SELECTING HYBRID PINE CLONES FOR DEPLOYMENT— THE POINTY END OF WOOD QUALITY IMPROVEMENT*

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ABSTRACT

A clonal forestry research programme on *Pinus elliottii* Engelm. (slash pine) × *P. caribaea* Morelet var. *hondurensis* Barrett & Golfari (Caribbean pine) hybrids commenced in Queensland in 1986. Each cycle of clonal tests covered about 5 calendar years from field planting, and studies of wood quality variation have so far been used in selecting superior clones from the first three series of tests for commercial plantation deployment. Experience from the Series III clonal selection round is used to highlight the difficulties of ranking elite clones given a large number of growth, form, and wood property traits. Three to six ramets were felled from the best 32 clones in the Series III trials at age 6.8 years and a 3-m butt log from each was sawn into 70 × 35-mm structural boards. The clones sawn were ranked for routine deployment using data on growth, form, and wood traits. All recovered boards were assessed for distortion and tested for modulus of elasticity and modulus of rupture. Various non-destructive wood evaluation methods were used to estimate modulus of elasticity (wood stiffness) in these trees. Standing tree acoustic velocity assessed with an ST300 tool was

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slightly less strongly correlated phenotypically with the average modulus of elasticity of the recovered boards (r = 0.88**) than with predictions of modulus of elasticity from resonance vibration test samples and SilviScan estimates (both r = 0.89**). Moderate phenotypic relationships were found for individual tree means between average twist of the sawn boards and the average spiral grain angle of growth rings 2, 3, and 4 (r = 0.70**) assessed using a breast-height 12-mm increment core, and between average bow in the boards and average microfibril angle (r = 0.64**) from SilviScan assessments of core samples.

Keywords: pine hybrids; clones; selection; stiffness; wood quality; non-destructive sampling.

INTRODUCTION

Wood quality assessments are an essential part of clonal selection in the Queensland southern pine breeding, and clonal selection and deployment programmes. Direct evaluation of wood properties is both expensive and time prohibitive for the number of samples required, and so cost-effective predictive methods are needed. It is important that assessment methods are economical, reliable, and easily used on a large number of samples to accurately rank clones.

Recent technological advances have provided a range of non-destructive evaluation (NDE) tools and assessment options. These tools enable predictive wood quality assessments on standing trees but vary in sampling costs and their accuracy for ranking genotypes consistently against specific product criteria. This study evaluated several standing tree predictive methods, used to screen and select Series III clones, compared results from a sawing study of 3-m butt logs that provided assessments on 70 × 35-mm sawn boards of modulus of elasticity, modulus of rupture, and distortion (twist, spring, and bow).

MATERIALS AND METHODS

All trees in the sawing study were previously assessed as standing trees as part of the routine screening/selection activities when the trees were 4 and 5 years old. To compare the cost-effectiveness and reliability of methodologies for future screening for wood quality, a range of standing tree assessment approaches was used (Table 1).

The sample sizes varied from six to 30 boards tested per clone, due to both the number of ramets (i.e., trees) of each clone available for sawing (Table 2) and to log size differences among the clones sampled. Twelve clones were selected based on their relative superiority of early age growth, form (stem straightness, and low incidence of forking and ramicorn branching), and branching (diameter and angle) assessments at ages 4 and 5 years, combined with above-average wood density and low spiral grain (as determined from 12-mm diametral bark-to-bark, breast-height

TABLE 1—Predictive wood quality assessment methods and wood traits* assessed or predicted by non-destructive evaluation techniques.

Standing tree sampling method	Density	Spiral grain	MfA	Acoustic velocity	Predict MoE
12-mm cores (H&FS)†	Yes	Yes			Yes (with ST 300)
Wood strip (Ensis) – "Paddlepop stick"	Yes			Yes	Yes
12-mm cores (Ensis SilviScan)	Yes		Yes		Yes
Director ST 300 (FPQ)‡				Yes	Yes (with density from 12-mm core)

* MfA = microfibril angle
MoE = modulus of elasticity
† H&FS = Horticulture and Forestry Science, Queensland Department of Primary Industries and Fisheries
‡ FPQ = Forestry Plantations Queensland.

increment cores). Some clones with low sample sizes were deliberately included in the study because of good wood property or form results. The performance of these clones was considered of interest to inform decisions on the relative emphasis to be placed on these traits for future selection.

The "Paddlepop stick" sampling and resonance testing methodology has been described by Ilic (2001, 2003). It requires the removal of a short block of wood from the outer wood of a standing tree and the processing of it to produce a small wood beam for testing that is approximately 5 mm tangentially × 20 mm radially × 120 mm longitudinally. The use of SilviScan measurements of density and microfibril angle to predict modulus of elasticity has been described by Evans & Ilic (2001). The Director ST300 is described on the FibreGen web-site [www.fibre-gen.com].

Increment cores removed for SilviScan analysis were sampled from the shortest diameter, perpendicular to any sweep or lean to avoid inclusion of compression wood. Forty-two clones were sampled using the Paddlepop technique and these samples were removed adjacent to the point of increment core extraction.

The initial plan was to assess one-quarter of the approximately 1200 clones in the clonal test series for wood density and standing tree acoustics. However, when the early performance of all clones was reviewed, only 175 clones met all criteria for superior volume and form required for deployment in commercial plantations. Once wood density of the increment cores and non-destructive assessments of the standing trees had been completed, these 175 clones were reduced to 34 based on volume, form, branching, wood density, and predicted wood stiffness. Core samples from these best 34 clones were then assessed using SilviScan to determine microfibril angle and wood density, and predicted modulus of elasticity.

TABLE 2–Average modulus of elasticity and modulus of rupture of 70 × 35-mm recovery from 32 Series III clones, comparing the "top 12" with 20 other selected clones, with sample sizes indicated for ramets (trees per clone) and number of 70 × 35-mm boards recovered.

Clone	Average MoE (Gpa)	Average MoR (Mpa)	Sample size (No. of boards)	Sample size (No. of ramets)
1	5.65	34.84	16	3
2	9.97	45.91	16	6
3	7.85	39.82	26	6
4	6.93	33.97	14	3
5	7.42	46.40	11	3
6	8.71	45.89	17	5
7	7.76	44.32	26	6
8	9.59	45.77	25	6
9	7.63	50.99	9	3
10	6.60	42.61	30	6
11	8.96	47.00	18	6
12	6.90	42.69	15	3
Mean (Top 12 clones)	7.83	43.35		
13	7.23	38.30	16	3
14	5.93	38.82	19	3
15	6.69	42.05	13	3
16	7.50	39.84	12	3
17	6.52	39.58	14	3
18	7.70	43.88	27	6
19	8.14	45.81	6	3
20	8.04	49.54	8	3
21	6.83	43.64	21	6
22	7.52	46.77	11	3
23	6.88	39.45	16	6
24	6.74	41.52	12	3
25	8.83	46.95	23	6
26	5.37	40.96	11	3
27	5.16	35.47	28	6
28	6.43	44.31	24	5
29	6.91	40.93	16	3
30	6.29	44.44	17	3
31	5.97	39.99	15	3
32	5.32	35.20	26	6
Mean (Clones 13 to 32)	6.69	41.37		

A year later, 32 of these best 34 clones, were destructively sampled from two of five trial sites (the other two clones were not tested at these sites). Samples were taken from trial sites located near Beerburrum and Maryborough when the trees were approximately 6.8 years old. Up to six ramets of each clone were sampled, three ramets from each of the two sites, depending on availability and all were felled at a standard stump height. A 3-m butt log was docked and de-branched and transported to Horticulture and Forestry Science's Salisbury experimental sawmill and research centre for processing and assessment of sawn boards.

Sawing Methods

The butt logs were green sawn into a 75-mm-wide centre cant with recovery of 75 × 40-mm green dimension boards where possible from log wings. Logs were oriented for sawing so that the centre cant orientation approximated the orientation of the increment core and Paddlepop stick collection points — i.e., oriented along the same diametric plane to enable direct comparison between these various results. The outer boards of each centre cant were identified and the small clear samples were sawn from these boards. Log small-end diameters ranged from about 100 to 180 mm.

Before processing into sub-samples, all boards were kiln dried at 130°C and planed to finished dry dimensions of 70 × 35 mm. The boards were then assessed for twist, spring, and bow to allow examination of phenotypic correlations with spiral grain assessments (for twist) and the impact of microfibril angle (on spring and bow). Engineering test samples, 1.5 m × 70 mm × 35 mm dried structural dimensions, were recovered from all boards above this field sampling point which approximated breast height (1.3 m). These boards were tested for modulus of elasticity and modulus of rupture on a Shimadzu Universal testing machine using four-point bending. The clonal average results obtained from these samples were compared with the clonal average modulus of elasticity predictions from the ST300 and the SilviScan analysis.

Small clear samples were recovered from only the outer boards of each centre cant below the previous field sampling level (avoiding splitting and/or damage at this point). The small clear-wood samples of 300 × 20 × 20 mm were cut from as close to the bark surface as possible, without including wane. These samples were taken to enable direct comparison to the Paddlepop stick samples taken from the standing trees. They were tested for modulus of elasticity (stiffness), and modulus of rupture (strength) with an Amsler timber testing machine using three-point bending.

Analysis

Phenotypic correlation between clonal average values of standing tree non-destructive evaluation traits and sawing study variables was undertaken using S-PLUS correlation analysis.

RESULTS AND DISCUSSION

Average modulus of elasticity and modulus of rupture results for the top 12 clones compared to the other 20 superior clones studied indicated small improvements in mean values for the top 12 over the mean of the other clones studied (Table 2).

The top 12 clones tested averaged 17% higher average stiffness and 4.8% higher strength than the other 20 clones tested (Table 2). This confirmed that the emphasis placed on wood quality in the selection process is reflected in improved quality of the clones selected for propagation and deployment in commercial plantations. At the same time it must be recognised that all current models developed by Forestry Plantations Queensland to compare the value of different genotypes still suggest that gain in volume yield per hectare is the main driver of improved value (Dr Kerrie Catchpoole, pers. comm.). Therefore, it is important to identify highly productive clones with good wood properties if gains are to justify the expense of the clonal testing and selection programme.

Future capacity to achieve gains would be improved by obtaining knowledge of parental wood quality traits so as to make strategic crosses that will increase the proportion of highly productive clones with superior wood quality for selection. This strategy is underpinned by knowledge of the inheritance patterns of these traits (Kain 2003). The results (Table 2) demonstrate that only four of the 12 top clones tested have produced average stiffness in this juvenile wood recovery exceeding 8.5 GPa, which should ensure that they would be part of a population of higher stress-grade structural timber (MGP10 under the current Australian pine grading system). The goal of the breeding programme is to improve the deployment population over time so that all deployed clones are of this stiffness quality standard as this should translate into a significant improvement in the overall grade recovery, and therefore economic return, when sawn. Several clones, such as 18, 19, 20, 22, and 25 (Table 2) have superior wood stiffness compared to some of those selected in the top 12, indicating that their performance or values for other traits when initial selections for hedge production were made in 2004 (ages 4 and 5 years) excluded them from the elite pool. However, in reviewing the results from this study at age 6.8 years, which was partly conducted to confirm the younger age selection rankings, some re-ranking of clones occurred. For example, Clone 25 with an average stiffness of 8.83 GPa was initially excluded due to high spiral grain in growth rings 2 and 3 (–5.7° and –4.0° respectively) combined with above-average incidence of ramicorn branches (29% of ramets), but in October 2006 it was included in the elite group due to its high stiffness combined with continuing well above-average volume productivity. In contrast, Clone 11 that had very good predicted stiffness from standing tree assessments in 2005, which was confirmed in this sawing study (mean modulus of elasticity of recovered scantling = 8.96 GPa), has now been excluded from the deployment population as its volume advantage has dropped from above average at ages 3 and 4 years to below average at age 6 years. Ranking and performance of clones for productivity, relative to the other clones in the tests, has been observed to change significantly between early age assessments undertaken annually at 3, 4, 5, and/or 6 years indicating that age-age correlations are not strong.

Relationships Between Standing Tree Non-destructive Evaluation Assessments

It is clear that strong linear relationships exist between clonal average ST300 velocity readings, SilviScan microfibril angle assessments, and predicted modulus of elasticity and Paddlepop sample modulus of elasticity predictions (Table 3). This is to be expected as these methods all rely on a fundamentally strong relationship between microfibril angle and acoustic or stress wave velocity. Nevertheless, these results provide some confidence that all methods are assessing much the same trait/s and are of similar utility for screening.

The critical relationships are between these non-destructive evaluation results and the sawn board results. These are summarised in Tables 4 and 5. Some moderately strong (around $r = 0.7$) and significant ($P = 0.01$) relationships were found between spiral grain angle (individual growth ring assessments at rings 2, 3, and 4, and the average of the absolute values of these angles) and the average twist measured in the scantling boards recovered from each ramet (Table 4). This provides encouragement to continue assessing this trait in screening assessments as twist can be an important source of downgrade. Microfibril angle has been associated with spring and bow but no significant correlations with spring were found in this study. Bow was moderately and significantly correlated ($r = 0.64$) with microfibril angle (Table 4) but also with ST300 mean velocity ($r = -0.51$; Table 4), which provides a relatively inexpensive indirect method of screening for improvement in this trait given the strong correlations between ST300 velocity and microfibril angle ($r = -0.91$; Table 3) and average modulus of elasticity of all boards ($r = 0.88$; Table 4).

Overall the relationships found in Table 5 for the more targeted outer board and small clear samples do not vary markedly from those found for the average recovery of all boards, which reflect wood from the full cross-section of each log. It was expected that results for the outer wood samples would have been more strongly correlated with ST300 velocity and Paddlepop stick results that also sampled this outer wood zone. However, it should be recognised that these results will be affected by some bias due to low numbers of boards being recovered from small trees and differing sample sizes as indicated in Table 2.

No wood density results were included in Tables 3, 4, and 5 because the only significant and/or strong relationships found involving density were amongst the

TABLE 3–Phenotypic correlation matrix for clonal average standing tree non-destructive evaluation traits with significance of each correlation coefficient indicated.

	ST300 mean velocity	SilviScan average MfA	SilviScan average predicted MoE	Spiral grain Ring 2	Spiral grain Ring 3	Spiral grain Ring 4	Average spiral grain (absolute values)	Paddlepop average MoE
SilviScan average MfA	–0.91 **	1						
SilviScanaverage predicted MoE	0.91 **	–0.92 **	1					
Spiral grain Ring 2	0.33 NS	–0.3 NS	0.27 NS	1				
Spiral grain Ring 3	0.40 *	–0.43 *	0.36 NS	0.85 **	1			
Spiral grain Ring 4	0.42 *	–0.44 *	0.39 *	0.66 **	0.78 **	1		
Average spiral grain absolute	–0.49 **	0.47 **	–0.41 *	–0.9 **	–0.92 **	–0.86 **	1	
Paddlepop average MoE	0.84 **	–0.84 **	0.89 **	0.44 *	0.55 **	0.47 **	–0.56 **	1

NS = not significant; * p = 0.05; ** p = 0.01

TABLE 4–Phenotypic correlation matrix for clonal average standing tree non-destructive evaluation traits *versus* sawn recovery averages for distortion, stiffness (MoE), and strength (MoR), with significance of each correlation coefficient indicated.

	ST300 mean velocity	SilviScan average MfA	SilviScan average predicted MoE	Spiral grain Ring 2	Spiral grain Ring 3	Spiral grain Ring 4	Average spiral grain (absolute values)	Paddlepop average MoE
Average twist	–0.23 NS	0.24 NS	–0.21 NS	–0.73 **	–0.68 **	–0.64 **	0.7 **	–0.23 NS
Average spring	–0.31 NS	0.36 NS	–0.28 NS	–0.04 NS	–0.07 NS	–0.02 NS	0.08 NS	–0.29 NS
Average bow	–0.51 **	0.64 **	–0.58 **	–0.15 NS	–0.23 NS	–0.23 NS	0.2 NS	–0.45 *
Average MoE all boards	0.88 **	–0.81 **	0.89 **	0.26 NS	0.39 *	0.38 *	–0.42 *	0.89 **
Average MoR all boards	0.43 *	–0.37 *	0.44 *	0.02 NS	0.14 NS	0.17 NS	–0.17 NS	0.56 **
Average MoE outer boards	0.84 **	–0.75 **	0.84 **	0.18 NS	0.35 NS	0.36 NS	–0.38 *	0.86 **
Average MoR outer boards	0.34 NS	–0.25 NS	0.31 NS	0.05 NS	0.17 NS	0.21 NS	–0.2 NS	0.43 *
Average MoE small clears	0.90 **	–0.86 **	0.89 **	0.18 NS	0.27 NS	0.24 NS	–0.33 NS	0.83 **
Average MoR small clears	0.50 **	–0.39 *	0.56 **	–0.21 NS	–0.05 NS	–0.04 NS	0.03 NS	0.52 **

NS = not significant; * p = 0.05; ** p = 0.01

TABLE 5–Phenotypic correlation matrix for clonal average sawn recovery averages for bow, stiffness (MoE), and strength (MoR), and small clear sample results with significance of each correlation coefficient indicated.

	Average bow	Average MoE all boards	Average MoR all boards	Average MoE outer boards	Average MoR outer boards	Average MoE small clears
Average MoE all boards	–0.56 **	1				
Average MoR all boards	–0.24 NS	0.66 **	1			
Average MoE outer boards	–0.48 **	0.97 **	0.72 **	1		
Average MoR outer boards	–0.21 NS	0.52 **	0.87 **	0.63 **	1	
Average MoE small clears	–0.48 **	0.81 **	0.47 **	0.81 **	0.4 *	1
Average MoR small clears	–0.27 NS	0.56 **	0.49 **	0.66 **	0.49 **	0.7 **

NS = not significant; * p = 0.05; ** p = 0.01–

various test method results — gravimetric whole-core extracted basic density, SilviScan air-dry density, and Paddlepop stick air-dry density. This is a somewhat unusual finding for material from Queensland plantations of southern pines: usually some correlation between density and modulus of elasticity and modulus of rupture has been found (e.g., Harding *et al*. 2000). However, these young trees (6.8 years old) were fast-grown, exceeding 150 mm diameter under bark at 1.3 m on average, and the largest tree was 233 mm diameter under bark at 1.3 m. The wide growth rings produced in these trees appears to have accentuated the impact of microfibril angle on distortion and stiffness characteristics of the 70 × 35-mm structural boards recovered compared to current seed orchard stock routine plantation thinning (18 years old) and clearfell (28 to 30 years old) sawn recoveries.

These findings emphasise the utility of several non-destructive approaches for screening standing trees in clonal trials for early juvenile wood properties. Given the high growth potential of these clones, the study has emphasised the importance of selection for wood quality to ensure that juvenile wood quality is improved in future plantings to meet our goal of significantly improving overall structural grade recovery. The future challenge is twofold: (i) to evaluate the potential to manage stands with silviculture regimes designed to produce the optimised log size distribution sought by the processing industry and (ii) to factor in selection and monitoring of wood quality so that the trees produced are of maximum value and fit for purpose for processors.

Relative Cost-effectiveness of Non-destructive Evalution Methods

The question of how cost-effective and reliable the methods are for future wood quality screening of genetic stock will be the subject of more consideration and discussion than is possible in this paper. However, it is clear that the ST300 acoustic tool offers a relatively rapid and inexpensive screening technology but one that needs to be complemented by increment core extraction for spiral grain angle evaluation. ST300 readings, or those of similar acoustic technology systems, can be obtained quickly and relatively cheaply compared to obtaining increment cores for laboratory processing (gravimetric density) and/or SilviScan assessment (sample machining, conditioning, and scanning) or “Paddlepop” samples (slower in field, followed by lab preparation, machining, and testing). Also, these latter approaches require significant resources for result capture and compilation and processing compared to the standing tree acoustic technology.

Additionally, gravimetric density assessments in this study would appear to have been of little value for this type and age of material, and their utility for future screening activities will need to be considered. Investment in density assessments could be reduced by screening only a final small sub-set of selections based on acoustic velocity screening results to confirm that threshold values are met. There is still an argument for taking increment core samples, or collecting destructive samples if the opportunity is available, to screen for spiral grain angle patterns to reduce the incidence of twist in sawn products.

CONCLUSION

Destructively sampling some of the best clones from two of the Series III tests planted in Queensland in 1999 provided an opportunity to consider the reliability and utility of several non-destructive wood quality evaluation screening technologies. Although more extensive evaluation will be undertaken, it is clear from this study that the reliability of all methods is comparable and therefore that ST300 combined with increment core sampling for spiral grain analysis provides a cost-effective approach to clonal screening. As spiral grain analysis is significantly more expensive than collecting ST300 readings it would make sense to undertake a two-stage screening based on ST300 sampling of large numbers of clones and ramets, followed by a more restricted sampling for spiral grain evaluation.

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