

Wood Properties and Genetic Improvement of Radiata Pine

Rowland D. Burdon* replies to previous articles on tree breeding with a sharp focus on wood properties

Summary

Wood quality in recent harvests of New Zealand radiata pine has often been disappointing, with poor stiffness, drying degrade, and instability in service, associated with radical silviculture and short rotations. This has raised understandable concerns over limited past commitment to genetic improvement of wood properties. While prospects of genetic gain in wood properties had long been researched, with promising results, forest growers and wood processors were, until recently, unwilling to risk gains in volume production by calling for genetic improvement of wood properties. There are genetic trade-offs, or adverse genetic correlations, between stem volume and most wood properties. These demand good information on the strength of the trade-offs and, above all, on the comparative economic weights of the traits concerned. Such information, however, is inherently elusive, since the trade-offs effectively operate at the whole-crop level at harvest age. Yet the breeder generally needs to select on the performance (or molecular attributes) of young individual trees.

Intensified research on significance of wood properties, on low-cost assays, and on gene expression is giving the breeders much better information, and selection for wood properties has now greatly increased. More fundamental research is aimed at extending the possible range of wood characteristics. Yet the problems posed by adverse genetic correlations involving wood properties remain. Addressing these problems effectively is likely to require intensive modelling of crop development using extremely solid data. An additional challenge is coping with widespread market imperfections whereby wood quality is not duly recognised in roundwood prices.

Multiple product lines, and large effects of sites and silviculture on different traits, have prompted breed differentiation in radiata pine. That largely finesses, but does not solve, the problems posed by limited explicit information on relative economic worth among traits.

‘Carbon forestry’, by favouring longer rotations and higher stockings, stands to mitigate but not eliminate problems with wood properties. Combining good wood quality with extremely high productivity, however, appears a special challenge. Overall, growing the species to best advantage remains a complicated but fascinating pursuit.

Introduction

Prof. John Walker (2010) has produced an article “Breeding - getting the most from radiata pine” in *New Zealand Tree Grower*. This effectively follows up on earlier articles in this journal (e.g. Walker 2007), his central point being that wood properties have suffered, through a process of neglect, in the context of New Zealand’s radiata pine genetic improvement programme. His concern is entirely understandable. I therefore welcome the article as a prompt to give the breeders’ side of the story, even though I have not been a truly hands-on breeder. Actually, the issues involved are complex, largely intertwined, and surely need to be spelled out. Some are essentially historic, which I will outline. A number, however, are technical and economic as well as historic, and some of them are very complex and challenging. In the background are some institutional issues.

This follows three recent articles (Burdon 2008a,b,c), but I revisit the issues with a much sharper focus on wood properties.

Historical perspective

Historically, the breeding programme has largely stemmed from technology push, albeit with some enthusiastic endorsement from industry. Despite that endorsement, the ‘demand-pull’ element was for a long time weak, which posed a big problem for the breeders. Wood processors often much preferred to accept the properties of the existing resource as a given, to be accommodated by adapting the processes, rather than risk making wrong calls as to what wood properties should be improved genetically. That was not helped by the fact that production-scale trials for paper- or board products, which might have given meaningful signals on product quality, were liable to generate variations that would disrupt quality control. There was enthusiasm among forest growers, who were operating in vertically integrated enterprises, for genetic improvement of wood density - until they were told



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Figure 1. A stand produced from controlled crosses between intensively selected parents at the age of 16 years. Planting was done on a fertile pasture site at 750 s.p.h. and a thinning had been done to 215 s.p.h. at age 8 years. Both growth and form were extremely impressive in this 'poster child' stand, but after harvesting at 18 years from planting, stiffness of sawn timber proved extremely disappointing. (Photo Scion)

that it could entail some trade-off with volume production. Given, too, the obvious need and potential for improving tree form, and the costs of assaying large numbers of trees for any wood properties, selection for wood properties was effectively shelved until around the mid- to late 1990s.

At no stage, however, did the breeders forget wood properties, although research on the inheritance of wood properties in radiata pine did not get the same publicity as the corresponding work on southern pines in USA. Indeed, the provisional plus-tree selections made in New Zealand in the 1950s had been assayed for wood properties. And assessment of wood properties proceeded in various genetic tests, in collaboration with wood-quality researchers, with data being analysed and the results reported. This happened with researchers mindful that the 'old crop' from the 1925-1935 planting boom would eventually run out, and that processing would shift to younger stands in which wood quality would become a much bigger issue. Warnings to that effect were issued (e.g. Harris and Wilcox 1975, Harris *et al.* 1976), and some light selection for wood density practised, primarily to avoid a genetic decline in wood density. However, between limited response from the sector, reflecting a reluctance to countenance any sacrifice in stem volume production, and the costs of screening for wood properties, the commitment to selecting for wood properties remained very limited - despite a generally encouraging pattern of good heritabilities for wood properties. Foresters, meanwhile, were very happy with the dramatic improvements in tree form, along with

markedly improved growth performance of intensively select material.

Some decline in wood density was noted, mainly in unpublished reports, in early crops resulting from radiata pine seed orchards. That probably reflected heavy over-representation in final crops of progeny of Clone 55, a parent noted for conferring extreme vigour but very low wood density. Yet natural and silvicultural selection that has occurred in dense New Zealand plantations of radiata pine had evidently led to a slight increase in corewood density compared with the Californian progenitor provenances (Burdon and Low 1992).

Nasty surprises

Eventually, problems with wood properties came to light in younger crops. While modelling of wood density in relation to tree age and silviculture had been developed (Tian *et al.* 1995), effects on wood quality proved markedly worse (e.g. McConchie 1996) than those expected from the reduced harvest ages and some genetic shifts towards lower wood density. Drops in stiffness (Modulus of elasticity - MoE) can be proportionally greater than reduction in density (Burdon *et al.* 2001). But, more significantly, radical silviculture, with much lower stockings and often elevated soil fertility, had two major effects:

- The reduction in harvest age, which also reflected efforts to reduce effective growing costs with a view to enhancing Net Present Value, was greater than anticipated by the breeders.
- Effects on stiffness that far exceeded those resulting from just reduced density. Poor stiffness has emerged as more critical for structural purposes than bending strength (Modulus of rupture - MoR), and can be strongly influenced by microfibril angle as well as by density (Cown *et al.* 1999), and microfibril angle is elevated in young trees, and by high soil fertility, exposure to wind, and low stockings.

Specifically, Mason (2008) has reviewed effects of site and silviculture, as well as genetics, on stiffness in young radiata pine. Other problems, which presumably represent associated effects, include: dimensional instability which reflects both longitudinal shrinkage and grain spirality; internal checking; and resin pockets.

Some basic breeding principles, and implications

Breeders knew that there were many traits that might be improved by selection. But the more traits one tries to improve, the more one tends to dilute genetic gain in individual traits (in a 'soft' trade-off), unless they are favourably intercorrelated genetically. That means that selection should be focussed on improving a limited number of traits that

1. are all of high economic importance,
2. show really worthwhile genetic variation and actual heritability, and
3. can be assayed (directly or indirectly) at reasonable cost.

Where adverse genetic correlations exist between traits (in a 'hard' trade-off), the scope for simultaneous genetic gains in those traits becomes much further reduced, greatly so if the correlations are strong. In such situations, the breeder has a great need for good information on:

- *The magnitude of the genetic correlations between economic traits* which, however, can be very slow, costly and difficult to estimate at all reliably. Moreover, given the pattern of intercorrelations between height, diameter and wood density (Burdon and Low 1992), and effects of competition, the trade-off between density and stem volume production may well play out differently - very likely worse - at the level of the crop from how it does among individual trees.
- *The comparative economic weights of the traits concerned.* This can be crucial if the correlations are marked. Wrong information in this area can lead the breeder to unwittingly reduce crop value, the more so the better the execution of the ongoing breeding programme. Yet good economic information can be remarkably elusive.

Complicating the challenge is the fact that the breeder wants to be able to select individuals while they are still young, in order to maximise genetic gain per unit time and/or its Net Present Value. This requires good information on genetic correlations between early performance and the harvest-age performance when economic worth is finally expressed. Indeed, the problem is even more difficult, because while the breeder must use early, individual-tree determinations (which may even include molecular data), these values need to be projected into whole-crop, harvest-age performance. For this projection, which will be the only valid basis of quantifying trade-offs between economic traits, genetic correlation information is not sufficient. Yet, in principle, such projection is a precondition for any assurance of obtaining appropriate correct weightings for different traits in selection. Achieving the projection, however, will clearly require a great deal of reliable growth modelling which will need very large, high-quality databases, and major research commitment.

Hard trade-offs between economic traits are clearly important. Results from genetic tests, where they relate to genetic correlations involving wood properties, have consistently pointed to adverse genetic correlations between stem diameter (and thence stem volume) and a range of wood properties (e.g. Wu *et al.* 2008). Thus the trade-offs extend well beyond the obvious case involving stem volume production and wood density.



Figure 2. Demonstration of a tool (IML Hammer) that has been used for evaluating wood stiffness in standing trees. This measures stiffness by using a calibrated relationship between stiffness and the velocity of acoustic signals. Two probes are inserted into the stem, at a measured distance, the acoustic signal is delivered by striking one probe with a hammer, and the time taken for the signal to reach the second probe is recorded electronically. Earlier evaluation of trees for wood properties is being researched, but other constraints in breeding timetables can limit the application. (Photo John Lee, Scion)

Market niche(s) for New Zealand radiata pine

Setting breeding goals requires information or assumptions concerning market niches. Yet the market niche for radiata pine grown in New Zealand is relatively complex. This contrasts with a much simpler situation in Australia where light structural uses dominate the market for radiata pine sawtimber, with pulpwood often essentially a by-product. Here we have major markets for export logs as well as wood products. Price signals for the logs are inherently difficult to interpret. In our wood-product markets appearance grades are important as well as the structural grades, while pulpwood is increasingly featuring as essentially a by-product for forest growers. On many sites we are struggling to achieve good structural grades, except on long rotations. Targeting market niches cannot be considered in isolation from branch habit, which is so hugely variable in the species and has figured prominently

as a selection criterion in New Zealand (Burdon 2008b). Adopting the 'short-internode', or 'multinodal' branching habit as part of the breeding goal amounts to 'swimming with the tide'; in at least some major New Zealand growing regions it aligns with both pressures of natural selection (Burdon *et al.* 1997) and favourable genetic correlations with various tree-form traits (Wu *et al.* 2008). For growing short-internode tree crops, it was conceived that pruned butt logs would provide clearwood to serve the appearance-grade market, while upper logs would provide the light structural timber. Indeed, M. Carson (1988) calculated that pruned crops of short-internode trees could thereby give better returns than crops of long-internode trees. However, things have not gone fully according to plan: with radical silviculture, the control of branch size above the pruned zone has been less effective than anticipated, and wood stiffness tended to be disappointing. Also, recent market returns for clearwood, produced through intensive pruning and thinning at significant sacrifice of volume production, have been disappointing; however, this may reflect current economic conditions in USA. The alternative option of catering efficiently for a clearwood market without pruning, by deploying longer-internode genotypes, is very challenging (Burdon 2008b), and is likely to depend on improved technology for mass-propagation of proven clones.

While increasing tree age can greatly improve wood quality for the more lucrative markets, longer rotations have generally been the proverbial 'dead rat' for forest growers, because of how they increase the effective growing costs. In fact, the dependence of wood quality on tree age has greatly sharpened the call for genetic improvement of wood properties, in order to counter the adverse effects on wood quality of the shorter rotations. R & D responses during recent years have occurred on several fronts:

- The industry-funded Value Recovery Project (Cown 2002) which focused on the impact of wood quality on wood processing and products.
- The Wood Quality Initiative (WQI), which has now morphed into Solid Wood Innovation (SWI), has been addressing wood properties in a consortium involving 23 New Zealand industry parties, Scion and three external parties. That has entailed surveys of the radiata pine wood resource, research on tools and methods for assaying for wood properties, and research on the basic properties that govern processing costs and especially product-performance properties.
- The New Zealand Radiata Pine Breeding Co. (RPBC) has actively engaged in supporting research on inheritance of wood properties, with a major emphasis on product-quality properties beyond just wood density and on accelerated screening technology for early evaluation of selection candidates. This research effectively complements, with a degree of coordination, that done under the auspices of WQI/SWI. Moreover, member companies involved in producing seed and planting stock have, for the last several years, placed a much-

increased emphasis on genetic merit for wood density and stiffness. Grower response is now positive, despite often little if any log price premiums for wood quality.

- Meanwhile, New Zealand Forest Research Institute Ltd (Scion, formerly FRI then Forest Research) has continued wood property research under full government funding. This has included assessment of wood properties in field genetic trials. In recent years there has been a major investment in much more fundamental research on wood properties, involving molecular genetics. This research has addressed developing genomic selection for wood properties, research on expression of genes governing wood properties, and developing technologies for modifying wood properties by genetic engineering (GE). GE, specifically, offers the prospect of conferring wood characteristics that are not available through conventional breeding.
- Currently, modelling the impacts of site, silviculture and genotype on wood quality is being addressed within the programme of Future Forests Research, a consortium of industry and Scion formed in late 2007.

While much remains to be learnt, we now have a far better idea of what basic wood properties matter, and much improved technology for assaying selection candidates for wood properties. In this light, the early breeding emphasis on growth rate, health and tree form, which gave easily captured genetic gains, still looks logical. Equally logical, with tree form now greatly improved and an increased knowledge base, is the heavy current emphasis on selecting for wood properties.

Impacts of carbon forestry

The recent focus on carbon sequestration has important implications for wood properties, as does the involvement of TIMOs (timber investment management organisations) which for various reasons can accept lower nominal rates of return than more traditional forestry corporates. Longer rotations and higher stockings now look much more attractive economically (Manley and Maclaren 2009), and if adopted will surely mitigate some major problems with wood properties. But they will only mitigate the problems. Moreover, longer rotations will increase heartwood content, which at least some end-users dislike; however, the prospects of selecting for reduced heartwood and extractives appear excellent (Cown *et al.* 1992) because of good heritabilities and very high coefficients of variation.

Breed differentiation and genetic portfolios for deployment

Is the same genetic improvement of wood properties needed to serve all planting in New Zealand (or other countries served by our breeding programme)? Given the very plastic behaviour of radiata pine, with wood properties and tree form showing very large site and silviculture

effects, and the wide range of end-uses, the answer is surely “No.” There are some sites where wood properties are already very satisfactory, at least for certain end-uses, such that genetic shifts in wood properties may offer little or no extra value, especially if achieved at the expense of genetic gain in other traits. At the other extreme, there will be sites where wood properties will be seriously limiting, sometimes such that it may not be worth attempting to grow wood for certain end-uses.

This situation has led to setting up differentiated breeds of radiata pine, in order to cater for different site categories and end-uses (Jayawickrama and Carson 2000; Burdon *et al.* 2008). The breeds address different breeding goals, in which very different economic weights for different traits are deeply implicit. This approach largely finesses (but does not eliminate) the problem posed by poor explicit information on comparative economic weights of different traits. Even without instituting breeds in the breeding population, portfolios of particular sets of families or eventually clones can be deployed for certain sites or end-uses, and current official RPBC policy (Dungey *et al.* 2009) is to abandon differentiated breeds. For blemish-related traits, e.g. resin pockets, culling of particular parents or clones may be indicated for certain site categories. Logistical and technical challenges, however, seem to be inevitable for matching material to sites, grower interests and prospective markets.

The role of wood properties in breed differentiation is somewhat problematic. While density is not directly important for many appearance-grade uses, it may have indirect importance in helping to confer resistance to internal checking. And, while stiffness may be of little direct importance for appearance grades, the low microfibril angles and freedom from compression wood that confer stiffness also improve dimensional stability.

The bigger domestication issue

Very importantly, we are still in the early stages of domesticating radiata pine. Its tolerance, as a pine, of quite low soil fertility will commend it to continued use over very large areas. Yet we would like to be able to grow it to take full advantage of site amelioration, such as raised soil fertility. The elevated fertility of ex-pasture sites is conducive to greatly enhanced productivity (Maclaren 1993, p. 3; M.O. Kimberley, pers. comm. 2010), in a way that apparently cannot be duplicated by fertiliser applications at or after stand establishment. Such fertility, however, tends to be bad news for both tree form and wood properties, adding up to very bad news for timber quality (McConchie 1996). The exact influences on wood properties are not clear, partly because the Wood Quality Initiative focussed on the forest-site stands of its membership, rather than the pasture-site crops that could greatly damage the reputation of radiata pine as a timber yet provide extremely valuable research information. In

any event, tree-architecture responses, involving both tree form and the wood properties, that are adaptive in nature can apparently become highly counterproductive with high soil fertility. Low wood stiffness, and large branches that subtend bark seams, which evidently result from high nitrogen status, are both bad in themselves. Moreover, they seem to account for the very high rates of top breakage and malformation that often occur, especially at low stockings, on ex-pasture sites.

Tree architecture has largely been shaped by the evolutionary imperative of competitive ability, but that does not align with the ideal of forest crops serving as optimally efficient ‘wood factories’ (Burdon 2008c).

Market failure

John Walker closes by effectively conceding that market failure is a big problem, with the market failing to give price signals in good time to drive correct business decisions. I agree that this problem is deeply embedded in our forestry sector. Admittedly, the market may have worked in driving a steady decline in real prices for radiata pine roundwood, which can be interpreted as tracking a decline in wood quality mainly through reduced harvest ages. Such delayed market responses, being hard to interpret, are doubly unhelpful. Indeed, J.M. Keynes’ celebrated observation “In the long run we are all dead” has been interpreted as a commentary on how markets can function too slowly to be of real practical help (Clarke 2010).

A manifest case of market failure exists for radiata pine in Australia, in that calculated economic weights among traits are quite different for the grower and processor respectively (Ivkovic *et al.* 2006). This means a log-price structure that does not reflect true value. Comparable documentation would probably reveal similar cases in New Zealand.

How can we overcome this problem of market failure? Scientists cannot operate themselves as an actual market. However, the prospect exists of providing much better information for addressing longer-term decisions. The questions involved can only be addressed by massive research commitments.

Concluding

I have heard the view that we know almost all we need to about growing radiata pine, so we should be moving on to other forestry issues. That, however, reminds me of a pronouncement in 1900, attributed to Lord Kelvin “There is nothing new to be discovered in physics now, all that remains is more and more precise measurement” (Isaacson 2007). Soon afterwards, the discipline was to be upended, with the flood of advances in relativity, quantum mechanics, and particle physics.

Growing radiata pine continues to present a fascinating paradox. Planting and leaving is often not too bad an option. However, the species can be highly responsive to a wide range of intensive management inputs, yet unforgiving of poor choice of measures, poor timing or poor execution. Getting things right entails negotiating a complex interplay between inheritance of various traits, economic-worth functions for both individual traits and trait combinations, effects of site, and effects of silviculture. This means plenty of research and management challenges ahead of us, many of which involve genetic manipulation of wood properties.

Acknowledgments

I thank Mike Carson, Dave Cown and Heidi Dungey for helpful input.

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