Breeding radiata pine for wood stiffness: review and analysis

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Summary

Radiata pine is widely planted in the southern hemisphere, and has a versatile timber. The mature wood of this species is strong and stiff enough for a number of industrial uses, but current trends of harvesting at below 30 years result in a high proportion of low-stiffness juvenile wood. Radiata pine breeders have countered this reduction, indirectly, by selecting progenies for dense juvenile wood. However there is evidence now that improving juvenile wood density may not be sufficient to fully address low stiffness. This has led to work on assessing stiffness itself, and to studies on using microfibril angle in the tree improvement program. Progress on breeding radiata pine for stiffness in New Zealand is reviewed in this paper, with a briefer account of work in Australia.

Several direct and indirect methods to improve stiffness are described. These include static bending tests on boards and small clear specimens, acoustic and stress wave methods, and microfibril angle, in addition to density and pilodyn penetration. Two tools using acoustic / stress wave methods have been developed by the New Zealand forestry industry, and are being used operationally to segregate logs. A third tool (FAKOPP), developed in Hungary, shows promise for use on standing trees and hence could be suitable in screening progenies. SilviScan is an important Australian breakthrough and could potentially be used to predict longitudinal stiffness on hundreds of short samples per day.

Combining acoustic / stress wave results with density and branch cluster frequency could well be a viable and cost-effective way to select progenies for clearwood stiffness in the juvenile wood zone. Information on stiffness could be combined with breeding values for growth rate, straightness and grain spirality to select parents for deployment and breeding.

Introduction

Radiata pine (*Pinus radiata* D. Don.) is one of the most important conifers used in plantation forestry, planted on 1.56 million hectares in New Zealand (1999 data; MAF 1999a), 0.64 million ha in Australia (1995 data; McLennan 1999) and 1.69 million ha in Chile (1994 data; Toro and Gessel 1999). The timber of this species is rated as very versatile, owing to its ease of drying, treatability and machinability (Cown 1999). Sawn timber is a major product obtained from this species; 3.0 million cubic meters were produced in New Zealand in 1999 (MAF 1999b).

It is well known that the average Modulus of Elasticity (MOE) of a radiata pine tree increases as the tree ages (Walford 1985). This happens because the MOE increases rapidly with increasing cambial age or ring number from the pith; older trees have a greater proportion of stiff mature wood. For several reasons, including faster growth due to better silviculture and genetic quality, rotations in New Zealand have become shorter (Macalister 1997). While post-World War II foresters called for rotations of 37, 40 or even 70 years (Anon 1945, Chapman 1949), the average area-weighted clearfelling age was 27.1 years in 1999 (MAF 1999a). There are reports of stands being felled at age 20 years (Macalister 1997). This reduction in rotation age affects the quality of timber produced, including the strength and stiffness of structural timber (Macalister 1997; Gaunt 1998; Walford 1996, 1999).

Seeing the need to counteract the reduction in stiffness resulting from shorter rotations, radiata pine breeders in New Zealand are focussing on improving this trait. This is an appropriate time to put the issues in perspective, and map out how this new wood property can be incorporated into the breeding programme. Sorensson *et al.* (1997) discussed improving spiral grain in the breeding programme; my objective is to give a brief account of recent developments in the genetic improvement of stiffness of radiata pine in New Zealand.

Historical background to the improvement of stiffness

The first wood property emphasised by New Zealand breeders was wood density, partly on the premise that wood density was a surrogate for stiffness; this was guided by strong published relationships between stiffness and density (e.g. 0.71 in Walford 1985; Table 6). This was one of the reasons for establishing a High Wood Density breed in 1986 (Jayawickrama and Carson, in press), and for making high-wood-density seedlots available in 1988 (Vincent 1997).

There has also been a contrasting view that improving density alone will not be fully sufficient to improve the stiffness of radiata pine (e.g. Cave and Walker 1994, Addis Tsehaye *et al.* 1995). As a result, there has been growing interest in looking beyond density alone to assess stiffness in radiata pine progenies, and to select for improved stiffness. This has been encouraged by early estimates that show stiffness, like most wood properties, is under substantial genetic control in radiata pine (Matheson *et al*. 1997a, Shelbourne *et al*. 1997) and other conifers such as Cryptomeria japonica (e.g. Fujisawa *et al*. 1992, 1994). Recently a "Structural Timber breed" has been formed as part of the radiata pine breeding population, emphasising the strength and stability of timber (Jayawickrama and Carson 2000)

Current issues and understanding

Target trait

Given that the main problem is in the juvenile-wood zone, the priority seems to be the improvement of stiffness in that zone. A resultant increase in mature wood stiffness would, of course, be beneficial as well. A similar focus on rings 8-10 was adopted in reducing grain spirality (Sorensson *et al*. 1997).

Radiata pine boards rarely break in normal use; much more frequently a load results in excessive deflection. Hence stiffness rather than strength is the limiting factor. Creep may also be an issue.

Options available for screening for stiffness

There are many ways to measure stiffness and attempt its improvement. Some of these are shown in Table 1.

Direct tests

The grading of radiata pine structural timber has evolved over time, from visual grading (Standards Association of Australia 1973) to stress-grading (F4, F5 F8, F11 etc; Standards Australia/Standards New Zealand 1992) and Machine Graded Pine (MGP-10, 12, 15 etc; Gaunt 1998, Syme and Livanes 1999). Major New Zealand companies produce and market machine-graded products (Anon 1998). Boards are tested in varying dimensions (e.g. Walford 1999, ***Forest Research*** 2000).

In-grade testing is the most direct method of assessing stiffness, accepted by industry and with the closest relation to operational processing of timber. To assess the stiffness of a complete tree, the most realistic technique is to saw the tree into boards, determine board stiffness by in-grade testing, and calculate a volume-based average MOE for the tree (Ridoutt *et al*. 1999). The high cost of this method, the need to fell the trees, and the need to wait till the trees are big enough to saw them, makes this procedure unsuitable for the routine screening of progenies.

The next step down, in terms of directness and cost, is the testing of small clear specimens. These can be 50 x 50 mm or 20 x 20 mm in cross section (Mack 1979). Of the two, the latter size has been used almost exclusively in New Zealand since 1970 (Walford 1991, Bier 1999). Very recently (in 1999) a tool was developed by ***Forest Research***, Rotorua, New Zealand to take wood specimens from standing trees; a team of skilled operators can sample 70 or more trees per day. These samples of wood can be taken at breast height on trees eight years old, and can be processed as small clear specimens (20 x 20 mm cross section).

Direct tests give the most information related to stiffness and strength, including MOE, Fibre Stress at Proportional Limit, Modulus of Rupture, Work done to Proportional Limit and type of failure.

Table 1. Some assesment options available for the genetic improvement of wood stiffness

	Name	Used on	Reference	Relative cost per tree	Application to genetic improvement
Direct measures of stiffness	In-grade testing	Boards	Gaunt 1998, Forest Research 2000	Very high	Mill studies
	Small Clears	Clearwood Specimens (20 x 20 x 300 mm)	Walford 1985, 1991; Bier 1999	High	Screen progenies, validate indirect methods
Indirect measures of stiffness	FAKOPP	Standing trees	Booker and Sorensson 1999, Harris and Andrews 1999, Anon 2000	Low	Screen young progenies
	Pundit	Clearwood specimens	Booker and Sorensson 1999	Moderate	Screen progenies
	Metriguard	Logs	Harris and Andrews 1999	Moderate	Screen progenies
	Silvatest	Logs and boards	Harris and Andrews 1999, Marchal and Jacques 1999	Moderate	Screen progenies
	GrindoSonic	Boards	Marchal and Jacques 1999	Moderate	Screen progenies
	HITMAN	Logs	Harris and Andrews 1999, IRL 1999	Moderate	Screen progenies at time of harvest
	SWAT	Logs	Parker 1999	Moderate	Screen progenies at time of harvest
	SilviScan	Specimens	Evans *et al.* 2000	Moderate	Screen progenies
Surrogate traits	Density	Cores	Cown 1999	Moderate	Screen progenies
	Pilodyn	Standing trees		Low	Screen progenies
	Microfibril angle	Cores	Cave and Walker 1994, Donaldson and Frankland 1997, Cave and Robinson 1998, Evans 1998	Moderate	Screen progenies

Indirect tests

Stress waves and vibrational waves have been used for the non-destructive evaluation of wood as far back as 1965 (Kucera 1997). The benefits of segregating plantation-grown logs based on stiffness have revived the development of indirect tests for stiffness. Stress-wave testing of logs has been shown to improve recovery of structural timber in New Zealand (Ridoutt *et al*. 1999). Two devices ("Hitman" and "SWAT") have recently been developed in New Zealand for this purpose and show promise as relatively fast techniques with good correlations with stiffness (IRL 1999, Harris and Andrews 1999, Parker 1999). The use of these and other tools that assess the stiffness of complete logs is limited for progeny trials by the need to fell the trees for assessment.

Stiffness estimated on clearwood samples, using a resonance frequency device ("Grindo-Sonic") and an ultra-sound device, ("Silvatest") correlated well with a standard static bending test for hybrid larch (Marchal and Jacques 1999). Similarly, dynamic MOE was estimated for 211 radiata pine specimens (of 20 x 20 x 300 mm dimension) using another ultrasound device ("Pundit") developed at ***Forest Research***. The dynamic MOE was very strongly correlated with static bending MOE, with an r^2=0.97 (Booker *et al*. 1998).

One of the few options currently available for use on standing trees is FAKOPP, a device developed in Hungary. This device measures the transit time of a stress wave between two transducers (Booker and Sorensson 1999, Anon 2000). Booker and Sorensson (1999) measured FAKOPP velocity on the stems of 200 four-year-old radiata pine trees, and reported an r^2 value of 0.55 for the correlation with bending MOE of 300 mm sticks.

Surrogate tests

As described earlier, the first surrogate trait used to improve stiffness was density. Pilodyn penetration, in turn, has been used as a surrogate for assessing density. Microfibril angle has been reported to have a strong influence on stiffness (Cave and Walker 1994, Addis Tsehaye *et al.* 1998, Booker *et al.* 1998, Hirakawa et al. 1998). However preparing the samples and assessing microfibril angle is labour intensive; some of the techniques (e.g. used in Booker *et al.* 1998, Butterfield and Pal 1998) also use very small samples of wood with the resulting issue of extrapolation to whole-tree values.

Assessment populations

A cost-effective procedure to improve wood properties is to screen for them in progeny trials, usually on a subset pre-selected for growth, form and health. This has been used for both wood density and grain spirality in New Zealand, and can be used for stiffness as well. The logic behind this approach is that minimum (threshold) levels of growth, form and health are needed before a parent clone can be used in seed orchards, regardless of its wood properties. The New Zealand radiata pine breeding programme has a large number of selections under test, with many of the trials 15 years old or less and of a suitable age for assessing juvenile-wood stiffness.

Future requirements

Breeding objectives and breeding goals

The importance to a genetic improvement programme of having a breeding objective has been stressed by animal breeders (e.g. Ponzoni and Newman 1989) and more recently in tree breeding as well (Borralho et al. 1993, Woolaston and Jarvis 1995). There are strong arguments for developing such breeding objectives for the various aspects of the New Zealand radiata pine programme, including the Structural Timber breed. There is also a need to set goals or targets for the programme, such as:

- an average clearwood Modulus of Elasticity of 7000 megapascals, in the eighth ring from the pith, at the bottom of the second log, on a typical central North Island site in New Zealand.

Such goals will help industry plan their production and investment strategies, and will be useful in monitoring and judging progress.

Selection traits

There is clearly a need for further development and refinement of selection methods, along with the development of breeding objectives. The ideal selection trait(s) would be relatively inexpensive, suitable for use on standing trees, give repeatable results and good heritabilities, and would give readings well correlated with the breeding objective trait (board stiffness). The current work on indirect tests for stiffness has been mentioned previously. There is also continuing work on methods to assess microfibril angle (e.g. Donaldson and Frankland 1997, Cave and Robinson 1998, Evans 1998).

Branch Index or BIX (the average of the largest branch diameter in each quadrant of the log) has a major impact on the recovery of structural timber grades; as BIX increases the proportion of high-value grades such as F8 decreases (Cown *et al.* 1987). Ridoutt *et al.* (1999) tested the use of small-end diameter, branch index, pilodyn penetration and stress-waves for selecting logs for structural timber. They obtained the best prediction of log stiffness by combining the results of small-end diameter, branch index and sound velocity. Removing either branch index or sound velocity from the model substantially reduced the accuracy of the prediction.

Radiata pine breeders in New Zealand are investigating direct and indirect methods to assess stiffness. My best guess is that combining acoustic/stress wave data with (1) density and (2) branch cluster frequency (or better still, knot area ratio) will give a viable and cost-effective method to select progenies for juvenile-wood stiffness. In addition to these traits, “Structural Timber” parents will be selected for growth rate, straightness and grain spirality.

Supporting research

Basic understanding of the genetic control (heritability, genetic correlations with other traits, genotype x environment interaction) of stiffness are needed. These estimates should be based on suitable populations, including progenies with low ranks for growth and form. Assessing wood properties only on the progenies ranked highly for growth and form (“Truncation Subsampling”) can bias the parameter estimates - in a simulation study, assessing only the top 40% of the families led to an estimated genetic correlation of 0.34 when the true correlation was -0.3 (Apiolaza *et al.* 1999). The heritability of clearwood stiffness, and the correlation of stiffness with other traits, is being estimated for radiata pine in New Zealand. The top seed orchard parents are also being ranked for a Juvenile Wood Quality Index, which includes information on microfibril angle, density and grain spirality (NZFRI 1997).

The relationships reported between stiffness on the one hand and indirect/surrogate measures (such as microfibril angle, density, and acoustic tests) on the other hand, have often been at the log- and wood-sample level (e.g. Walford 1985, Hirakawa *et al.* 1998, Booker and Sorensson 1999, Marchal and Jacques 1999). Breeders now need to establish how strong these relationships are at the family-mean and clone-mean level, eliminating confounding effects such as distance from the pith. This is because breeders are interested in selecting between progenies, grown in designed experiments in a common environment at a common age.

Although there have been a few studies on the variation of stiffness up the stem of radiata pine trees (Hinds and Reid 1957, Booker and Sorensson 1999), more work is needed on the topic. It is far from clear at what point on the stem it would be most appropriate to sample radiata pine progenies, or how many trees need to be assessed per progeny. Neither is it clear what size samples are needed to characterise a tree: for example, a 100 x 50 mm board, 2.4 meters long, contains 100 times as much wood as the 20 x 20 x 300 mm specimens used in testing small clears.

Australian work on genetic improvement of wood stiffness in radiata pine

Australian work in this area should also be acknowledged, since Australia has been recognized as a pioneer in wood properties research (e.g. Zobel and van Buijtenen 1989) and because a key recent advance in wood property measurement has occurred there. There are strong parallels in the work done in both countries, and methods that work in one are likely to work in the other. Some key Australian publications on this topic are listed below.

Strategies for the genetic improvement of stiffness

As in New Zealand, the improvement of wood density was viewed for a long while as the main means to improve stiffness (e.g. Bamber and Burley 1983). To this end, the inheritance of wood density was studied extensively (e.g. Fielding 1953, Dadswell *et al*. 1961, Nicholls *et al*. 1964, Dean *et al*. 1983) and the trait used in breeding programmes (Pederick 1978, Johnson 1989, Boomsma 1997, White *et al*. 1999). Recently genetic parameters have been presented for wood stiffness itself in Australia, along with strategies for the genetic improvement of sawn timber stiffness and product value. (Matheson *et al*. 1997a,b). Evans *et al*. (2000) view the advent of SilviScan (described below) as opening new possibilities in genetic improvement of stiffness.

Instrumentation

The development of SilviScan by the Commonwealth Scientific and Industrial Research Organisation, Forestry and Forest Products Division (Evans 1994) is a major breakthrough for wood properties research. The first version of this sophisticated instrument, SilviScan-1 (described as combined image analyser and scanning microdensitometer) was designed to measure an array of wood properties from radiata pine and other softwoods, and has already led to several publications on the inheritance of wood properties (e.g. Shelbourne et al. 1997, Nyakuengama *et al*. 1999). Evans *et al*. (2000) felt that after adding an automated sample changer, a service instrument based on SilviScan-2 could predict the longitudinal stiffness of wood in several hundred short samples per day and would require only 5 mm increment cores. Such a development would revolutionize the assessment of stiffness, if the service becomes readily available at a reasonable cost.

Prospects

New Zealand's radiata pine genetic improvement programme has been shown to deliver large gains, important to the industry, in traits such as diameter and volume (Carson *et al*. 1999), straightness, log quality, and branch cluster frequency (Vincent 1997, Jayawickrama *et al*. 1998). The recent success in screening the New Zealand radiata pine breeding population for wood density and grain spirality (Vincent 1997, Sorensson *et al*. 1997) gives encouragement that similar results can be obtained for wood stiffness.

Once the information is collected, the established procedures for using the information and making it available to growers (breeding value estimation, genetic certification) can be applied (NZFRI 1997, Vincent 1997). Efforts to improve stiffness should be viewed as refinements of previous breeding efforts, rather than their replacement. As mentioned earlier, breeders have worked to improve wood density for several years, and these efforts will have positively impacted on stiffness.

Radiata pine breeders are not alone in their attempts to genetically improve wood stiffness. This is evidenced by the recent literature on genetic parameters, variation between clones and strategies for improvement (e.g. Fujisawa *et al*. 1997, Bhat and Indira 1997, King *et al*. 1997, Rozenberg *et al*. 1999, Harding et al. 2000). It is to be hoped that the next few years will add greatly to our understanding of this important topic.

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