean performance with high within family variance. This was investigated further using only those families tested on all four of the southern sites which were represented by a minimum of 18 trees per site – the Byfield site was not included as the overall within family variance was much higher in this site than the other four (Table 26).

Table 26. Mean within family variance (standard deviation indicated in parentheses) estimated for each of the five test sites. Mean number and range of observations per family used to estimate the mean within family variance are also indicated in the table.

Site:		749/2a		749/2b		749/2c		749/2d		749/2e	
Trait / Age		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Height	4yrs	0.027	(0.014)	0.013	(0.008)	0.024	(0.013)	0.020	(0.011)	0.016	(0.010)
Height	6yrs	0.057	(0.046)	0.023	(0.017)	0.045	(0.032)	0.038	(0.026)	0.032	(0.022)
Height	10yrs	0.138	(0.136)	0.036	(0.034)	0.060	(0.056)	0.059	(0.051)	0.070	(0.062)
Volume	10yrs	103.8	(54.9)	27.9	(12.4)	36.2	(17.9)	30.3	(15.9)	17.7	(9.5)
Straightness	6yrs	0.047	(0.025)	0.026	(0.009)	0.024	(0.008)	0.039	(0.017)	0.032	(0.013)
No. Obs. per Family		19.3	(3.3)	19.4	(4.8)	22.7	(2.3)	21.8	(3.4)	22.4	(3.2)
Range (min./max.)†		1/25		5/26		14/34		1/34		1/28	

† If means were only calculated based on families with ≥ 18 individuals per family per site, the means only changed very slightly.

Table 27. Correlations (Pearson) between within family variance and predicted average family effects, and probability that correlation is significantly different from zero.

Site:		749/2a		749/2b		749/2d		749/2d		749/2e	
Trait / Age		Corr.	Prob.	Corr.	Prob.	Corr.	Prob.	Corr.	Prob.	Corr.	Prob.
Height	4yrs	-0.19	0.03	-0.17	0.03	-0.25	<0.01	-0.14	0.06	0.24	<0.01
Height	6yrs	-0.32	<0.01	-0.19	0.02	-0.27	<0.01	-0.31	<0.01	-0.29	<0.01
Height	10yrs	-0.38	<0.01	-0.21	0.01	-0.45	<0.01	-0.48	<0.01	-0.44	<0.01
Volume	10yrs	-0.10	0.24	-0.08	0.32	-0.10	0.20	-0.04	0.59	-0.06	0.45
Straightness	6yrs	-0.25	<0.01	0.06	0.46	-0.10	0.23	0.33	<0.01	0.37	<0.01

When the level of within family variance is plotted against the predicted mean performance of each family at each site (Figures 22 and 23), there were some families such as entry 154 (1ee2-066 × 3ch6-318) which combined above average performance for both volume and straightness with low within family variance, on at least three of the four southern sites. By contrast family 73 (1ee1-161 × 2ch6-246) had an above average performance of volume on three sites, but this was coupled with very high within family variance (Figure 22). The former family would appear to provide a good choice for deployment under family forestry, while the second may be a good candidate for inclusion in future clonal tests. These results however require further scrutiny, and also validation through inspection of trees in the field. Further, it is also important to examine whether family performance and variability for wood quality traits behaves in a similar manner.

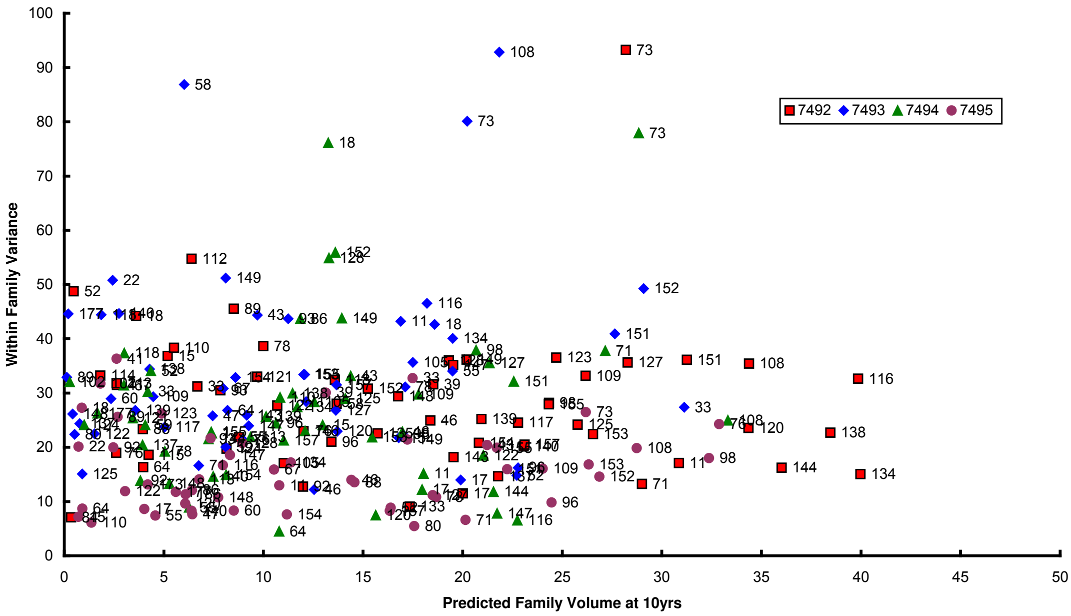


Figure 22. Estimated within family variance for volume at 10 years plotted against predicted family performance, by site – only those families with above average volume are included. (Label = family entry code; family performance expressed as deviations from the overall mean of each test.)

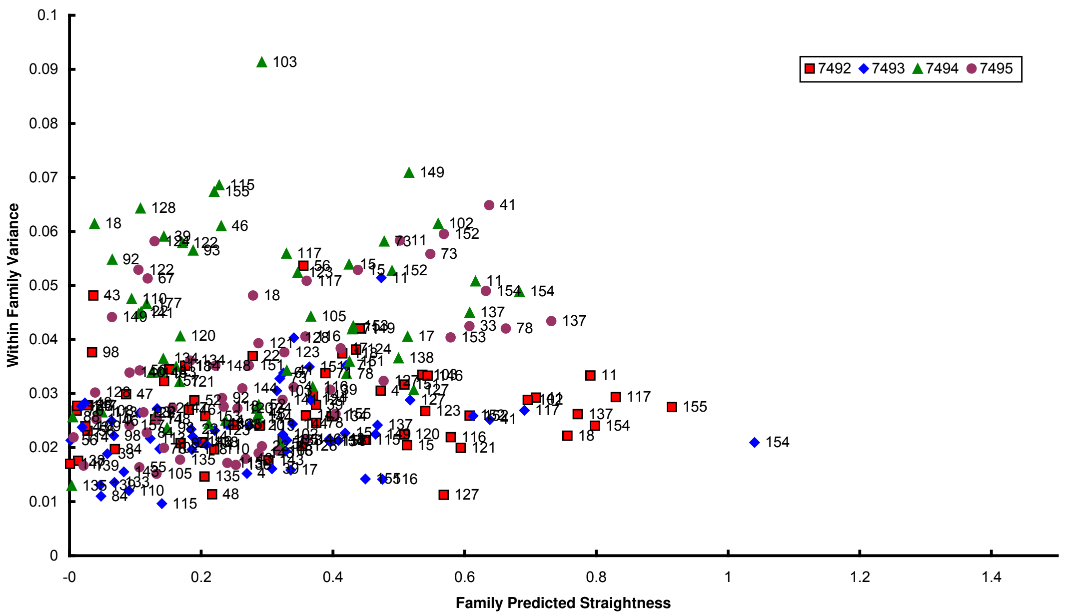


Figure 23. Estimated within family variance for stem straightness at 6 years plotted against predicted family performance, by site – only those families with above average straightness are included. (Label = family entry code; family performance expressed as deviations from the overall mean of each test.)

Extracted basic density – Family trial

Basic density results for resin-extracted increment core samples from Exp. 749/2b segmented into two radial segments, pith to growth ring 5 and growth ring 6 to bark inclusive, and for the basal area weighted whole core average are charted in Figure 24. Values of weighted whole core average extracted basic density for each family are provided in Table28.

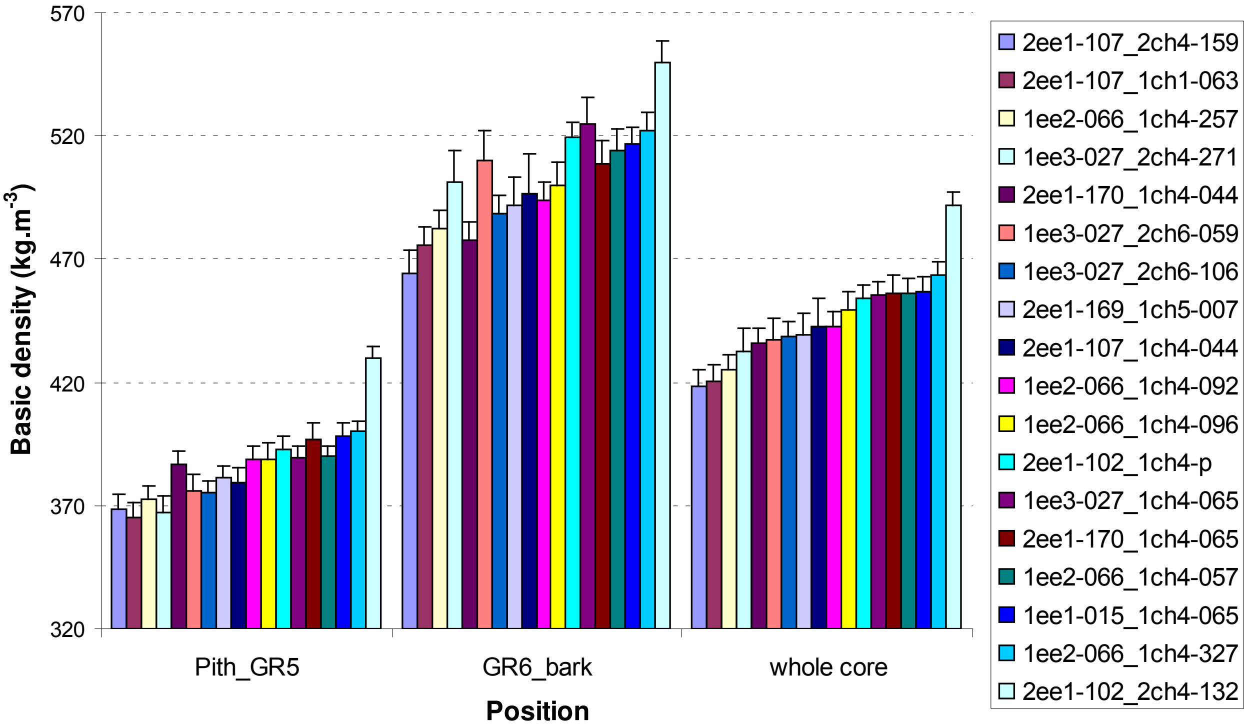


Figure 24. Average resin-extracted basic density of radial segments and basal area weighted whole core samples (with standard error bars) for families in Exp. 749/2b. Note: values charted in ascending order based on whole core basic density

Table 28. Basal area weighted whole core average resin-extracted basic density, range and standard error of mean by family in Exp. 749/2b.

Family	Number of observations	Mean ($kg.m^{-3}$)	Range ($kg.m^{-3}$)	SE ($kg.m^{-3}$)
1ee1-015 x 1ch4-065	15	457	421 - 515	6.3
1ee2-066 x 1ch4-057	16	456	412 - 490	6.1
1ee2-066 x 1ch4-092	16	442	398 - 494	6.2
1ee2-066 x 1ch4-096	15	449	356 - 479	7.6
1ee2-066 x 1ch4-257	16	425	384 - 475	5.9
1ee2-066 x 1ch4-327	15	463	422 - 500	5.7
1ee3-027 x 1ch4-065	11	456	428 - 482	5.3
1ee3-027 x 2ch4-271	14	432	381 - 494	9.4
1ee3-027 x 2ch6-059	12	437	389 - 486	8.5
1ee3-027 x 2ch6-106	12	439	407 - 473	5.8
2ee1-102 x 1ch4-p	15	454	418 - 487	5.5
2ee1-102 x 2ch4-132	15	492	444 - 528	5.8
2ee1-107 x 1ch1-063	16	420	366 - 461	6.8
2ee1-107 x 1ch4-044	11	442	403 - 498	11.6
2ee1-107 x 2ch4-159	13	418	389 - 467	7.0
2ee1-169 x 1ch5-007	13	439	374 - 489	8.7
2ee1-170 x 1ch4-044	8	436	414 - 461	6.0
2ee1-170 x 1ch4-065	14	456	418 - 495	7.7

Standing tree acoustic velocity and predicted Modulus of Elasticity

Mean standing tree acoustic velocities obtained with a FibreGen® ST300 tool for the trees sampled within each family for basic density in Exp. 749/2b are charted in Figure 25. These values are used to estimate modulus of elasticity (MoE) (Table 29). Family average ST300 acoustic velocity squared and weighted average extracted basic density are plotted against DBHOB in Figure 26.

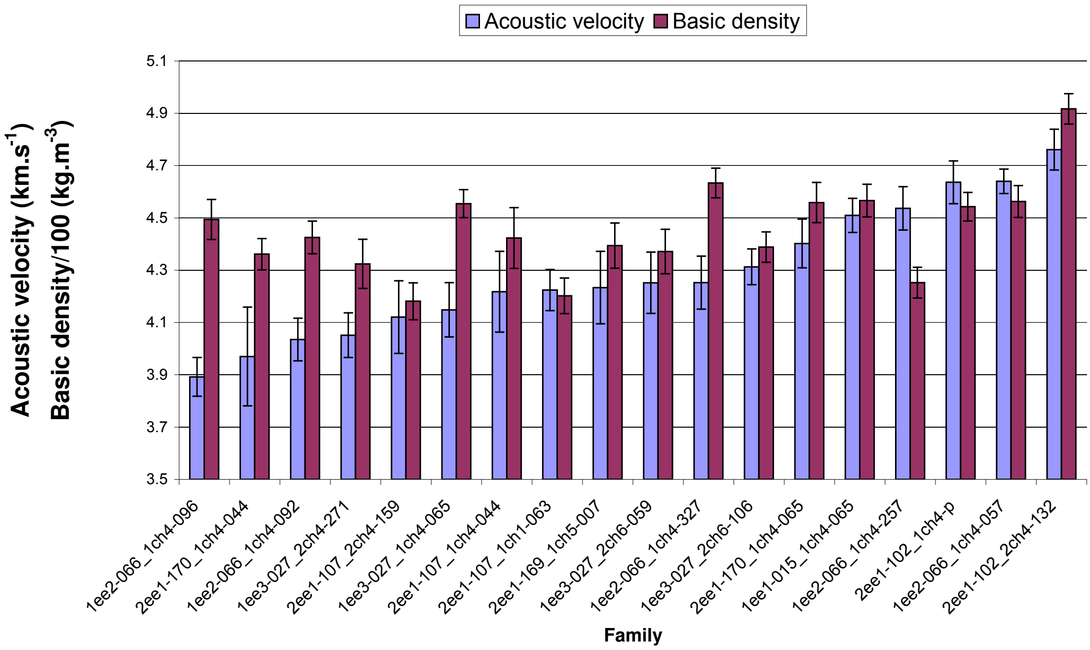
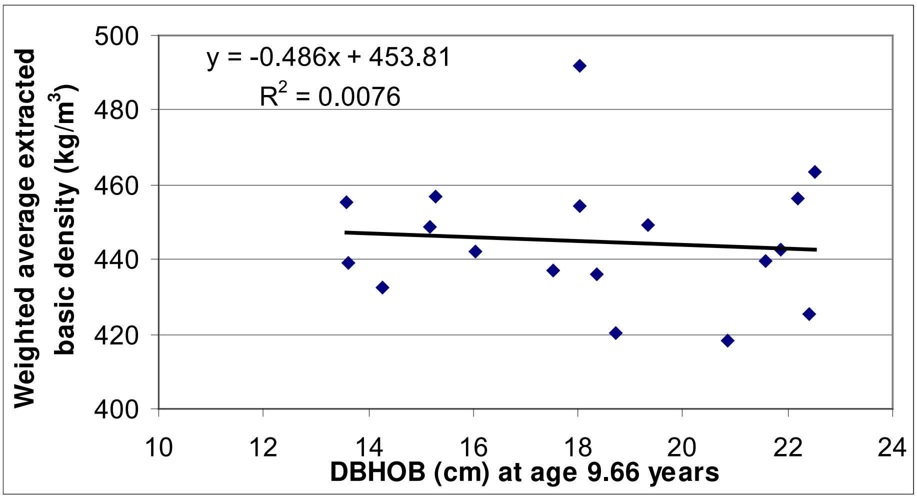


Figure 25. Mean standing tree acoustic velocity assessed with an ST300 tool and extracted basic density (divided by 100) of selected families sampled in Experiment 749/2b (standard error bars included).

Table 29. Mean, standard error and range of modulus of elasticity (MoE)† values estimated using ST300 standing tree acoustic velocities for selected families sampled in Exp. 749/2b. "Top 3" families shaded blue.

Family	Number of observations	Mean (MPa)	Range (MPa)	SE (MPa)
1ee1-015 x 1ch4-065	**15**	**9338**	**7595-11723**	**347**
1ee2-066 x 1ch4-057	**16**	**9862**	**7967-12721**	**299**
1ee2-066 x 1ch4-092	16	7285	4866-9644	357
1ee2-066 x 1ch4-096	15	6867	4161-8745	310
1ee2-066 x 1ch4-257	16	8828	6142-12095	397
1ee2-066 x 1ch4-327	15	8487	5465-11554	467
1ee3-027 x 1ch4-065	11	7896	4936-9517	397
1ee3-027 x 2ch4-271	14	7192	4716-10874	429
1ee3-027 x 2ch6-059	12	8014	4618-10628	508
1ee3-027 x 2ch6-106	12	8171	6850-9276	238
2ee1-102 x 1ch4-p	15	9818	6794-11574	372
2ee1-102 x 2ch4-132	**15**	**11222**	**8701-13719**	**446**
2ee1-107 x 1ch1-063	16	7531	5971-9901	299
2ee1-107 x 1ch4-044	11	8099	5486-12431	785
2ee1-107 x 2ch4-159	13	7223	3448-10006	493
2ee1-169 x 1ch5-007	13	8041	4453-10358	586
2ee1-170 x 1ch4-044	8	7009	4444-10026	706
2ee1-170 x 1ch4-065	13	9063	5983-11558	427
F prob. across families<0.001				

† calculated using acoustic velocity and whole core basic density (MoE = $v^2 \times$ BD)



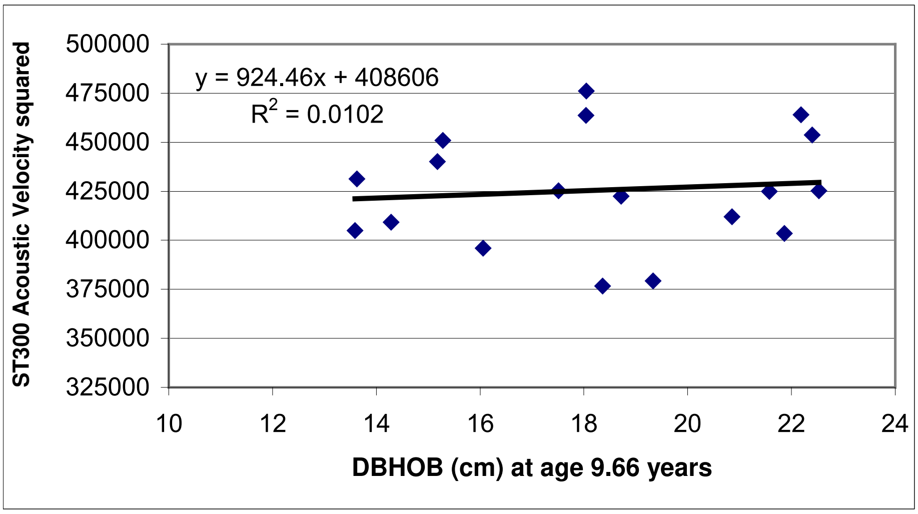


Figure 26. Family average ST300 acoustic velocity squared and weighted average basic density relationships with DBHOB in experiment 749/2b

Spiral grain – Experiment 749 families

Spiral grain readings measured on the latewood – earlywood interface of growth rings 3, 4 and 5 are charted in Figure 27. These results are also charted in slash pine parental groupings in Figure 28 to examine the variation within these female parental groups**.**

Family averages plotted in Figure 27 emphasise the high degree of variation available for genetic manipulation and selection. The maximum value of spiral grain angle for Queensland exotic pine taxa has generally been observed in these early juvenile growth rings between 3 to 5 rings from the pith (Harding, 2009). Average grain angles in these families vary from excellent (≤ 2.0 degrees) to acceptable (< 4.0 degrees) to poor (> 4.0 degrees). Grain angles of 4.0 to 4.5 degrees and above have been associated with higher levels of distortion (particularly twist) and reduced timber stiffness. The average of only one family in this sample has exceeded 4.0 degrees and few individuals exceeded this threshold.

The high grain angle values observed in both Figures 27 and 28 were found in a cross involving a bulk Caribbean pine pollen lot (1ch4-p). It is probable that little or no screening for grain angle was undertaken within the source of this pollen lot (1st generation orchard?) compared to other specific parent trees used in these crosses.

This supposition could be confirmed by assessing other material that has been produced with this pollen batch.

Multiple crosses available within some of the slash pine parent groups plotted in Figure 28 suggest that significant variation has arisen due to the Caribbean pine parents used in crosses – for example, within the five families produced using slash pine parent 1ee2-066. However, other patterns suggest a differential influence of the female slash pine parent, such as for 2ee1-107 where all three families have consistent and relatively low grain angles. There is a significant difference in the mean grain angles for 1ch4-065 when it is crossed to three different slash pine parents – the cross with 2ee1-170 produced lower grain angles than the other two crosses. These observations suggest that specific combining effects may produce both favourable and unfavourable grain patterns that may offer some scope for improvement when considered strategically in the crossing program.

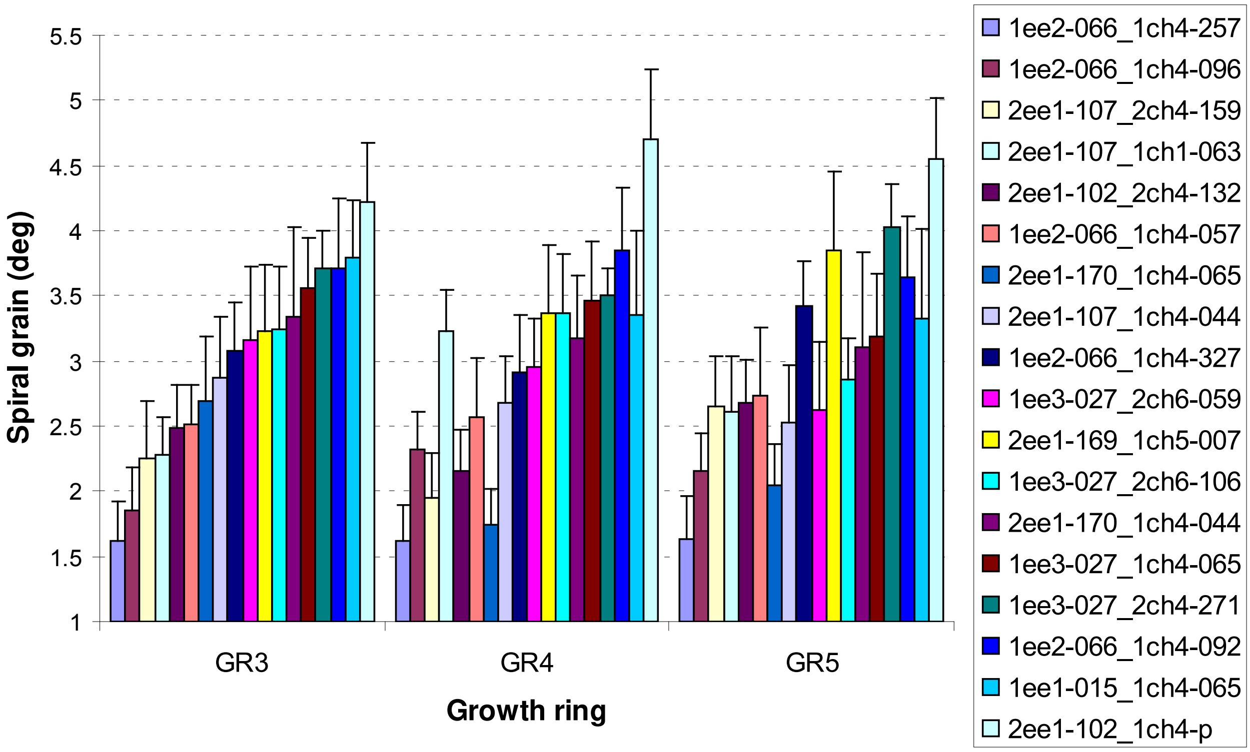


Figure 27. Average spiral grain at growth rings 3, 4 and 5 (standard error bars included) for selected families in Experiment 749/2b. Note: family values for growth rings 4 and 5 ordered in ascending order based on growth ring 3 values.

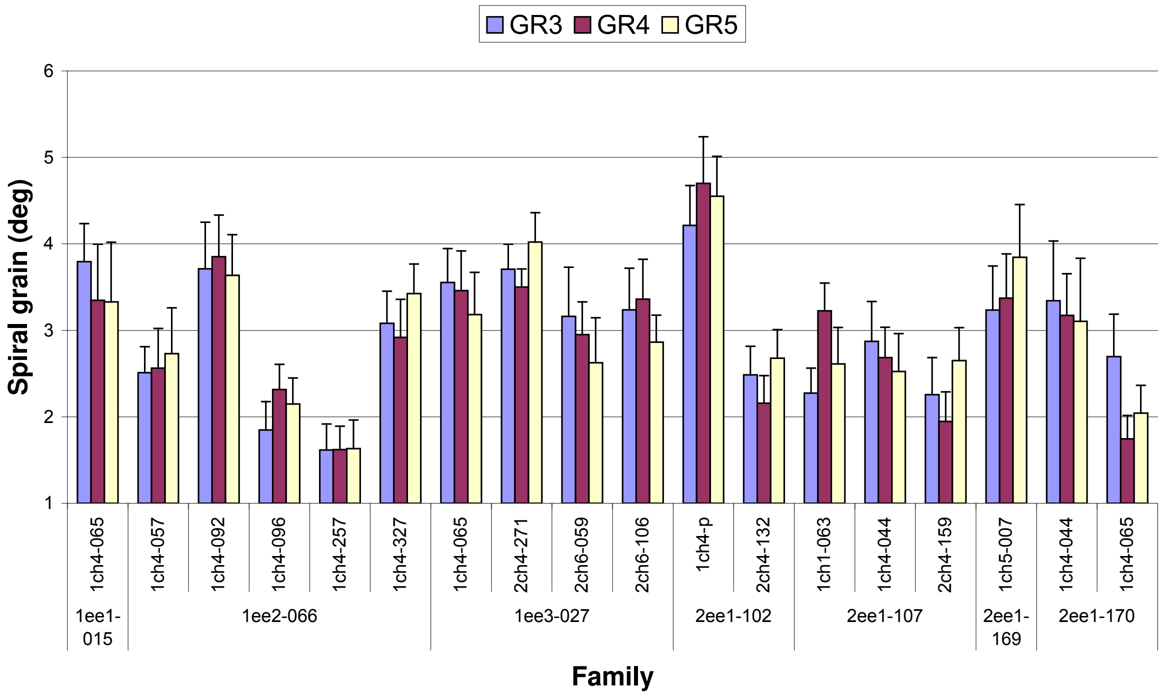


Figure 28. Average spiral grain at growth rings 3, 4 and 5 (standard error bars included) for selected families in Exp. 749/2b ordered in PEE parental groupings.

Discussion - Hybrid pine family evaluation trial series (749 TBS)

The family trial (749 TBS) studies identified large and economically valuable differences between the best and worst families in important wood traits (predicted MoE, acoustic velocity, wood density and spiral grain). The high variability and highly significant differences among genotypes indicate positive prospects for selection at the parental and family levels. This study additionally yielded various genetic parameters relevant to selection and breeding strategy to improve wood quality in PEE × PCH. The implications of these findings are discussed individually.

High non-additive genetic variance in growth and spiral grain in family study

Non-additive genetic variance for growth traits in the family study was in most cases similar to and in some cases greater than additive genetic variance. This result is similar to that found by Kain (2003) in growth traits in the F_1 PEE × PCH hybrid and has two major implications for breeding and deployment strategy. Firstly in relation to mating design, each parent will need to be involved in a greater number of crosses than if dominance genetic variance were low, to predict parental additive genetic effects with the same accuracy. Secondly, it increases both the potential genetic gain from full-sib family forestry and clonal forestry relative to deployment of open-pollinated families, and the risk of deploying small sets of untested hybrid families with performance predicted based on parental breeding values. Further analyses will be needed to determine whether non-additive genetic variance is as large in the F_2 hybrid. The results are likely to have implications for synthetic hybrid breeding and deployment strategy.

Similarly in spiral grain, the high and statistically significant variation at the family-within-parent level shown in Figure 28 suggests high non-additive genetic variance in the trait, as also found by Kain (2003) in 48 F_1 hybrid families. In the context of vegetative deployment of full-sib families, the results suggest that backward selection would be necessary to screen out families with high spiral grain. One third of the families in this study had mean spiral grain exceeding 3.5 degrees in at least one ring, and the within-family distributions indicated that a substantial proportion of individuals in these families would have spiral grain exceeding the 4 degree threshold above which spiral grain can cause distortion of sawn boards. The results highlight the importance of monitoring spiral grain, particularly in the deployment population.

G × E interaction low in clonal study, high in growth traits in family study

The very high type B genetic correlations estimated in the clonal study (across 7 sites), for both stem volume (0.85) and acoustic velocity (0.90 - 0.91), are helpful for genetic improvement, confirming previous studies indicating low genotype by environment interaction in Queensland (e.g. Woolaston *et al.* 1991 in PCH). However, in the family study 749 TBS, while genotype by environment interaction was low for stem straightness, it was unexpectedly large for stem diameter and volume across five test sites (r = 0.43 - 0.56), though the dominance by environment interaction was very low. The results could reflect limitations in the incomplete factorial mating design of the study material. Further investigation of the moderate to high genotype by environment interaction for growth traits detected in 749 TBS is warranted to examine the pattern across sites and at various levels of family structure.

Identification of superior hybrid families for multiple wood property traits

One family combination (2ee1-102 × 2ch4-132) stands out as being superior for extracted basic density compared to the other families sampled (Figure 25) with 6% higher average density than the next highest family. The slash pine parent 2ee1-102 also features in a cross with 1ch4-p that is above average for density and is the parent or ancestor of eleven of the best 15 clones recommended by Peters and Toon (2009) for consideration for operational deployment. This family also ranks first of those sampled for acoustic velocity (Figure 24) but this is not unexpected given its superior density. It is likely that the impact of microfibril angle (MfA) on standing tree acoustic velocity would be greatly reduced by age 11 when these trees were sampled and MfA values would be expected to be around 10-12 degrees and show relatively little variation among families. Additionally this family ranks in the top five for low spiral grain (Figures 27 and 28) with mean values of 2.2 to 2.7 degrees for growth rings 3 to 5, well below the 4.0 to 4.5 degree level where spiral grain starts to become problematic for distortion and reduced timber stiffness.

The within family variation in average resin-extracted basic density in Exp. 749 TBS (data not shown) tended to be reasonably consistent with two-thirds of the families tested producing standard errors of between 5.3 and 7.0 kg/m^3 (range in individual tree values per family of between 47 and 95 kg/m^3). Several families stand out in the summary of estimated MoE results (Table 29) – the minimum values for the top three families are all above 7500 MPa compared to the minimum values of below 5000 MPa for eight of the eighteen families assessed. The standard errors for the mean MoEs of these three families, (Table 29, blue print, 1ee1-015 × 1ch4-065, 1ee2-066× 1ch4-057 and 2ee-102 × 2ch4-132) are also low to medium. Family 2ee1-102 × 2ch4-

132 stands out with the highest mean estimated MoE (11,222 MPa) and the highest individual tree estimate (13,719 MPa), but its standard error is above average, although it must be classified as superior overall as its range of individual tree estimates (8,701 – 13,719 MPa) is the highest by far (approximately 10% higher than the next best minimum and maximum and nearly 14% higher than the mean of the second ranked family).

Considering extracted basic density, acoustic velocity, estimated MoE and spiral grain, families 2ee-102 × 2ch4-132 and 1ee2-066× 1ch4-057 stand out as combining high rankings for density (1 and 4 respectively), acoustic velocity (1 and equal 2), estimated MoE (1 and 6) and spiral grain (5 and 6) and family 1ee2-066× 1ch4-257 ranks highly for acoustic velocity (4), MoE (6) and spiral grain (1) although it has relatively low density. These results suggest that there is some scope for selecting more uniform families that combine above average performance in several important wood quality traits. This is important for identifying families for short term deployment options but also highlights the need for reliable economic weights to apply in an index selection to favour genotypes with an optimised set of characters that will maximise economic value overall. Plots of family mean basic density and ST300 acoustic velocity squared against DBHOB (Figure 26) reveal very little to no relationship between these important growth and wood traits for the families studied providing further encouragement for their joint tree improvement.

Conclusions - clonal and family hybrid trials

This study has identified some very well performed hybrid families and clones. These combine desirable growth and form with superior wood quality traits and provide useful indications of a suite of parents, families and clones that should be prioritised in tree improvement programs. The studies yielded the following specific conclusions:

1. Large and economically valuable differences were identified between the best and worst clones and families in important wood traits (predicted MoE, acoustic velocity, wood density and spiral grain) indicating positive prospects for genetic improvement through selection at the parental, family and clonal levels;
2. The gains achieved through clonal selection should be leveraged in the breeding population by using selected clones with superior wood properties as parents;
3. Acoustic velocity and stem volume were very weakly (though adversely) genetically correlated, consistent with evidence from previous studies indicating favourable prospects for concurrent selection for growth and wood quality in the slash × Caribbean pine hybrid**;**
4. Non-additive genetic variation was similar to additive genetic variation in many of the traits studied, indicating potential for both clonal selection and full-sib family selection and deployment, to capture additional gain beyond that achievable by parental selection;
5. Results in both the clonal and family studies indicated that the most outstanding full-sib families for stem volume tended to have lower within-family variance. These were also the families yielding the highest proportion and number of clonal selections in the clonal study. It suggests limited potential for finding outstanding, variable families for testing under clonal deployment, yet good potential for finding a suite of outstanding full-sib families with low variability

for deployment in full-sib family forestry. The value of selecting variable families in more highly heritable traits may be worth investigating in the context of a clonal program.

6. The low genotype by environment interaction for acoustic velocity in the clonal study supports the findings of previous studies showing high genetic correlations across sites for wood density and stiffness in the slash × Caribbean pine hybrid in Queensland.
7. Acoustic velocity measures on different sides of the tree were very strongly genetically correlated, indicating the need only to measure one side.

Hybrid pine genetics × silviculture trial (350 GYM)

Methods - Hybrid pine genetics × silviculture trial (350 GYM)

Experiment 350 GYM was established in order to assess the relative benefits, both short term and long term, of some major factors and their interactions in slash pine × Caribbean pine hybrid plantations when grown on average sites in south-east Queensland. The experiment contains 11 treatments, comprising 3 control treatments and 8 treatments generated from a three-way factorial structure with two levels in each factor, as follows:

- genetic stock: 'F_2 best' seedlings versus high-performing F_1 clonal cuttings;
- fertiliser: routine practice versus luxury levels; and
- weed control: routine practice versus luxury levels.

The control treatments additionally involved minimal and zero weed control, and zero fertiliser. When the experiment was established these additional treatments were considered inadequate for routine operations.

Table 30 provides further detail of the experimental design, and Table 31 describes the allocation of factor levels to treatments, and treatments to field plots. Notably, while these F_1 hybrid clonal cuttings were considered high-performing when this experiment was established, they were selected in the very early days of the clonal program at FPQ and so should not be considered representative of the genetic gains achieved during the course of that program.

The experiment was planted during May 1999 at Toolara in the Fraser Coast region (Refer Table 30 for general site details). None of the plots were mounded, but many were waterlogged for extended periods during the first year after planting when there was unusually high rainfall. Several drought periods occurred in subsequent years. The experiment was last assessed for growth at about age 8 years in 2007, and for stem straightness and standing tree acoustic velocity at about age 9 years in 2008.

Plate 5. Wood core collected from 350 GYM to assess basic density and spiral grain.

Table 30. Description of sites and experimental layout for Experiment 350 GYM

Experiment number	**350 GYM**
General location	South-east Queensland
State Forest number	1004 (Toolara)
Compartment and Logging Area	207, 208 & 217 South Dempster
Latitude	26°04´S
Longitude	152°49´E
Height (m) above sea level	Approximately 60 m
Soil	Generally grey podzolics or moderate to poor drainage, limited better drained yellow earths.
Slope	Slight slope (1 to 5 %)
Average annual rainfall (mm)	1,369
Original vegetation	Original vegetation typical of coastal lowlands. Details not known. Planted to slash pine 1967-68. Clearfelled October 1997 – May 1998
Slash pine SI[13] (m)	20 – 22 m (first rotation)
Weed spectrum	Mainly grass trees (*Xanthorrhoea* spp) and blady grass (*Imperata cylindrica*)
Site preparation	Strip plough with "Elvis" sub-surface plough. In hindsight, some (most) blocks should have been mounded considering wet conditions post-plant.
Pre-plant weed control	Tractor-mounted band spray (7.2 L/ha glyphosate and 10 L/ha simazine) two weeks before planting. Woody weed control (D50, 10 L/ha) and Grazon (1.5 L/ha) in January 1999.
Planting	4 – 5 May 1999 under good soil moisture conditions
Design	Nominally a randomized complete blocks design with 11 treatments in seven blocks. However plots sizes are quite large and it was not possible to find sufficiently large uniform areas which could act as blocks and which could accommodate 11 plots. Thus one or more treatments are missing from every block. The eight key interaction treatments, viz. 2 genetic stock × 2 fertiliser × 2 weed control given by treatment numbers 1–8, are fully replicated in block numbers 1, 4, 5 and 6.
Plot size	Each gross plot is nominally 0.1920 ha with 10 rows × 16 trees planted at a 5.0 m × 2.4 m spacing yielding 833 stems/ha. Each nett plot is nominally 0.0720 ha with 6 rows × 10 trees.

[13] Site index (SI) is a measure of site quality and is the average height of the tallest 50 trees/ha at age 25 years.

Table 31. Allocation of treatments to plots in Experiment 350 GYM, with missing plots shaded in red.

Treatment number	Stock	Fertiliser	Weed control	Block number						
				1	2	3	4	5	6	7
1	F1	Rout fert	Rout wc	9		15	21	30	43	47
2	F1	Rout fert	Lux wc	4	11		23	34	44	
3	F1	Lux fert	Rout wc	2		17	26	32	46	
4	F1	Lux fert	Lux wc	8	14		25	28	41	48
5	F2	Rout fert	Rout wc	10		16	24	27	42	50
6	F2	Rout fert	Lux wc	1	12		20	33	39	51
7	F2	Lux fert	Rout wc	3		18	22	35	37	49
8	F2	Lux fert	Lux wc	7	13		19	29	45	
9	F1	Rout fert	Min wc	5					38	
10	F2	Rout fert	Min wc	6				36	40	
11	F2	Nil fert	Nil wc					31		

In 2009, following preliminary analysis of growth and acoustic velocity data, breast height wood cores (Plate 5) were collected to enable comparisons between F_1 clones and F_2 seedlings under routine fertiliser, routine weed control treatments. The cores were assessed for basic density and spiral grain, and the sampling strategy is described in Table 32.

Table 32. List of cores of F_1 / F_2 clones and F_2 seedlings for experiment 350 GYM.

Taxon	Clone number	Family	Number of cores extracted and analysed for BD and SG
F_1 clones	3574	2ee1-102 × 1ch6-29	33
	3640	2ee1-102 × 2ch4-232	5
	3721	2ee1-169 × 2ch4-270	20
	3827	2ee1-169 × 2ch4-270	4
	3839	2ee1-102 × 1ch4-98	16
	3840	2ee1-102 × 1ch4-98	19
	3842	2ee1-102 × 1ch4-98	20
F_2 clone	3926	eh17 × eh31	2
F_1 and F_2 clones total			119
F_2 seedlings total			112

Results - Hybrid pine genetics × silviculture trial (350 GYM)

Presentation of results

These results evaluate the differences among:

1. Individual treatments (e.g. F_2 hybrid seedlings with luxury fertiliser and routine weed control versus other treatments);
2. Mean values for factor levels across all treatments (e.g. routine fertiliser vs. luxury fertiliser);
3. F_1 hybrid clones.

Due to some missing plots, the sampling of acoustic velocity in a subset of replicates, the existence of clonal sub-plots in the F_1 treatments, and the subset of treatments with a factorial structure, the data were partitioned in three different ways to implement the comparisons listed above, respectively:

1. *11 treatments:* The additional control treatments, numbers 9-11 (refer Appendix 3), are of special interest to FPQ so a view involving all 11 treatments is essential. Furthermore ST300 readings were collected only in blocks 1, 5 and 6. In order to maintain the tightest possible linkages between the growth data and the velocity data the decision was made to analyse the growth, straightness and velocity data as 11 treatments in three blocks (1, 5 and 6) with several missing plots.
2. *2×2×2 factorial:* Treatments 1–8 form a complete factorial arrangement, and all of these treatments occur in blocks 1, 4, 5 and 6. The growth and straightness data were analysed as a 2×2×2 factorial in four blocks, and the velocity data were analysed as a 2×2×2 factorial in two blocks (1 and 6) since not all of the factorial treatments were assessed for acoustic velocity in block 5.
3. *Clonal split-plot:* The F_1 plots were extracted from the 2×2×2 factorial and analysed as 2 fertiliser × 2 weed control in four blocks (1, 4, 5 and 6) as main plots, with 10 clones as sub-plots. (Only two blocks were used for analysis of acoustic velocity).

Results for 11 treatments in three blocks

The following figures summarise the results from the analyses of variance for all 11 treatments. In each Figure the 5% LSD refers only to the final measure, and those pairs of treatments for which the difference of the means exceeds the LSD may be regarded as being statistically significantly different at the 5% level.

Survival has been good overall (93 to 99 %) with the treatments in which luxury levels of fertiliser are applied being in the lower range (93 to 96%).

In Figure 29 the range of 2m in final predominant heights is surprisingly narrow. Perhaps the most interesting aspect is that the nil–nil treatment (F_2 with nil fertiliser and nil post-plant weed control) was lagging behind in the early years but had caught up with some other treatments by age 8 years. The final average heights in Figure 31 also clearly show the treatments separating into groupings based on genetic stock and weed control. It is important to note that there is no discernable difference between the minimum weed control treatments and the corresponding routine weed control treatments for average height in Figure 31.

Figure 30 shows that the luxury weed control has had a massive beneficial impact on diameter growth. In Figure 30 the genetic stock differences do not appear to be very large, and the nil–nil treatment is still lagging behind all other treatments, although not significantly. Again it is important to note that there is no discernable difference between the minimum weed control treatments and the corresponding routine weed control treatments.

Figure 31 and 32 show that by age 8 years the treatments have separated into very distinct groupings for average stem volume and total standing volume respectively on the basis of genetic type and weed control, with F_1 clones and luxury weed control generating the largest stem volumes. The effect of fertiliser is mostly negligible. Again it is important to note that there is no discernable difference between the minimum weed control treatments and the corresponding routine weed control treatments.

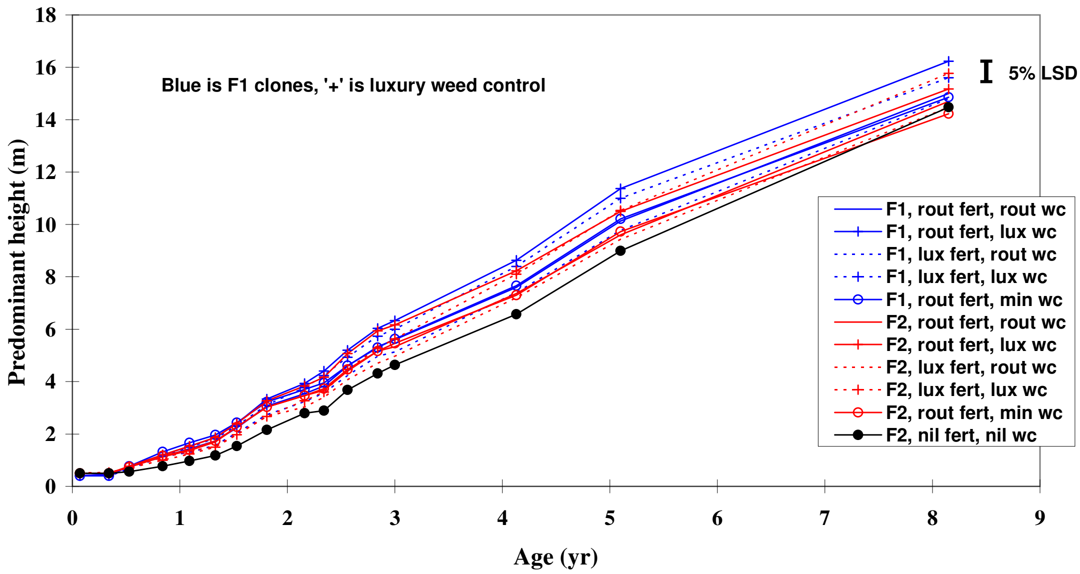


Figure 29. Predominant height versus age for each treatment in Experiment 350 GYM.

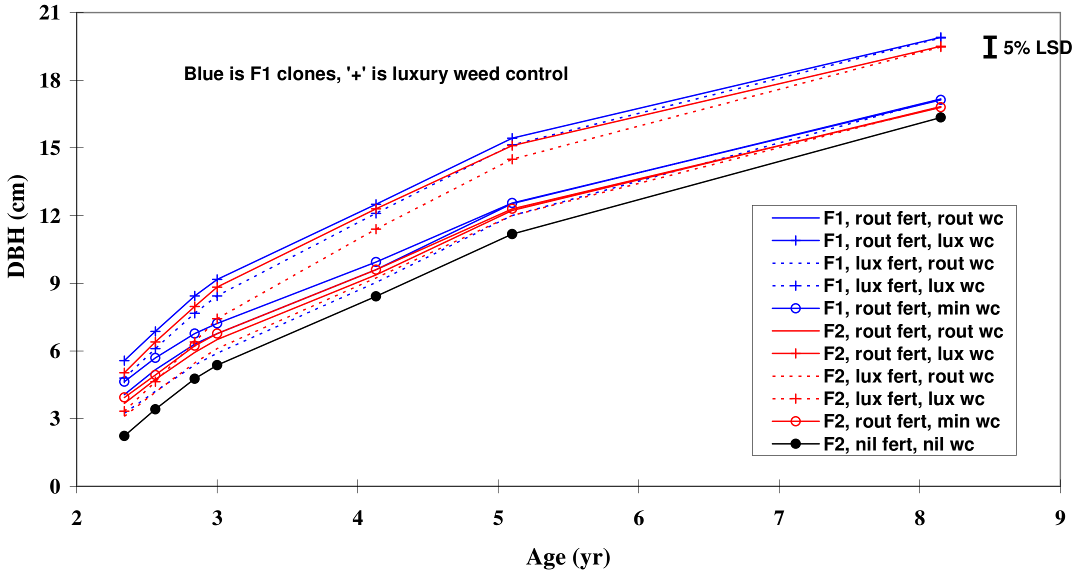


Figure 30. Average DBH of live useful stems versus age for all treatments in Experiment 350 GYM**.**

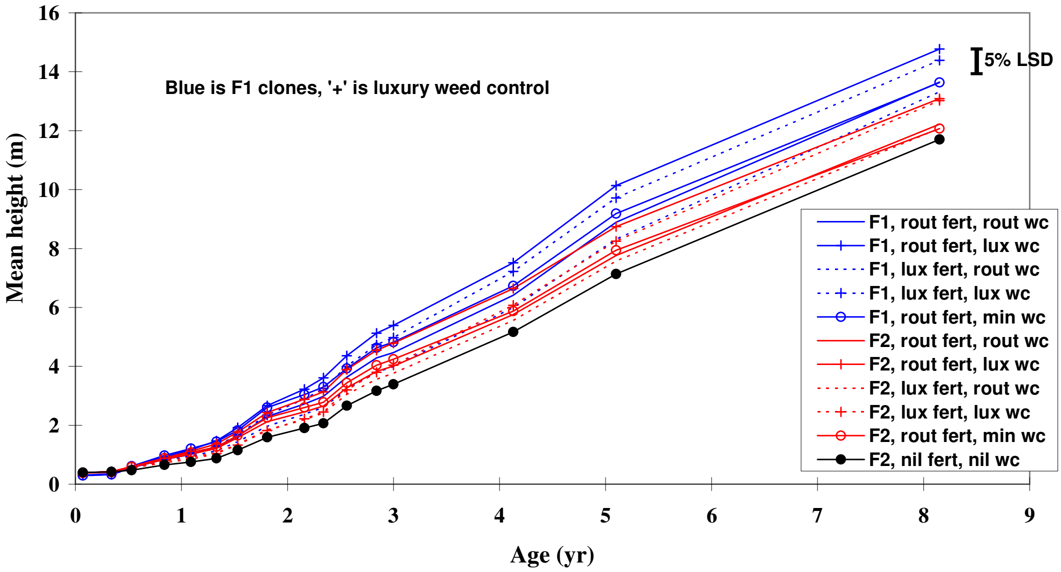


Figure 31. Mean height of live useful stems versus age for each treatment in Experiment 350 GYM.

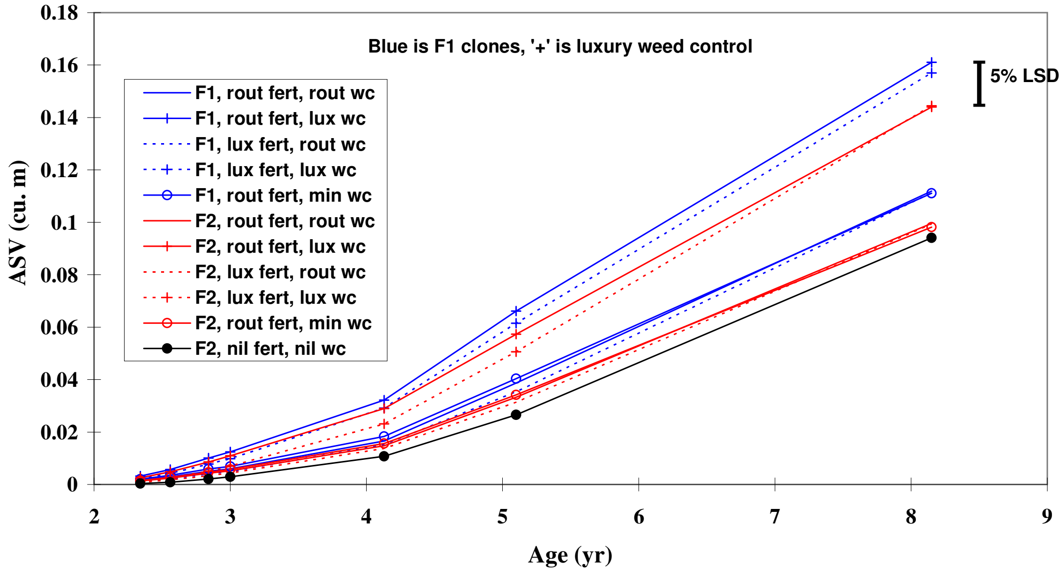


Figure 32. Average stem volume (underbark, total above 15cm stumps) of live useful stems versus age for each treatment in Experiment 350 GYM.

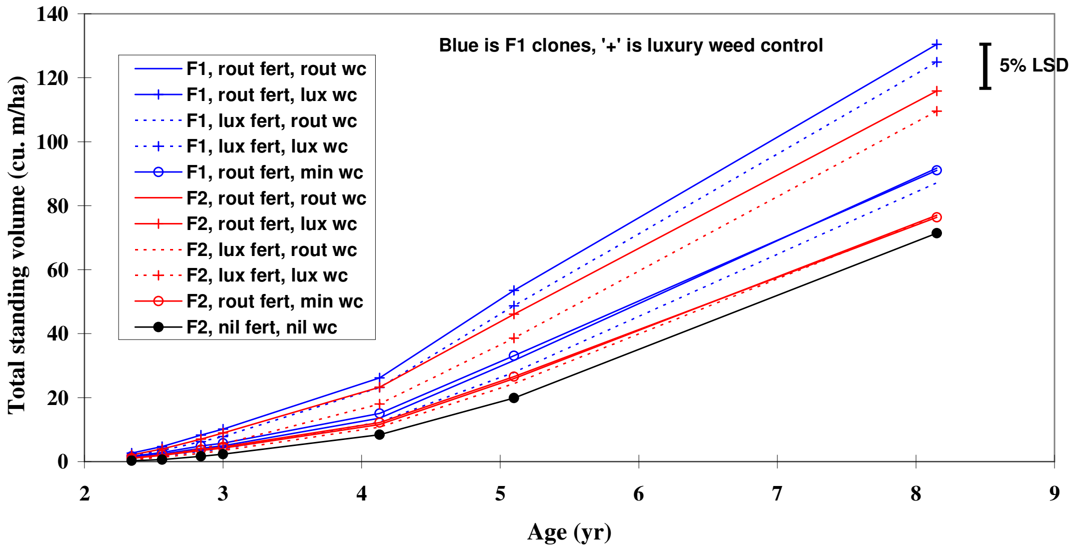


Figure 33. Estimated total standing volume per hectare (underbark, above 15cm stumps) of live useful stems versus age for each treatment in Experiment 350 GYM.

Figures 29 - 33 capture survival and average growth effects but variability, especially with respect to diameter, is also of importance to FPQ and its markets. Coefficient of variation (CV) is a measure of the relative variability of a stand, and is computed by dividing the standard deviation by the mean, and then multiplying by 100 to express the result as a percentage. Variability has two aspects, viz. how variable are the trees for the given age, and how variable are the trees for their given average size. Both aspects of this variability are presented in Figures 34 and 35. Scale is a critical aspect of variability. Thus for some purposes variability within a fraction of a hectare might be important, but for other purposes total variability within a compartment might be important. The CV's in Figures 34 and 35 are essentially averages of within-plot CV's. Thus they are measures of local variability at the fraction of a hectare level and therefore do not necessarily reflect total variability over a whole compartment, say.

Generally speaking, the F_1 treatments were least variable and the nil–nil treatment was most variable. Luxury fertiliser had a slight tendency to increase variability, and there was no difference between the minimum weed control treatments and their corresponding routine weed control treatments for variability.

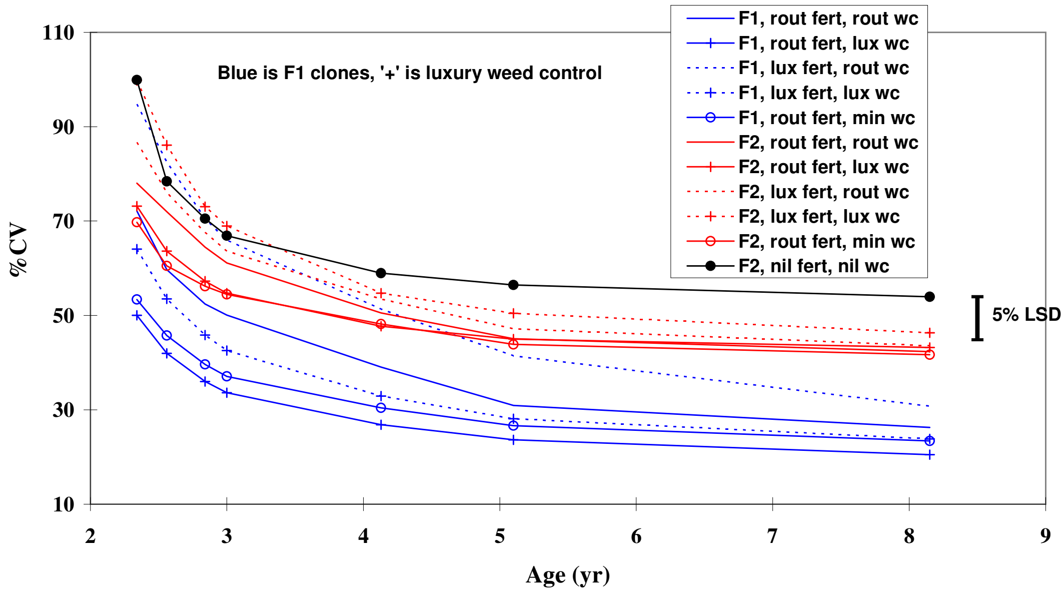


Figure 34. Percent coefficient of variation for stem volume of live useful stems versus age for each treatment in Experiment 350 GYM.

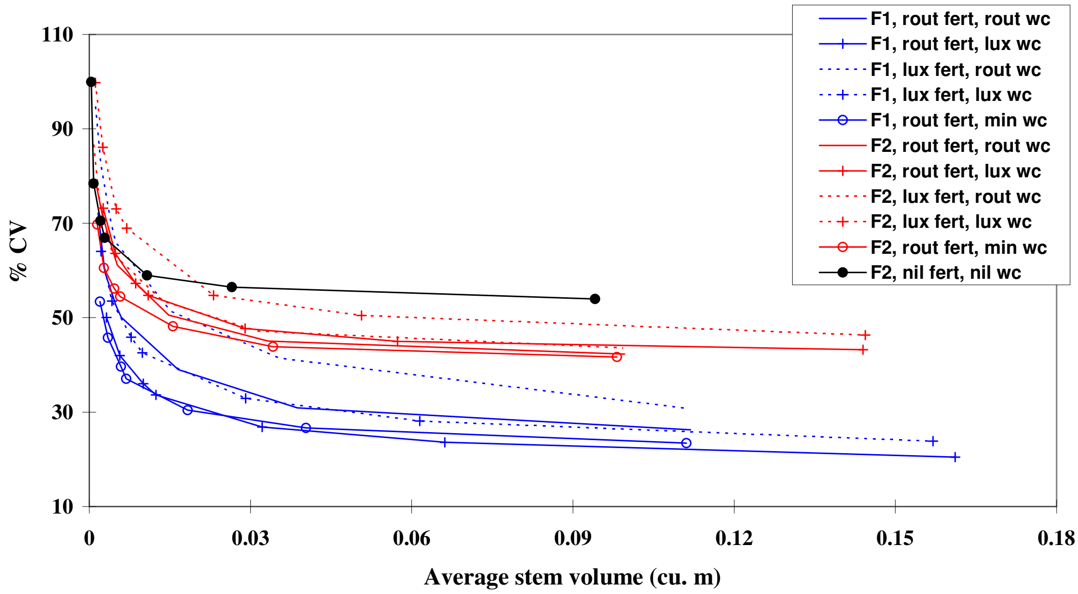


Figure 35. Stem volume coefficient of variation versus average stem volume for all treatments in Experiment 350 GYM.

The percentage of stems with poor straightness in each treatment is presented in Figure 36, and is defined as the percentage of stems for which the maximum deviation from a straight edge for a 2.5m length of stem is at least 2cm. The results indicate that the F_1 clones are generally straighter than the F_2 seedlings. There is no evidence that the minimum weed control treatments have poorer straightness than the corresponding routine weed control treatments. Although not significant, there is an indication that the luxury weed control may have had a deleterious effect on straightness of the F_2 seedlings.

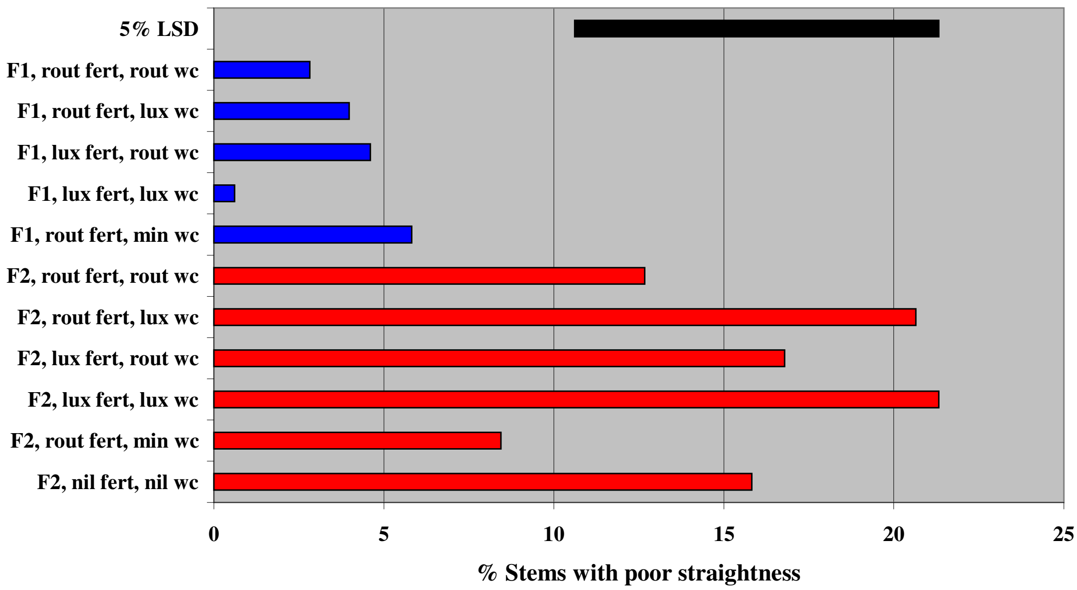


Figure 36. Percent stems with poor straightness for each treatment in Experiment 350 GYM at age 9.5 years.

Velocity squared (vel^2) was selected as a proxy for wood stiffness, since stiffness can be predicted as $velocity^2 \times density$. In Figure 37 the F_1 clonal cuttings generally had higher vel^2 than the F_2 seedlings, and luxury fertiliser seems to have significantly reduced vel^2. Importantly, minimum weed control has not impacted adversely on vel^2, and the nil–nil treatment is about mid-range for vel^2 among all of the F_2 treatments.

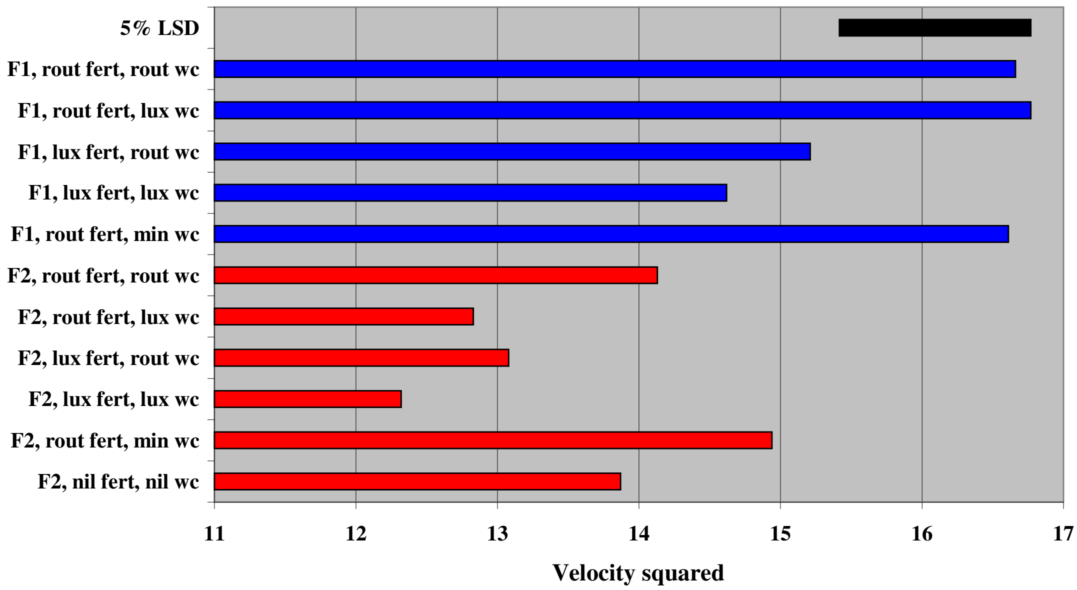


Figure 37. Average velocity squared for standing tree ST300 assessments of each treatment in Experiment 350 GYM at age 9.6 years.

Results for the 2×2×2 factorial

The following figures presenting the main effects for one factor are averages over both levels of the other two factors. As such, it is the difference between the two main effects for a factor which is crucial rather than the actual magnitudes of the individual main effects.

Even though the different genetic stock have comparable predominant heights in Figure 38, the F_1 has a significantly higher average height than the F_2 in Figure 39 - the difference being about 1.4m. Thus the fastest growing F_2 seedling stock are growing as quickly as the fastest F_1 clonal stock, but overall the F_1 still has superior height growth relative to the F_2.

In Figure 40 the F_1 clones had superior average stem volume at the most recent measure, and the absolute difference in stem volumes seems to be increasing with age. The F_1 clones were also superior for standing total volume at age 8.2 years. In fact the margin was 12.9 m^3ha^{-1} and was very highly significant (probability less than 0.001). This absolute volume advantage seems to be increasing with time. It is also important to note that the slightly higher stocking rate of the F_1 will tend to boost its values for standing basal area per hectare and standing volume per hectare.

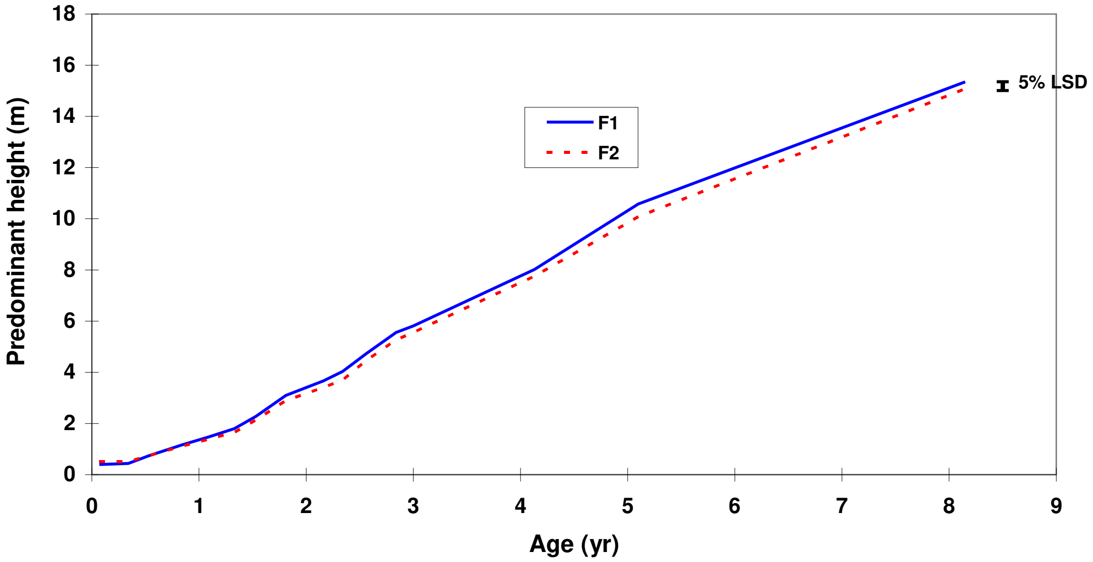


Figure 38. Genetic main effects for predominant height versus age in Experiment 350 GYM.

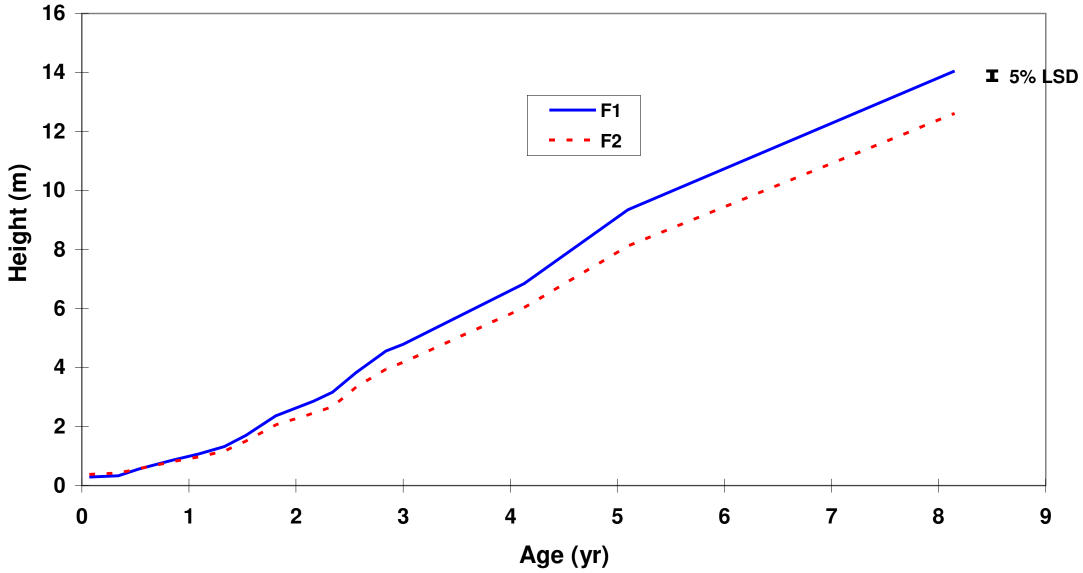


Figure 39. Genetic main effects for average height of live useful stems versus age in Experiment 350 GYM.

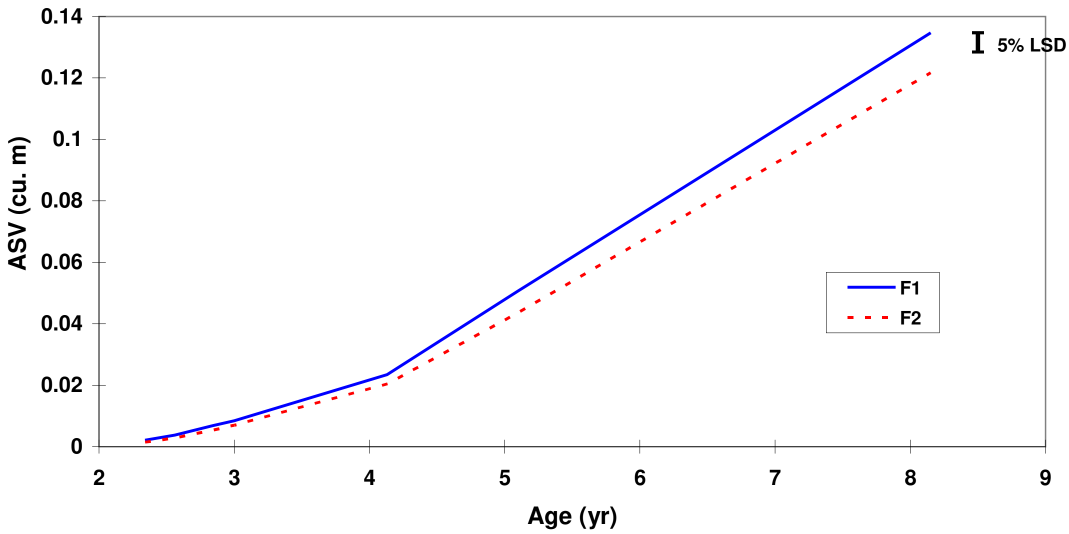


Figure 40. Genetic main effects for average stem volume (underbark, total above 15cm stumps) of live useful stems versus age in Experiment 350 GYM.

Luxury fertiliser had a significantly poorer survival rate than the routine fertiliser, and results were similar for stocking rate (data not shown). With regard to growth rate the luxury fertiliser was significantly inferior to the routine fertiliser at young ages, but at the most recent measure there was no significant difference between the fertiliser main effects for any of the growth parameters considered in this report (data not shown).

Luxury weed control created a massive response for average stem volume (Figure 41) and total standing volume (Figure 42) at age 8.2 years.

The advantage of the luxury weed control over the routine weed control for standing volume in Figure 42 is a huge 37 m^3ha^{-1} and is very highly significant. The absolute volume advantages in Figures 41 and 42 seem to be increasing with age.

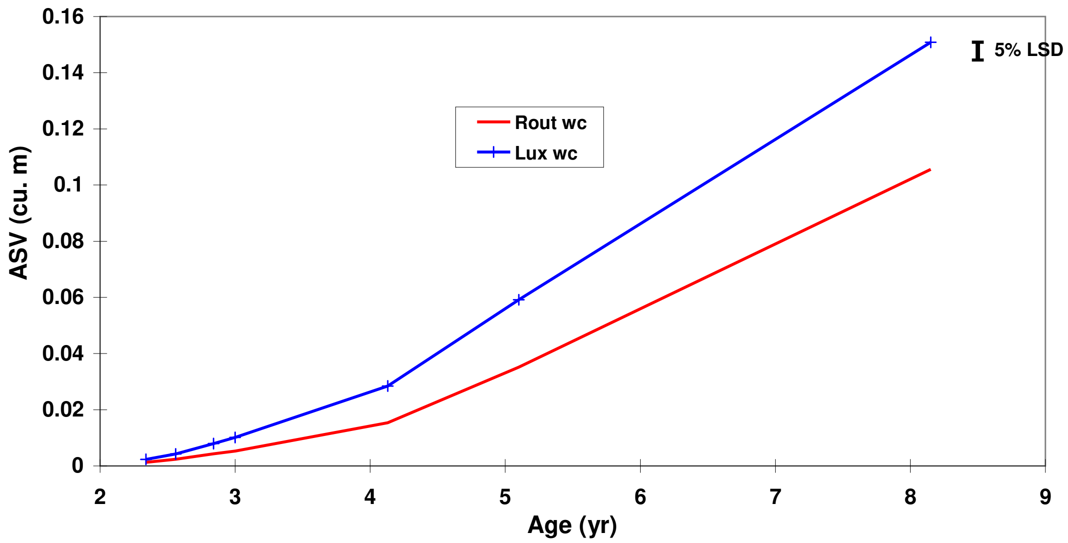


Figure 41. Weed control main effects for average stem volume (underbark, total above 15cm stumps) of live useful stems versus age in Experiment 350 GYM.

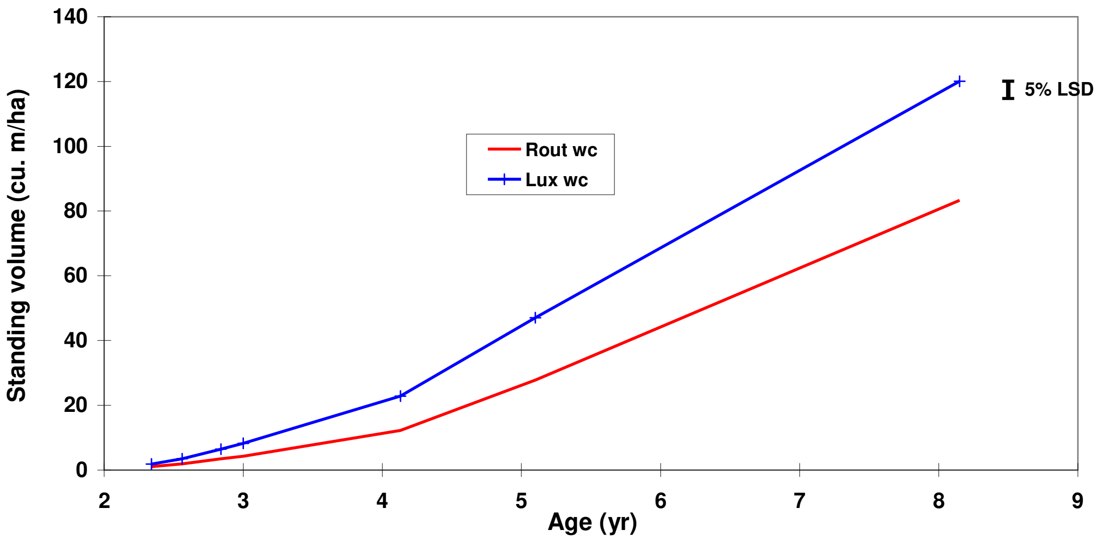


Figure 42. Weed control main effects for estimated total standing volume per hectare (underbark, above 15cm stumps) of live useful stems versus age in Experiment 350 GYM.

None of the interactions for percentage of stems with poor straightness or for vel^2 (acoustic velocity squared) were significant. The 5% LSD's in Figures 43-44 are applicable to each pair of main effects. In Figure 43 the F_2 seedlings are very much poorer than the F_1 clonal cuttings for straightness. The fertiliser and weed control main effects are both not significant for straightness. In Figure 44 the F_1 clones are quite superior for vel^2. Both luxury fertiliser and luxury weed control have reduced vel^2, although the latter is not statistically significant at the 5% level.

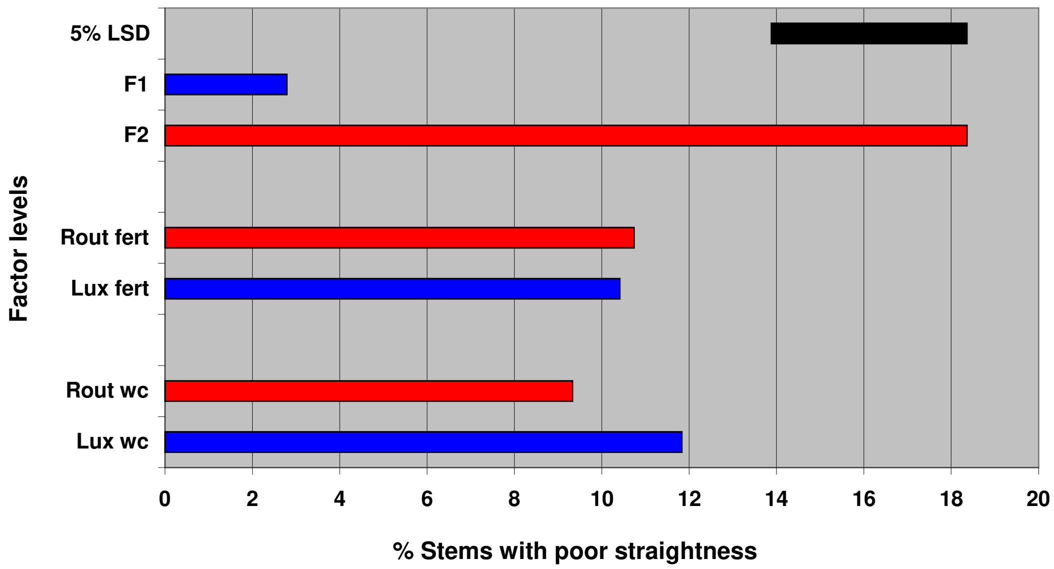


Figure 43. Percent stems with poor straightness for each factorial main effect in Experiment 350 GYM at age 9.5 years.

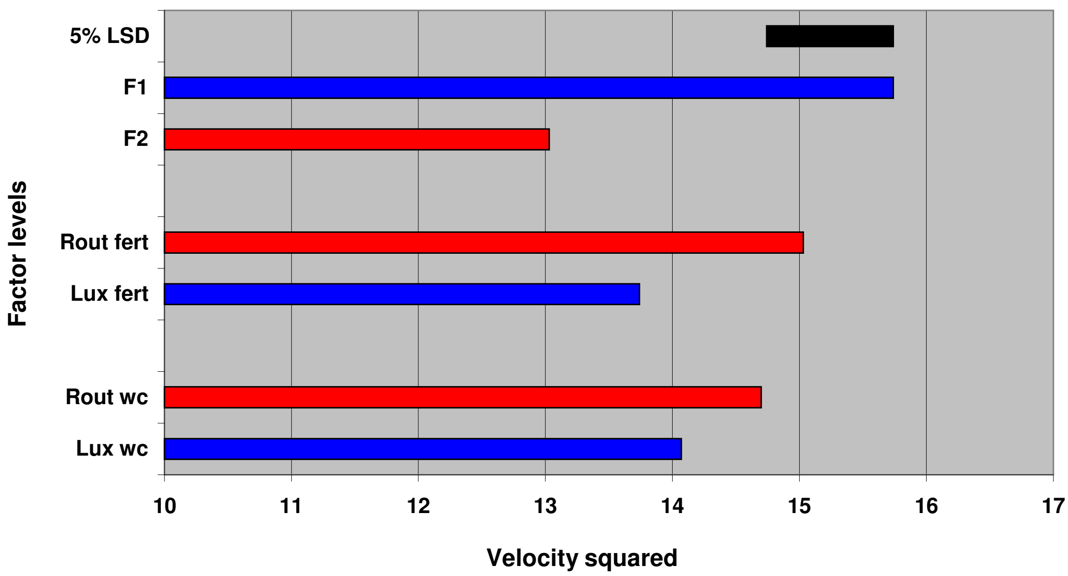


Figure 44. Average standing tree ST300 velocity squared for each factorial main effect in Experiment 350 GYM at age 9.6 years.

Results for clones

The graphs in this section present values for the most recent measure, rather than trends with age. All clonal values are main effects averaged over all weed control and fertiliser levels. Most graphs include overall values for the F_1 and F_2 (main effects from the 2×2×2 factorial) for comparison purposes. All LSD's strictly refer to comparisons among clones, rather than to comparisons involving the F_1 or F_2. Each clonal value is based on about 90 stems for growth and straightness, and about 45 stems for acoustic velocity. In most cases if a clone was a "top 10" Series II clone then its Series II ranking has been appended to the clone number.

The clonal main effects for growth are all statistically very highly significant. In Figure 45 clones 3574, 3827 and 3842 are outstanding for average DBH. The top 10 clone 3640 is somewhat poorer than the average F_2, by about 0.6cm, and so is clone 3926. In Figure 46 the average height of every clone is greater than that of the F_2 seedlings.

The three clones which were outstanding for average DBH are also outstanding for average stem volume in Figure 47. The top 10 clone 3640 is not much different from the F_2 average, but clone 3926 is still performing relatively poorly even compared with the F_2.

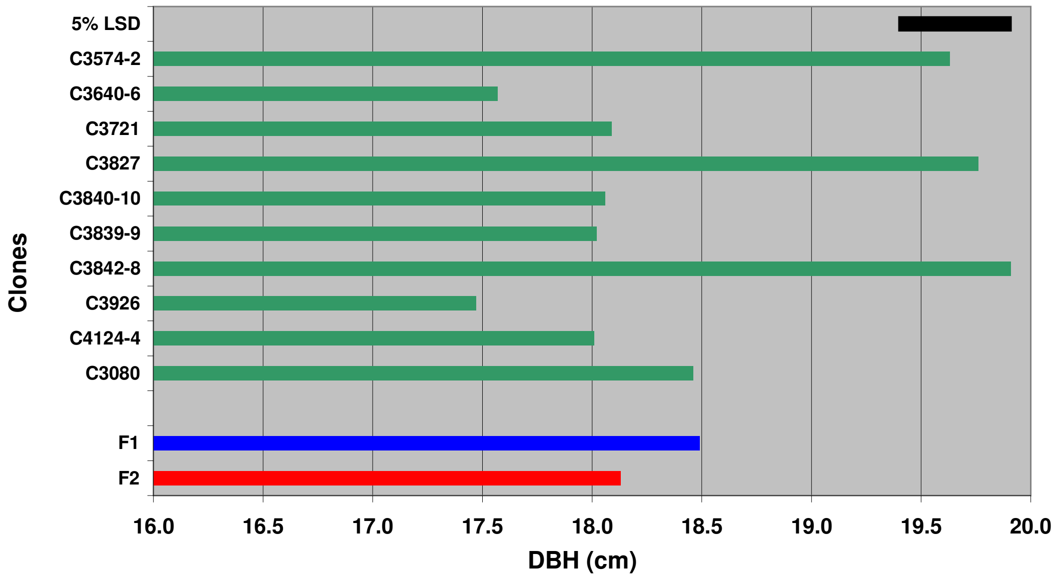


Figure 45. Average DBH of live useful stems for each clone in Experiment 350 GYM at age 8.2 years.

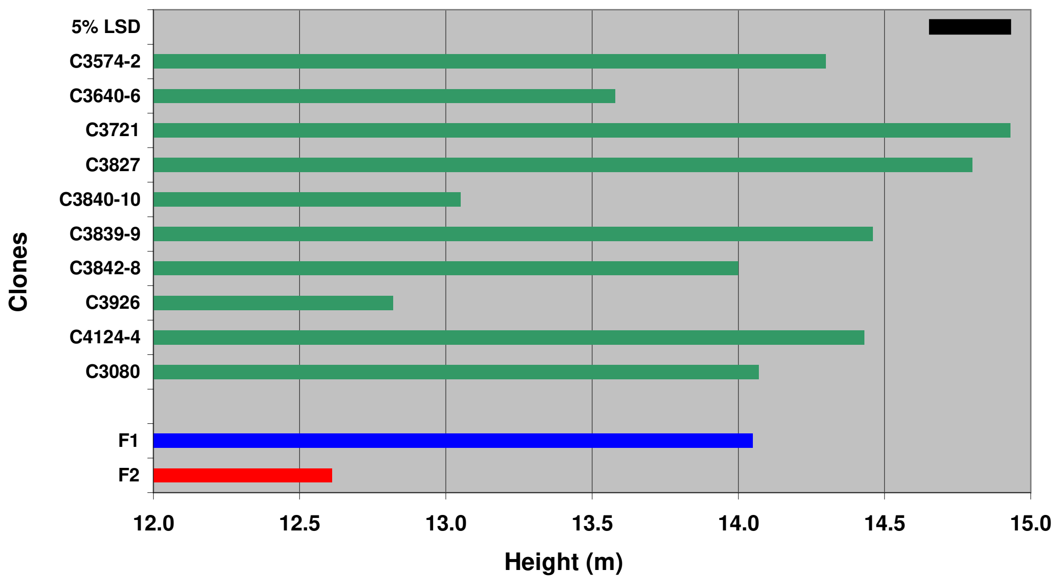


Figure 46. Average height of live useful stems for each clone in Experiment 350 GYM at age 8.2 years.

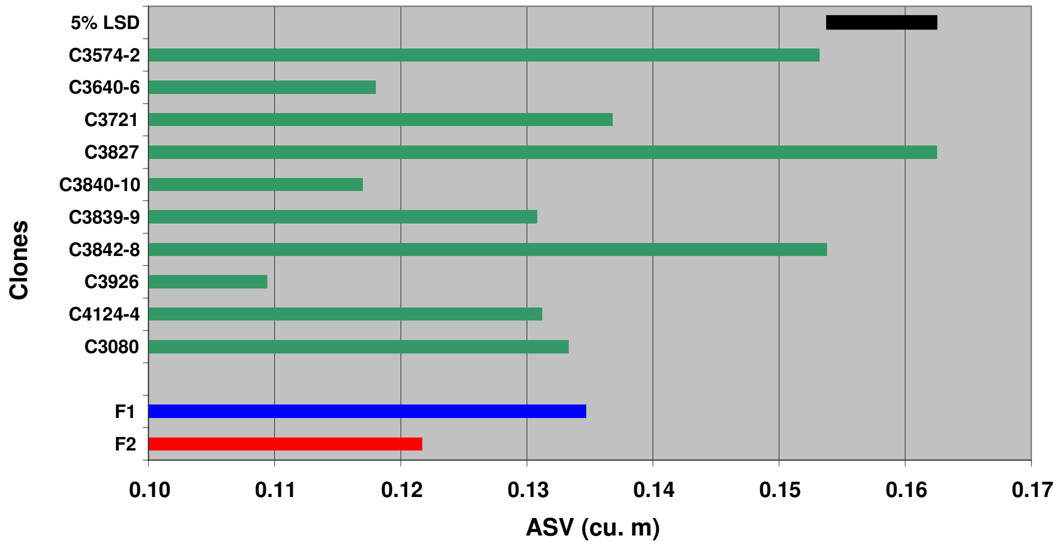


Figure 47. Average stem volume (underbark, total above 15cm stumps) of live useful stems for each clone in Experiment 350 GYM at age 8.2 years.

Figure 48 reinforces the poor stem straightness of the F_2 seedlings. It is noteworthy that the top 10 clone 3640 is at least twice as poor as all other clones observed here, but is still twice as good as the F_2 seedlings.

Of the three clones which were exceptional for growth rate, viz. 3574, 3827 and 3842, only clone 3574 had a relatively high vel^2 (acoustic velocity squared) in Figure 49. Clone 3827 had by far the lowest vel^2, and clone 3842 had the second lowest vel^2 among the clones but was still "better" than the F_2 seedlings. Top 10 clone 3640 had a substantially higher vel^2 than the F_2 seedlings.

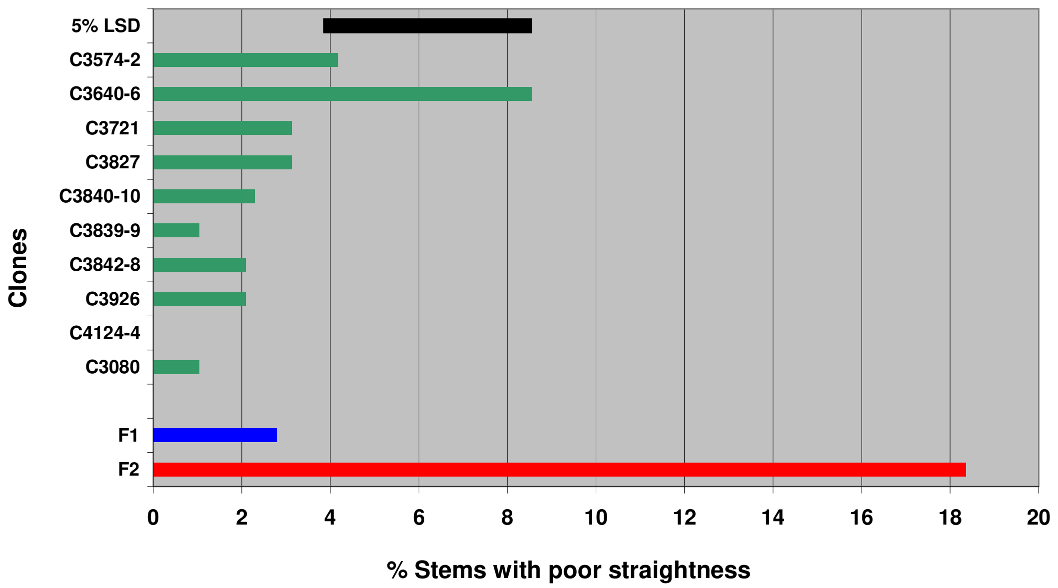


Figure 48. Percent stems with poor straightness for each clone in Experiment 350 GYM at age 9.5 years.

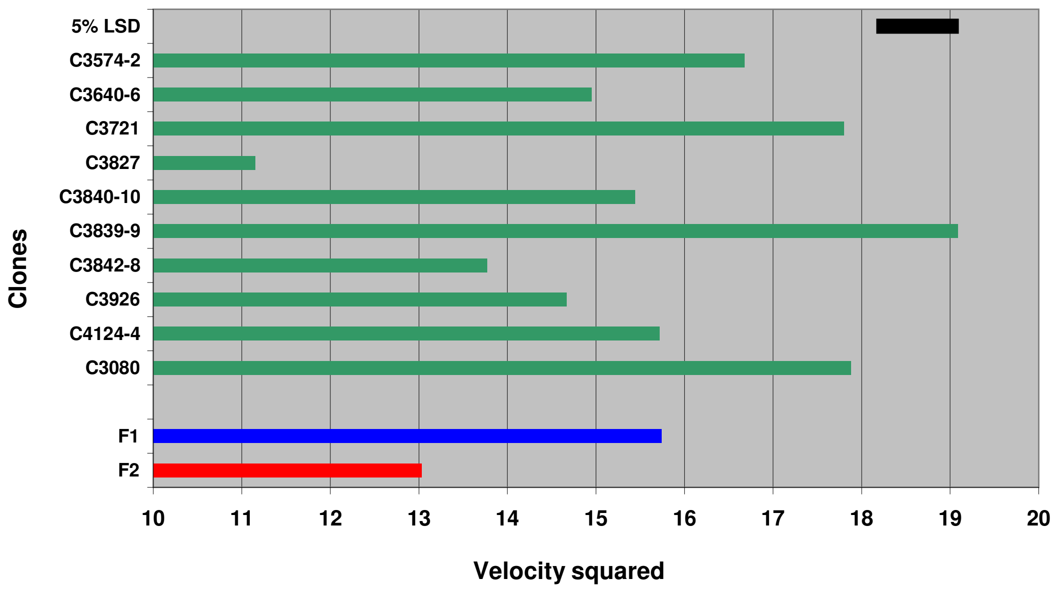


Figure 49. Average velocity squared for standing tree ST300 assessments for each clone in Experiment 350 GYM at age 9.6 years.

The higher acoustic velocity of the F_1 hybrid than the F_2 hybrid was uncharacteristic of previous studies, including the results from the studies of 674 TBS and 464 TBS in this report. A further study was carried out to compare the wood density and spiral grain of the F_1 and F_2 hybrid populations in 350 GYM.

Spiral grain readings were measured on the outer latewood – earlywood interface of growth rings 3, 5 and 9 for individual F_1 clones and F_2 seedlings. The F_1 hybrid had lower grain angle in growth ring 3 than in the F_2 hybrid (p=0.082; Figure 50) though aside from this there were no statistically significant differences between the two populations, consistent with the findings in Experiment 674 TBS in Figure 11. The variation in spiral grain among the individual F_1 clones demonstrated that all the clones assessed have acceptable to superior grain angles with relatively low values - well below the 4.0 to 4.5 degree level where spiral grain can become problematic for distortion and reduced timber stiffness. Interestingly, the clones with the lowest grain angles also were superior for predicted MoE, and clones 3840 and 3842 also ranked highly for wood density.

Basic density results for resin-extracted increment core samples from Experiment 350 GYM segmented into two radial segments, pith to growth ring 5 and growth ring 6 to bark inclusive, and for the basal area weighted whole core average are charted in Figure 51. The results show no significant differences in wood density between the average of the 8 F_1 clones and the F_2 hybrid seedling populations. This is broadly consistent with the results in Figures 7 and 13 (from Experiments 674 TBS and 464 TBS, respectively; Harding *et al.* 2009) where the F_2 hybrid often had higher wood density than the F_1 hybrid but the difference was not statistically significant on three of four sites, and most likely due to genetic sampling effects. The F_1 clones are generally faster growing than the F_2 seedlings; in this particular study the F_1 was about 10% larger than the F_2 for stem volume (Nester 2009c). Based on earlier experience in FPQ, this led to the expectation that the slower growing F_2 might be denser than the F_1. While the means were not different, it should be noted that the F_2

hybrid had a wider spread of density values than the F_1 hybrid in this experiment (Zbonak *et al.* 2010).

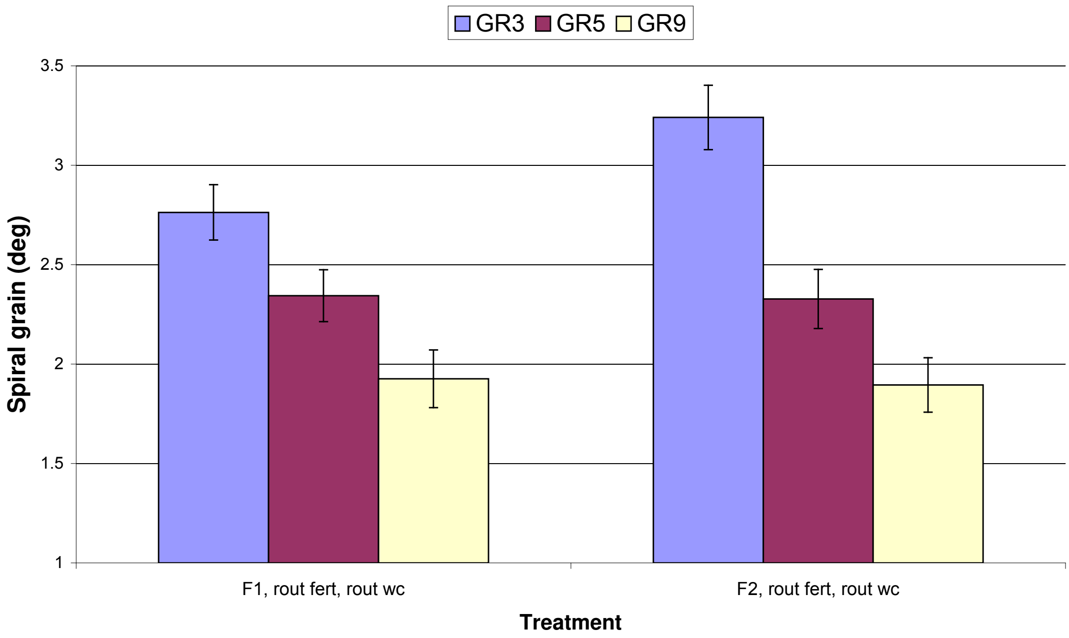


Figure 50. Average spiral grain angle (degrees) at growth rings 3, 5 and 9 (standard error bars included) across F_1 clones versus F_2 seedlings for routine fertiliser, routine weed control treatment in Experiment 350 GYM

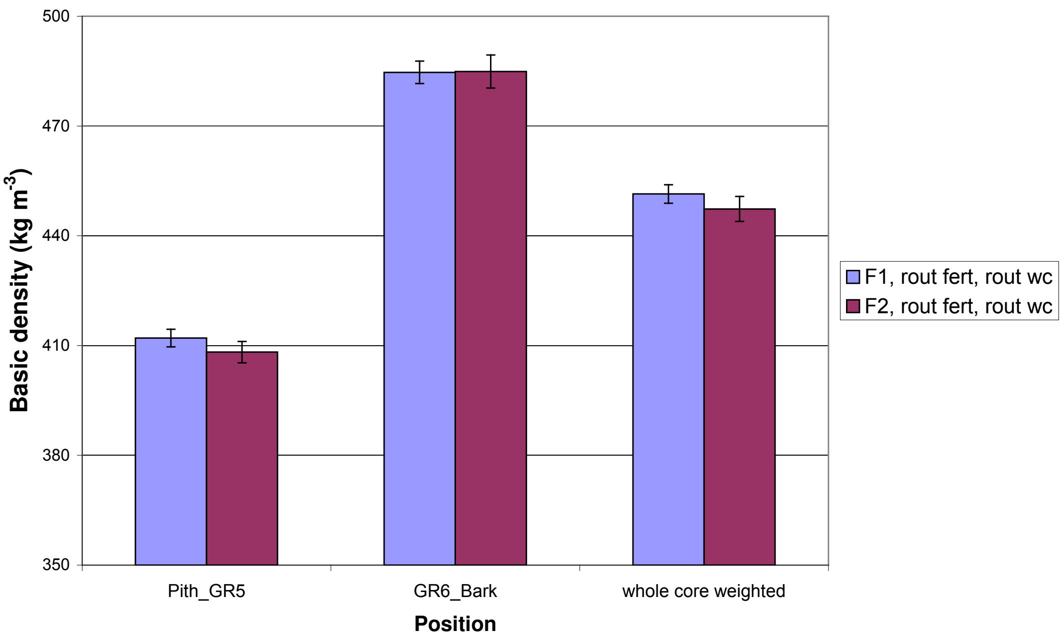


Figure 51. Average resin-extracted basic density of basal area weighted inner wood (Pith_GR5), outer wood (GR6-bark) and whole core samples (with standard error bars) for F_1 clones and F_2 seedlings sampled from routine fertiliser, routine weed control treatments as part of Experiment 350 GYM.

Discussion - Hybrid pine genetics × silviculture trial (350 GYM)

Weed control effects

By far the biggest growth response in experiment 350 GYM has been to luxury weed control. For example, in the 2×2×2 factorial luxury weed control boosted final standing volume by 37 m^3ha^{-1} relative to the routine weed control, but the F_1 clones have boosted volume by only 13 m^3ha^{-1} relative to the F_2 seedlings. However if the cost of the luxury weed control treatment were to be properly evaluated then it seems likely that it would be too expensive to be a profitable management option, unless a cheap method of adopting a "bare earth" policy can be found. Nonetheless the luxury weed control provides a benchmark for what is potentially achievable with this PEE × PCH hybrid taxon at this stocking rate on these kinds of sites under the prevailing climatic conditions, without resorting to the application of very special inputs such as irrigation.

Of greater immediate relevance for FPQ are the results for the "routine" weed control which required 2-4 post-establishment band tends, the minimal weed control which was restricted to exactly one post-establishment band tend, and the nil–nil treatment in which no fertiliser was applied and no post-establishment band tending was undertaken. With regard to growth rate and stem size variability there was no discernable difference between the minimal weed control treatments and the corresponding routine weed control treatments at age 8 years. Furthermore there was no evidence that the minimal weed control treatments had poorer straightness or lower vel^2 (acoustic velocity squared) than the corresponding routine weed control treatments at about age 9 years. Despite the fact that much of the site was heavily infested with blady grass it seems that the repeat band tends of the routine weed control incurred costs but gained nothing. Unless FPQ decides to adopt something like a bare earth policy for weed control, such as keeping sites completely weed free for one or more seasons, there seems little point in doing more than one post-establishment band tend. These remarks must be qualified, as usual, since they are based on just one experiment with just one stocking configuration under a particular set of prevailing climatic conditions.

The nil-nil treatment, using F_2 seedlings, is more problematic. Although its predominant height is satisfactory its overall productivity is still the lowest among all 11 treatments. For example in Figure 22 the nil-nil treatment is lagging the F_2, routine fertiliser, minimal weed control treatment by about six months, and the trends with age indicate that this gap will remain for at least several more years. FPQ's most recent fertiliser prescription would require the application of either 25 kg ha^{-1} of P at planting, or no fertiliser at all, depending on how much P fertiliser was applied during the slash pine first rotation. Either way, given that the nil-nil treatment is currently growing at the same rate as the F_2, routine fertiliser, minimal weed control treatment (but simply lagging by six months) it seems unlikely that P is currently limiting for the nil-nil treatment. This would then mean that the absence of a single post-plant tend has caused the nil-nil treatment to continue to lag. This in turn would mean that a single post-plant band tend at age 4 months, as in the minimal weed control treatment, has an effect which lasts at least eight years, but 1-3 additional band tends, as in the routine weed control treatment, have no long term impact. Experiment 350 GYM is not designed to try to disentangle the fertiliser and weed control effects associated with the nil-nil treatment. It will be interesting to monitor this treatment for many more years. It would also be interesting to know if the beneficial six month gain in volume growth of combined routine fertiliser and minimal weed control are sufficient to offset their combined costs.

Fertiliser effects

Overall the luxury fertiliser treatments have performed very poorly with respect to both growth rate and variability. It is believed that this is a result of the combined effects of potassium in the luxury fertiliser treatment, lack of mounding, frequent heavy rains and long periods during which the sites remained waterlogged in the first year after planting.

Given that the luxury fertiliser treatments are finally catching up with the routine fertiliser treatments, it seems that now is the time to consider applying additional fertiliser to the luxury fertiliser treatments.

F_1 clones

The results for clone 3640 in particular are most pertinent for FPQ. This clone was ranked sixth "best" among the Series II clones. It also happens that, due to its superior nursery propagation performance compared with the other clones, this clone has been planted on more than 13,000 ha by FPQ, and is the most widely planted Series II clone, representing 57% of the Series II estate. In Experiment 350 GYM on a supposedly average site in the Fraser Coast (Toolara) region of south-east Queensland the productivity of clone 3640 has been marginally less than that of the F_2 seedlings at about age 8 years. The overall straightness of clone 3640 is considerably better than that of the F_2 seedlings, although its straightness is quite poor compared with the other clones considered here. This relatively poor straightness of clone 3640 might not be very relevant at clearfall, especially if stands of clone 3640 are subjected to commercial thinnings at about age 18 years, which is currently common practice in FPQ's exotic pine plantations. Promisingly, clone 3640 had a substantially higher vel^2 than the F_2 seedlings.

Forestry Plantations Queensland has been carefully reviewing its investment in, and commitment to, clonal forestry. After carefully considering a range of alternative management regimes, site qualities, possible pricing structures including premium prices for high quality clones, and various assumptions, FPQ concluded that clones needed to achieve 10% more volume on average sites and 15% more volume on high quality sites relative to the PCH benchmark in order to justify their deployment. Considering the information in Nester (2008), the productivity of the F_2 best seedlings is about comparable with that of PCH so the F_1 clones need to have a volume advantage of about 10–15% over the F_2 seedlings in order to justify their deployment.

Table 33 presents some average volume advantages (%Adv) for the high performance Series II clones which were planted in Experiment 350 GYM. Only data for the routine fertiliser, routine weed control plots (treatment numbers 1 and 5) in blocks 1, 4, 5 and 6 were used. The predicted %Adv's for ages 15, 20 and 25 years were calculated by assuming that volume growth rates between ages 5.1 and 8.2 years can be linearly extrapolated into the future.

Table 33 indicates that the particular Series II clones planted in this experiment would comfortably reach the target %Adv of 10–15% in an unthinned regime (planted at 830 stems/ha). However if we consider a commercial thinning regime in which 430 stems are retained through to clearfall then the F_1 clones will not reach their target, but can at least be expected to yield considerably larger thinning volumes than the F_2 seedlings. Of course the actual clearfall %Adv in a commercial thinning regime will depend on the thinning intensity. If more stems are retained then the %Adv of the F_1 clones will increase, but if fewer stems are retained then the %Adv will decrease. In fact projections not tabulated here show that if only about 300 stems are retained through to clearfall then the volume advantage of clones will be 0%.

Table 33. Average percent volume advantages for the 10 Series II clones tested in Experiment 350 GYM. The advantages based on the Series II test sites are for stem volumes with respect to the averages of all clones in the Series II tests. The advantages based on Experiment 350 GYM are for standing volume per hectare with respect to the F_2 best seedlings.

Circumstance	%Adv
Series II coastal ridge sites at about age 5 years	59
Series II coastal swamp sites at about age 5 years	32
Series II all sites combined at about age 5 years	30
Experiment 350 GYM, age 5.1, rout fert + rout wc	26
Experiment 350 GYM, age 8.2, rout fert + rout wc	21
Experiment 350 GYM, age 15, rout fert + rout wc (PREDICTED)	19
Experiment 350 GYM, age 20, rout fert + rout wc (PREDICTED)	19
Experiment 350 GYM, age 25, rout fert + rout wc (PREDICTED)	19
Experiment 350 GYM, age 5.1, rout fert + rout wc, biggest 430 stems/ha	11
Experiment 350 GYM, age 8.2, rout fert + rout wc, biggest 430 stems/ha	6
Expt 350 GYM, age 15, rout fert + rout wc, biggest 430 stems/ha (PREDICTED)	4
Expt 350 GYM, age 20, rout fert + rout wc, biggest 430 stems/ha (PREDICTED)	4
Expt 350 GYM, age 25, rout fert + rout wc, biggest 430 stems/ha (PREDICTED)	4

As usual it should be emphasised that Table 33 refers only to a single experiment with a particular climatic history. %Adv's can certainly vary from site to site, as even exemplified by the first two rows of Table 33 where the %Adv on tested ridge sites was 59% but on the tested swamp sites it was only 32%. Furthermore only a particular suite of Series II clones were tested in Experiment 350 GYM. The degree to which results are applicable to other FPQ clonal Series is uncertain.

Conclusions - Hybrid pine genetics × silviculture trial (350 GYM)

1. The early age deleterious effects of the luxury fertiliser are now waning. It is even conceivable that the luxury fertiliser will soon surpass the routine fertiliser.
2. Maximum treatment response was achieved through luxury weed control, far outweighing the genetic effect in this experiment. Luxury weed control

provides a benchmark for the maximum growth rates achievable on a typical exotic pine site in south-east Queensland without resorting to special inputs such as irrigation. Unfortunately current costs and technology render luxury weed control uneconomical.

3. If luxury weed control is not an option then a single post-plant tend has as much long term benefit on growth as two to four post-plant tends.

4. The nil fertiliser, nil weed control treatment and the minimum weed control treatments were very similar to, and not statistically significantly different from, their corresponding treatments with routine weed control. If these "low-input" treatments do not deteriorate in the future then they might be economically worthwhile alternatives to the former routine regime. However, as the nil/nil control treatment was unreplicated, a follow-up field trial would be necessary to draw firm conclusions regarding this treatment.

5. On average the F_1 Series II clones tested in Experiment 350 GYM have superior growth, superior straightness, higher standing tree acoustic velocities, and probably superior stiffness to the 'F_2 best' seedlings. However in commercially thinned stands the superior growth and straightness of the F_1 clones might not translate into measurable superiority at clearfall, but merely to more volume of better quality stems in the thinned fraction.

6. Unfortunately, due to differences in ease of propagation, Series II clones were planted disproportionately across south-east Queensland. The approximate 13,000 ha planted with clone 3640 is unlikely to achieve better productivity than could have been achieved using F_2 seedlings. Any dividend from clone 3640 will have to come from its improved stem quality.

7. The F_1 hybrid clones and F_2 hybrid population in this experiment did not differ significantly in wood density or spiral grain, consistent with other findings in this report and previously. The higher acoustic velocity of these 10 F_1 clones than the F_2 families is most likely due to sampling effects in microfibril angle, since neither population had been selected for wood traits.

8. There was very little evidence of strong interactions among the genetic stock, fertiliser and weed control factors at the latest measure. If this lack of interaction continues through to advanced ages then it is very good news for forestry research and enhances confidence in some inferences drawn from experiments.

9. Experiment 350 GYM is now old enough to provide reasonably reliable results, interpretations and conclusions but it will be many more years before we have definitive results.

Summary of Project findings against Key Questions and Expected Outputs and associated recommendations

Key questions addressed by the Project include:

1. Are growth rates and wood properties of sub-tropical pine taxa significantly different within and between geographic locations?
2. How do hybrid pine growth rate and wood properties vary within and between families and across different sites?
3. Do different deployment strategies (hybrid pine seedlings versus family cuttings versus clones) result in significant differences in growth rate and wood properties? If so, on what basis should hybrid families be characterised as being (a) suitable for direct family forestry deployment (b) better suited for clonal testing and selection or (c) both?
4. How do weed control, genetics and nutrition impact on hybrid pine growth rate and wood properties, separately and in combination?

Expected Outputs from the Project include:

- Improve the understanding of long-term growth trends and wood properties of major sub-tropical pine taxa to inform the economic analysis of comparisons made by forest growers between a range of plantation management, harvesting and deployment alternatives;
- Identify superior hybrid pine families and clones for operational use that take account of growth and commercially important wood properties; and
- Identify the effects of weed competition, fertiliser and genetics on growth and wood properties and utilise these to modify silvicultural regimes to reflect their economic significance to plantation returns.

Principal conclusions and recommendations relating to key question 1 are described under the heading "Taxa comparison". Those relating to key questions 2 and 3 are addressed under "Clonal and family comparisons", and those relating to key question 4 are addressed under "Effects of weed control, nutrition and genetics".

Taxa comparison

Conclusions

The following overall conclusions can be drawn from the taxa comparison studies:

1. Caribbean pine (PCH) and the slash x Caribbean pine hybrid (PEE × PCH) have similar stem volume on average across a range of sites, far surpassing that of slash pine (PEE);
2. Outerwood MoE of the PEE × PCH hybrid (predicted using acoustic methods) was more similar to the stiffer parent, slash pine, than to Caribbean pine on three of the four sites examined;

3. The superiority of slash pine wood density over Caribbean pine and the PEE × PCH hybrid began to emerge only after the first five growth rings, and was greatest in the outerwood after rings 16-20, while the hybrid remained intermediate between the parental species;
4. Slash pine had significantly higher spiral grain than Caribbean pine at both Tuan and Beerburrum, and significantly higher than the PEE × PCH hybrid at one site. Spiral grain in the PEE × PCH hybrid varied greatly between the two sites;
5. The F_2 hybrid had higher basic density, acoustic velocity and predicted MoE than the F_1 hybrid on all sites examined, though the difference was rarely significant and most likely a genetic sampling effect;
6. Relative rankings of PEE, PCH and PEE x PCH in all wood properties were very consistent across sites, though the *differences* between the taxa were much greater on some sites than others. No relationship to trends in latitude or other known site characteristics could be identified;
7. Relative rankings of the Tuan and Beerburrum regions for wood density were reversed in these two experiments. Further investigation of the characteristics of the four sites may help elucidate the causes of this site-related variation in wood properties and that described in point 6.

Recommendations

This study of thinning age and clearfall age pine taxa experiments has produced a range of significant results in wood properties across sites and among the taxa studied. It would be prudent to conduct processing studies in Experiment 464 TBS when it is harvested to ultimately define whether the observed differences are of practical importance to structural grade recovery. Without providing this link to commercial processing outcomes it is difficult to predict whether these wood property differences are large enough to justify changes to taxa deployment or silvicultural management and processing options to improve returns to either grower and/or processor. Experiment 464 TBS presents a rare opportunity to compare the sawn timber quality at clearfall age of the slash × Caribbean pine hybrid - which will form the bulk of future feedstock for softwood timber processors in Queensland - with its parent species, which formed the bulk of their past feedstock. Experiment 674 TBS provides a second opportunity to do this in around seven year's time.

Recommend:

1. Batched stem studies be carried out to capture taxon level dried dressed and graded recovery comparisons at clearfall age in Experiment 464 TBS. The Tuan site is a logical first priority due to the similarity of its silviculture to current routine. Replication of the study at the Beerburrum site would allow consideration of the combined impact of growth rate, stocking and wood property variation on potential grade recovery and therefore stand value.
2. Further standing tree wood property studies at clearfall age in Experiment 674 TBS to confirm taxa trends with age.
3. Site studies of edaphic factors at the sampled Tuan and Beerburrum sites in both Experiments 464 TBS and 674 TBS to provide more information to consider why

density trends with location are reversed in the two experiments, and why wood properties vary greatly among taxa at some sites but not others.

4. A sawing study is conducted in Experiment 674 TBS at about 30 years of age to provide matching comparisons to those collected for Experiment 464 TBS if recommendation 1 above is accepted and initiated.
5. That FPQ review the economic viability of retaining and maintaining a capacity within the tree improvement and production programs to produce and deploy the best available slash pine or hybrid backcross to slash pine.
6. That FPQ further investigate the inter-variety hybrid *Pinus caribaea* var. *caribaea* × *Pinus caribaea* var. *hondurensis*, which, though only its parent species are included in Experiment 464 TBS, shows outstanding promise in other experiments as a wind-firm hybrid for North and Central Queensland. These regions are predicted to experience increasing severity of damaging storm events due to climate change.

The comparison of spiral grain across taxa in Experiment 674 TBS indicated that PEE had the highest or least desirable grain angle values and PCH the lowest with the hybrids being intermediate though very variable between the two sites.

Recommend:

7. Further taxa comparisons are undertaken in other parental versus hybrid plantings to determine if the spiral grain taxa rankings seen in Experiment 674 TBS are consistent across sites and experiments.

Comparing acoustic velocities across sites in Experiment 464 TBS suggests that PEE mean values are not much changed by stocking rate, whereas the velocities of all other taxa tended to reduce when grown at a high stocking rate at Beerburrum. Therefore it is hypothesised that the other taxa may be more reactive to both site and stocking level.

Recommend:

8. Survey acoustic velocity in a controlled range of similarly aged stands with significantly different stocking levels for PEE, PCH and their F_1 and F_2 hybrids to consider whether the latter taxa are more reactive to competition levels than PEE.
9. Additionally, as a complementary study, investigate the impacts on trends of using whole core density or density for some group of outer rings only (and green versus basic density values) along with ST300 velocity to predict wood stiffness.
10. Incorporate results from these recommended new studies into a modelling platform such as the Win-Epifn Decision Support Systems platform to consider the nominal value of a stand, taking into account both density (at breast height and up the stem) and volume of wood recovered in various stiffness classes.

Clonal and family comparisons

Conclusions

This study has identified some very well performed hybrid families and clones. These combine desirable growth and form with superior wood quality traits and provide useful indications of a suite of parents, families and clones that should be prioritised in tree improvement programs. The studies yielded the following specific conclusions:

1. Large and economically valuable differences were identified between the best and worst clones and families in important wood traits (predicted MoE, acoustic velocity, wood density and spiral grain) indicating positive prospects for genetic improvement through selection at the parental, family and clonal levels;
2. The gains achieved through clonal selection should be leveraged in the breeding population by using selected clones with superior wood properties as parents;
3. Acoustic velocity and stem volume were very weakly (though adversely) genetically correlated, consistent with evidence from previous studies indicating favourable prospects for concurrent selection for growth and wood quality in the slash × Caribbean pine hybrid;
4. Non-additive genetic variation was similar to additive genetic variation in many of the traits studied, indicating potential for both clonal selection and full-sib family selection and deployment, to capture additional gain beyond that achievable by parental selection;
5. Results in both the clonal and family studies indicated that the most outstanding full-sib families for stem volume tended to have lower within-family variance. These were also the families yielding the highest proportion and number of clonal selections in the clonal study. It suggests limited potential for finding outstanding, variable families for testing under clonal deployment, yet good potential for finding a suite of outstanding full-sib families with low variability for deployment in full-sib family forestry. The value of selecting variable families in more highly heritable traits may be worth investigating in the context of a clonal program.
6. The low genotype by environment interaction for acoustic velocity in the clonal study supports the findings of previous studies showing high genetic correlations across sites for wood density and stiffness in the slash × Caribbean pine hybrid in Queensland;
7. Acoustic velocity measures on different sides of the tree were very strongly genetically correlated, indicating the need only to measure one side.

Recommendations

1. Future planning consider a re-evaluation of these trials at later ages to coincide with major trial measures e.g. at thinning age (approximately 18 years) for the family trial and age 10 years for the clonal trial. Assessment of large numbers of trees for acoustic velocity would be a high priority both due to the importance of timber stiffness predictions for structural product quality and to provide large data sets for genetic analysis.

2. Further investigate the genetic correlations between economically important growth and wood traits (Modulus of Elasticity, acoustic velocity, spiral grain), and the inheritance of these traits, in a larger sample of parents, to obtain estimates suitable for use in the process of plus tree selection;
3. Further investigation of patterns of genotype by site interaction in growth traits in the PEE × PCH hybrid, in 749 TBS and other suitable datasets;
4. Further study to examine whether the observations of genetic architecture in F_1 hybrid populations are reflected in advanced generation hybrid populations (currently either F_2 or a mixture of F_2 and F_3).
5. Acoustic velocity to be assessed concurrently with routine assessment of growth and form traits in genetic field tests at 6 years of age.
6. A return-to-tree sawing study to evaluate the relative influence of growth traits, corewood stiffness, stem straightness, spiral grain and other potential selection criteria on sawn board recovery and value, in rotation age slash x Caribbean pine hybrids grown under typical silviculture, to provide the information needed to estimate economic weights for a sawn timber breeding objective.

Effects of weed control, nutrition and genetics

Conclusions

1. The early age deleterious effects of the luxury fertiliser are now waning. It is even conceivable that the luxury fertiliser will soon surpass the routine fertiliser.
2. Maximum treatment response was achieved through luxury weed control, far outweighing the genetic effect in this experiment. Luxury weed control provides a benchmark for the maximum growth rates achievable on a typical exotic pine site in south-east Queensland without resorting to special inputs such as irrigation. Unfortunately current costs and technology render luxury weed control uneconomical.
3. If luxury weed control is not an option then a single post-plant tend has as much long term benefit on growth as two to four post-plant tends.
4. The nil fertiliser, nil weed control treatment and the minimum weed control treatments were very similar to, and not statistically significantly different from, their corresponding treatments with routine weed control. If these "low-input" treatments do not deteriorate in the future then they might be economically worthwhile alternatives to the former routine regime. However, as the nil/nil control treatment was unreplicated, a follow-up field trial would be necessary to draw firm conclusions regarding this treatment.
5. On average the F_1 Series II clones tested in Experiment 350 GYM have superior growth, superior straightness, higher standing tree acoustic velocities, and probably superior stiffness to the 'F_2 best' seedlings. However in commercially thinned stands the superior growth and straightness of the F_1 clones might not translate into measurable superiority at clearfall, but merely to more volume of better quality stems in the thinned fraction.

6. Unfortunately, due to differences in ease of propagation, Series II clones were planted disproportionately across south-east Queensland. The approximate 13,000 ha planted with clone 3640 is unlikely to achieve better productivity than could have been achieved using F_2 seedlings. Any dividend from clone 3640 will have to come from its improved stem quality.
7. The F_1 hybrid clones and F_2 hybrid population in this experiment did not differ significantly in wood density or spiral grain, consistent with other findings in this report and previously. The higher acoustic velocity of these 10 F_1 clones than the F_2 families is most likely due to sampling effects in microfibril angle, since neither population had been selected for wood traits.
8. There was very little evidence of strong interactions among the genetic stock, fertiliser and weed control factors at the latest measure. If this lack of interaction continues through to advanced ages then it is very good news for forestry research and enhances confidence in some inferences drawn from experiments.
9. Experiment 350 GYM is now old enough to provide reasonably reliable results, interpretations and conclusions but it will be many more years before we have definitive results.

Recommendations

1. It is recommended that volume advantage calculations for all treatments (all combinations of fertiliser, weed control and genetic control factors) be updated at age 13 years. Of primary interest will be whether the treatment with nil fertiliser/nil weed control, and the treatments with minimum weed control, which all show promise at age 8, can still be supported as viable management options based on later age growth data.
2. A follow-up experiment should be established to specifically examine the promising low-input treatments identified in this study, most importantly including multiple replications of the nil fertiliser/nil weed control treatment.

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Appendix 1: Comparison of Queensland-grown Caribbean pine wood properties with "southern-grown" radiata pine

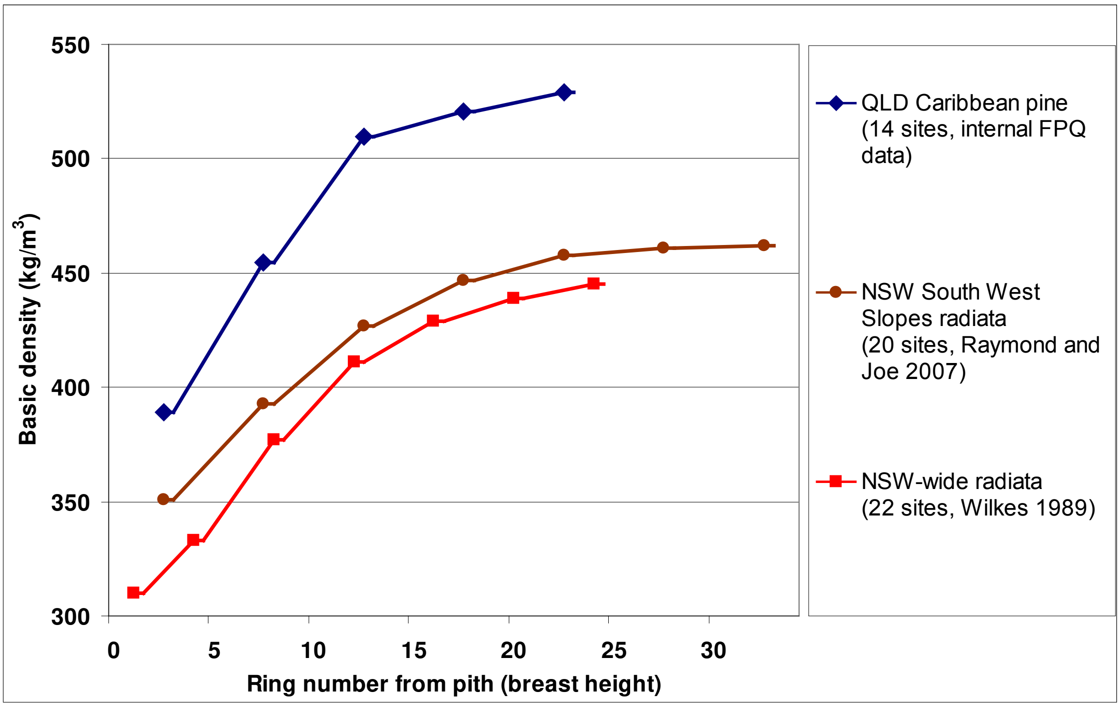

Figure 1 Radial profiles of extracted wood basic density at breast height – Queensland-grown Caribbean pine compared with NSW-grown radiata pine.

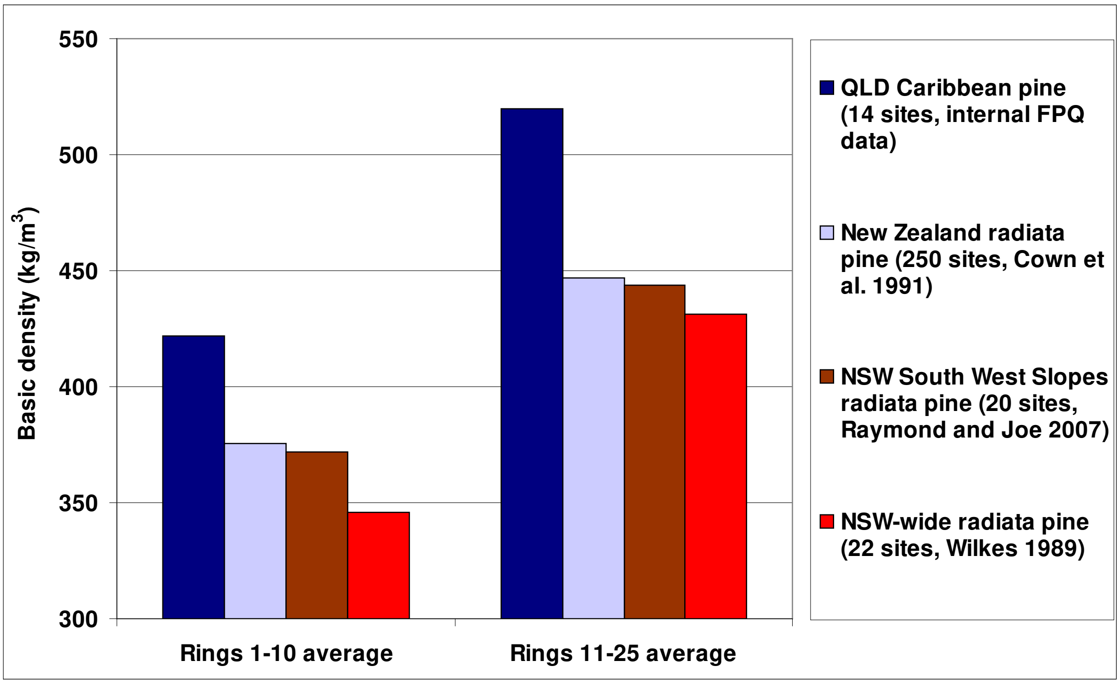

Figure 2 Average corewood (juvenile wood) and outerwood (mature wood) density of QLD Caribbean pine compared with radiata pine from several southern growing regions. Extracted basic density at breast height.

Table 1. Data from Figure 2 (density in kg/m^3)

Resource	Corewood density (rings 1-10)	Outerwood density (rings 11-15)	Unweighted average density (rings 1-25)
QLD Caribbean pine (14 sites, FPQ internal data)	422	520	481
New Zealand radiata pine (250 sites, Cown *et al.* 1991)	375	447	418
NSW South West Slopes radiata pine (20 sites, Raymond and Joe 2007)	372	444	415
NSW-wide radiata pine (22 sites, Wilkes 1989)	346	431	392

Notes

- Breast height unweighted extracted densities were the only type of densities comparable between all of the studies, and are an accurate predictor of whole tree densities (e.g. Zobel and van Buijtenen 1989 p.124), though likely to be slightly higher.
- Wood density is a moderate to strong predictor of sawn board stiffness, and a strong predictor of sawn board strength, in the Queensland exotic pines and in radiata pine.
- Microfibril angle and branch size are two lesser but still significant contributors to sawn board stiffness in Queensland exotic pines. Caribbean pine has significantly finer branching than radiata pine, and while current datasets are not sufficient for a comparison in microfibril angle, studies to date have shown a tendency towards lower microfibril angle (favourable) in Queensland exotic pines than in radiata pine (e.g. Wu *et al.* 2009).
- Relative to wood stiffness, spiral grain has a minor but still significant influence on sawn board recovery. Studies in Queensland exotic pines have tended to show lower spiral grain than in radiata pine (e.g. Harding and Copley 2000, Wu *et al.* 2009).
- Queensland Slash pine wood density at breast height is on average 3.5% higher than Caribbean pine at 10-15 years, and 9% higher than Caribbean pine at 20-25 years (data from Harding and Copley 2000 and Smith *et al.* 1990).

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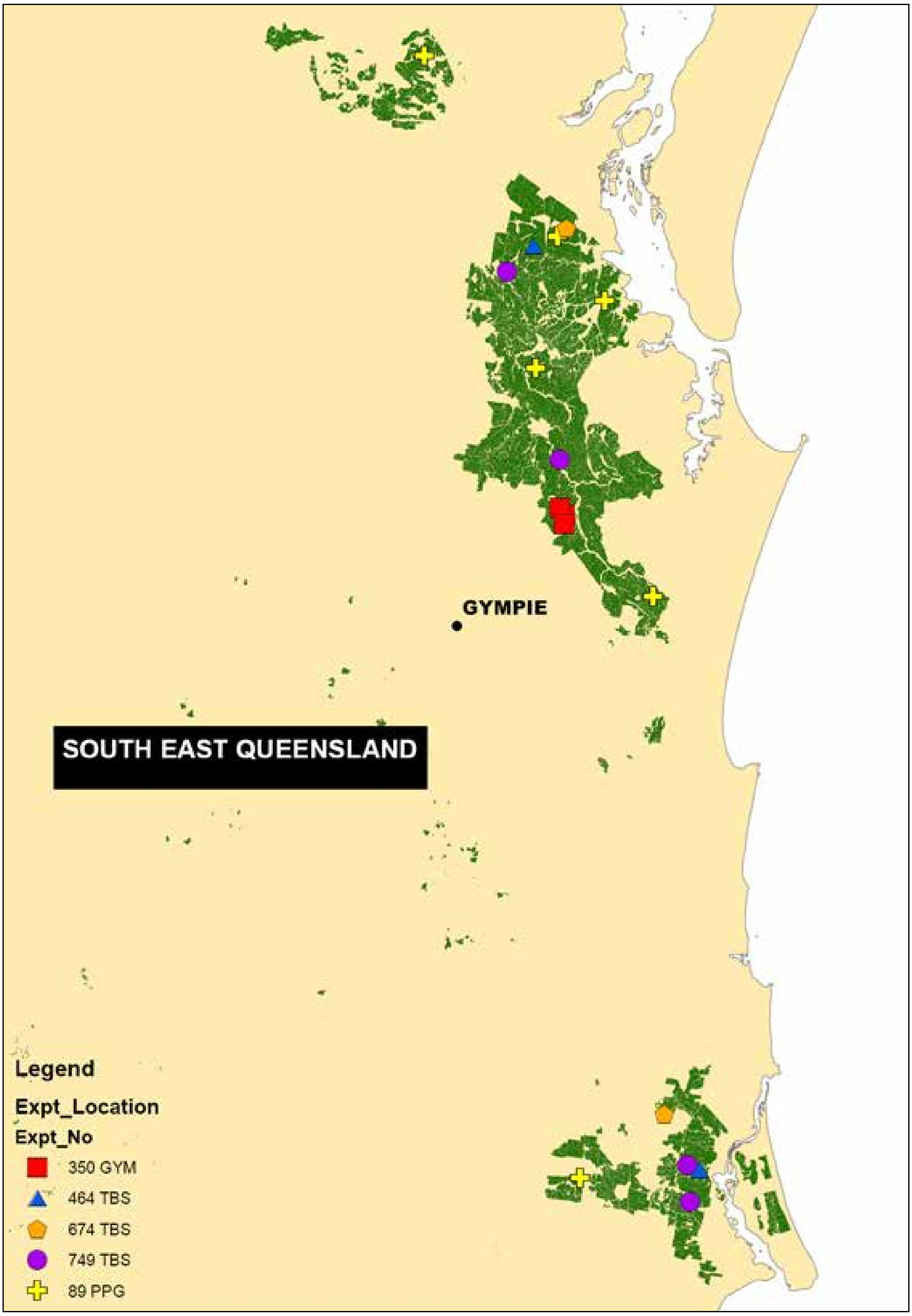
Appendix 2: Location of main trial sites referred to in report.



Appendix 3: Further details on treatments used in 350 GYM

Treatments: There are three major factors each at two levels, viz.:

- Genetic stock: 'F2 best' seedlings versus superior Series II F1 clonal cuttings;
- Fertiliser: current (1999) routine practice versus perceived optimal; and
- Weed control: current (1999) routine practice versus perceived optimal.

There are additional control treatments involving minimal or zero weed control and zero fertiliser. When the experiment was established these additional treatments were considered inadequate for routine operations. The full list of treatments is in Table 1 below .

Table 1. Treatment list for Expt 350 GYM.

Treatment number	Genetic stock	Fertiliser	Weed control	Number of replications
1	F1	Routine	Routine	6
2	F1	Routine	Luxury	5
3	F1	Luxury	Routine	5
4	F1	Luxury	Luxury	6
5	F2	Routine	Routine	6
6	F2	Routine	Luxury	6
7	F2	Luxury	Routine	6
8	F2	Luxury	Luxury	5
9	F1	Routine	Minimal	2
10	F2	Routine	Minimal	3
11	F2	Nil	Nil	1

Treatment details – F2 best seedlings: F2 best, batch 10040, 1998 collection, was sown into copper dipped "QFS" container pots at the Beerburrum nursery during August 1998.

Treatment details – superior F1 clones: Plots with PEE × *Pinus caribaea* var. *hondurensis* (PCH) F1 hybrid cuttings are mixtures of ten high growth performance clones based on FPQ's "Series II" clonal selection trials. These clones were recommended by S. Walker (pers. comm.) and are listed in Table 2. (Note that clone number 3926 is actually an F2 clonal cutting). The F1 cuttings were set in small "net" pots during October 1998 in a potting mixture of 50 % peat and 50 % perlite.

Table 2. List of clones for Expt 350 GYM.

Clone code	Clone number	Family	Position of clone in FPQ's 2003 list[a] of top 10 Series II clones
1	3574	2ee1-102 × 1ch6-29	2
2	3640	2ee1-102 × 2ch4-232	6
3	3721[§]	2ee1-169 × 2ch4-270	
4	3827	2ee1-169 × 2ch4-270	
5	3840	2ee1-102 × 1ch4-98	10
6	3839	2ee1-102 × 1ch4-98	9
7	3842	2ee1-102 × 1ch4-98	8
8	3926	eh17 × eh31	
9	4124	2ee1-102 × 2ch4-132	4
10	3080	2ee1-102 × 1ch4-98	

[§]It is possible that clone number 3965 was used instead of 3721.

[a]List provided by Kate Murray on 9 May 2003.

All plots with clonal cuttings have the same basic layout as that presented in Table 3, except that there is a different randomization for each plot.

Table 3. General layout of each superior F1 cutting gross plot in Expt 350 GYM. A–J denote a randomization of the ten clones.

Row no.	Tree number															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
10	H	B	B	B	B	D	D	F	F	H	H	J	J	J	J	E
9	H	H	B	B	B	D	D	F	F	H	H	J	J	J	E	E
8	H	H	B	B	B	D	D	F	F	H	H	J	J	J	E	E
7	G	H	B	B	B	D	D	F	F	H	H	J	J	J	D	E
6	G	G	B	B	B	D	D	F	F	H	H	J	J	J	D	D
5	G	G	A	A	A	C	C	E	E	G	G	I	I	I	D	D
4	F	G	A	A	A	C	C	E	E	G	G	I	I	I	C	D
3	F	F	A	A	A	C	C	E	E	G	G	I	I	I	C	C
2	F	F	A	A	A	C	C	E	E	G	G	I	I	I	C	C
1	F	A	A	A	A	C	C	E	E	G	G	I	I	I	I	C

<u>Treatment details – routine fertiliser</u>: This treatment followed the then routine practice, and 50 kg/ha of P (phosphorus) in the form of monoammonium phosphate ("GF MAP") was applied on the 21 July 1999 about two months after planting. MAP

is reported to supply 10 % elemental N (nitrogen) and 21.9 % P (phosphorus). The fertiliser was supplied in 1 tonne bags by Grow Force Australia Ltd, and was applied by machine as a band application servicing three rows per swathe delivering 226 kg/ha product.

Treatment details – luxury fertiliser: The purpose of this treatment is to maintain maximum possible growth rates, whilst avoiding undesirable side effects such as "speed wobbles" (distorted stems). Luxury fertiliser applications are solely at the discretion of a nutrition expert. A band application of 50 kg/ha of P in the form of MAP was applied on the 21 July 1999 about two months after planting. In addition, a special mix of 5 kg/ha of Cu (copper), 5 kg/ha of Zn (zinc), and 5 kg/ha of B (boron) was applied manually on the 22 July 1999 as a basal tree dressing. Potassium fertiliser (KCl) was applied manually as an individual tree application on 7 September 1999 about four months after planting at a rate of 50 kg/ha of K (potassium), i.e. 120 g/tree of Muriate of Potash. Instructions were issued to place the KCl fertiliser no closer than 20 cm from the base of each tree.

Treatment details – nil fertiliser: No fertiliser whatsoever was applied in this treatment.

Treatment details – pre-establishment weed control: All plots were sprayed along the bands with 7.2 L/ha glyphosate and 10 L/ha simazine using a tractor mounted multi-boom on 22 April 1999 about two weeks before planting. Woody weed control using a combination spray of 2,4–D (D50, 10 L/ha) and Grazon (1.5 L/ha) was carried out in January 1999 for plots 1–45, and in April 1999 for plots 46–51. The luxury weed control plots received additional pre-plant tending along the interrows as described below.

Treatment details – routine weed control: In this treatment, post-establishment weed control followed FPQ's routine prescription with respect to the bands and the interrow zones. Weed control operations were mainly carried out using research staff and followed advice provided by the local Forest Ranger. The then routine prescription stipulated that vegetation should not exceed an average 20 % cover during the initial nine months; and at the cessation of band tending:

- weed cover should be less than 5 %;
- trees should be vigorous;
- diameters at ground level (DGL) should be greater than 2 cm;
- trees will not be seriously overtopped; and
- soil moisture should be adequate.

Treatment details – luxury weed control: In this treatment, frequency and intensity of weed control was aimed at maintaining maximum growth rate. Treatment of the interrow zone commenced on 28 April 1999, one week prior to planting. However, blady grass kill from that initial treatment was poor and so the interrow zones were resprayed on 23 July 1999 about two months after planting. Only the luxury weed control plots received interrow tending prior to planting. Follow-up tending, primarily with glyphosate, occurred approximately quarterly through to early 2002 and then annually until early 2005.

Treatment details – minimal weed control: This treatment received routine pre-plant tending and exactly one post-plant tend.

Treatment details – nil weed control: This treatment received routine pre-plant tending, but no post-plant tending.

Treatment details – additional weed control: Sites 3–4, i.e. blocks 5–7, were slashed in 1/2001 but there is no record of which particular plots were slashed—probably all of them, including the nil fertiliser, nil weed control treatment number 11. Sites 1–2 were not slashed.