Internal wood quality of radiata pine on farm sites - a review of the issues

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This article is a summary of a longer report commissioned by the Forest & Farm Plantation Management Cooperative. The full text, including references, can be found on the Forest Research website www.forestresearch.co.nz, followed by Research\Cooperatives\Forest & Farm Plantation Management\Outputs\Link to Report on Wood Quality.

This review focuses on *internal* wood quality of radiata pine, especially as regards modern *clearwood* regimes on ex-*farm* sites. This is not to say that other aspects of wood quality are unimportant.

Brief background to the wood quality debate

Differences of opinion

The issue of wood quality has been approached from different directions, and the backgrounds of researchers or foresters may influence their current attitudes. At the one extreme there are specialists in wood quality who (naturally enough) tend to rank the issue as being of paramount importance. Some traditionalists may regard the 1960s "old crop" (long rotation ages, tight stockings, unimproved genetics) as being the pinnacle of wood quality, and that progress has been retrograde ever since.

It is certainly true that the quality of structural wood from the old-crop was superior, given the limits of radiata pine. The trees were grown to long rotation ages at high stockings on relatively infertile sites. Consequently, they had small branches, with a low volume of juvenile wood and a large volume of relatively dense outerwood. Problems such as excessive taper, compression wood, high microfibril angle and spiral grain were minimised. As for appearance-grade products, clearcuttings were easily obtainable from the long internodes that commonly occurred in unimproved genetic stock.

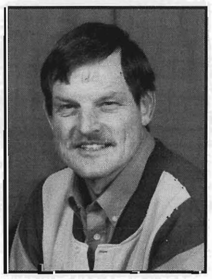
In the other corner of the ring, there are proponents of direct, clearwood regimes and farm site planting. They say that profit from the sale of wood is only one of the reasons for growing trees. Other potential drivers include shelter for livestock, erosion prevention, carbon sequestration, and riparian protection for water quality.

Even if the debate focuses entirely on profitability, they argue that wood quality does not necessarily take centre stage. Profitability of a tree crop depends on the stumpage price per cubic metre of wood, which presumably will – at least over the long term – have a close connection with its intrinsic properties. But profitability is also related to cost (e.g. lower stockings), wood volume (farm sites and modern genetics), and rapid turnover of capital (short rotation lengths). There is also the factor of risk, which includes marketing risk (eg the flexibility that clearwood provides). The "Sutton" philosophy has consistently argued that the future prospects for clearwood look bright, but the world has abundant pulpwood. The argument extends to say that structural timber will not be in short supply to the same extent as clearwood, and that radiata pine is in any case a poor species with which to grow structural wood (medium density, large branches, weak corewood).

Being a multinodal species with persistent branches, the production of a large proportion of clearwood from radiata pine implies pruning of the butt-log. Pruning is ineffective if stockings are high, or unpruned trees (followers) are allowed to compete with crop trees for a protracted period. Pruning ties up considerable capital, increasing the pressure to reduce rotation age. It can easily be demonstrated that using prevailing costs, prices and economic criteria, the "Fenton-Sutton" direct-clearwood regime is currently the most profitable. The widespread adoption of this regime – now 51% of the entire radiata resource – has resulted in a large pruned element, but with problematic top logs. This is especially the case on ex-farm sites where spectacular diameter growth of the stems is mirrored in similar growth of the branches, there being a well-known correlation between the two. Structural out-turn from top logs is further compromised in that farm sites and some modern genotypes both lead to lower density wood.

In contrast to its problematic knotty wood, New Zealand radiata pine clearwood is superior for many uses. In a NZFRI study it performed as well as, or better than, 13 common North American species, for planing, shaping, turning, cross-cutting, boring, sanding, gluing, and hardness. It was quite good at mortising, finger-jointing, nail-withdrawal, nail-splitting, and screw-splitting. In stability, it performed similarly to many species but significantly inferior to sugar pine and Douglas-fir. Other studies have compared radiata pine to "high performers" of target Asian species or other species with similar results.

When discussing the (few) deficiencies of New Zealand radiata pine clearwood especially with challenging sites or regimes, the debate should be kept in context. It is rational to focus on problems, because that is the way progress is made, but care needs to be taken to avoid highlighting the problems unduly.



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What do we mean by "ex-farm" sites?

Available nitrogen is the element that most clearly distinguishes "farm sites" with "forest sites". Needles on nitrogen-rich soils are longer, fatter and darker green. Presumably, they contain more chlorophyll per needle and photosynthesise more efficiently. The extra biomass of foliage generates larger branches and stem diameters. Basal area growth rates are perhaps 40% higher at least up to canopy closure, and 20% higher at harvest. The average Productivity 300 Index for ex-farm sites (1737 observations) is 30.7 m^3/ha/year, as opposed to 24.4 for ex-forest sites (3593 observations). Although it is too early for a definitive statement, it seems likely that the "farm site effect" will persist into the second rotation, given that nutrient levels (as evidenced by the Tikitere Agroforestry Trial near Rotorua) are still high at the end of the first.

By way of contrast, a forest site may have a number of regenerating woody understorey species that compete with the planted trees. It has often received no deliberate fertilisation, and has not usually been grazed. The soil composition, structure, fauna and mycorrhizae differ, with some forest soils being traditionally described as *mor* whereas most grassland soils are *mull*. In New Zealand, forests have historically been sited on land unsuited to agriculture, often because of inferior soils or higher elevations. The low-nitrogen soils have tended to produce relatively straight trees with relatively small branches. In other words, these are the sites that produce wood more suited to the traditional structural markets.

What do we mean by internal wood quality?

Wood quality can be divided into characteristics that are externally visible on a tree, and those that are not. The former includes straightness and lack of forking; branch size and branch distribution. The latter comprises a wide range of attributes, including those at the scale of the individual fibre or cell. Among the most prominent are stiffness, strength, stability, hardness, wood density, microfibril angle (MFA), compression wood, spiral grain, internal checking, resinous characteristics (including resin pockets, blemishes, streaks and patches), needle fleck, heartwood, and colour. Some of the attributes (e.g. density, MFA, compression wood and spiral grain) are causative agents affecting others (eg stiffness, strength, and stability). Some defects (resinous patches, needle fleck and colour) are important only if the wood is to be used for appearance grades.

Although internal wood quality is mostly discovered only in the course of processing, some internal features can be inferred from external clues: for example, young trees grown at high altitudes in Southland are likely to have low wood density; trees with an unbalanced crown or a marked lean are likely to have compression wood; old trees have a high heartwood content; trees with external resin bleeding are more likely to have higher degrade in clearwood due to resinous characteristics.

It is noteworthy that 90% of the problems are caused by 10% of the logs. This emphasises the importance of product segregation: the need to separate out the bad element and give the highest possible assurance of quality to the remainder, at all points in the supply chain. An increasing proportion of New Zealand clearwood is sold to outlets such as the Home Depot in the United States, which places a special emphasis on quality of product. One dissatisfied customer can counteract the goodwill from many satisfied ones. Without quality control, the presence of internal checking or resin pockets in 10% of the pieces could downgrade the value of the whole consignment or even make it unmarketable. This point needs to be highlighted.

Unpruned top logs on farm sites

As previously mentioned, the spectacular diameter growth of trees on ex-farm sites comes at a cost – large branches. This problem can be overcome by increasing final stockings. Unpruned top logs from high stockings on farm sites – if assessed externally – closely resemble logs from lower stockings on forest sites. The superficial similarity, however, is misleading. Detailed analysis of internal wood quality shows that such logs are inferior for both appearance and structural uses.

Appearance grade potential

The large branches commonly found on farm sites, particularly in combination with direct, clearwood regimes, restrict appearance grades to knot-free wood. This is found in the pruned butts, and in unpruned logs from clearcuttings. The latter is derived both from internodes and from gaps between the branches in a whorl (particularly in large logs).

A study of 18-year old farm site trees at Ngatira with '850' genetic stock yielded almost no clearcutting grades, due to the highly multinodal habit of the stand. A comparative study of 26 farm versus forest sites by Leith Knowles and Don McConchie showed that internode lengths were considerably less than expected from their locations (internode length tends to increase towards the south of the country). This was particularly the case at low stockings. The authors attributed the cause to greater whorl depth and to an increase in the number of whorls per metre.

In addition to the farm and stocking effects, a major problem has arisen from the choice of genetic stock in recent years. In the quest for good growth and form, and for small shallow-angled branching, popular modern seed selections are considerably more multinodal than unimproved stock. The debate over multinodality appears to have become dichotomised: extreme multinodality *or* extreme long internodes, with very little industry support for the latter. Although the possibility of intermediate-length internodes has been always been present in the breeding population, this opportunity has not been developed. It is hoped that a farm site breed, incorporating clones with intermediate-length internodes, will become available shortly.

Structural grade potential

As previously mentioned, radiata pine is not a preferred species for structural grades, especially when grown on "modern" regimes. The typical grade recovery of all structural grades for New Zealand structural mills is about 50%, as opposed to 80% for Australia, 90% for the U.S. South and 95% for British Columbia Interior. New Zealand averages 420 kg/m^3 in density, but the figure can be substantially lower than this in younger trees, on colder sites and in the corewood. Radiata pine branches tend to be large, especially on farm sites combined with low stockings.

Although the branching habits of farm site trees were reasonably well known prior to the Ngatira Sawing Study (1990) of 18-year-old trees, the poor grade outturn came as an unpleasant shock. Although the predicted outturn of No.1 Framing was 20%, the actual results were reported to be less than half the SAWMOD prediction (either10% or 8% depending on the source of information). These poor results appear to be supported by other studies, but the definitive Tikitere (26 year old trees) evaluation is still pending.

Specific quality problems

Wood density

Wood density has long been regarded as one of the leading quality issues in timber. There may have been excessive emphasis on this feature, given that, as Wayne Miller says, "density (per se) is NOT important for many uses"(original emphasis). Many of the traditional species for joinery, eg ponderosa pine, eastern white pine, western red cedar and redwood, have lower density than New Zealand radiata pine. For one thing, stability tends to be improved with lower density. On the other hand, the "official FRI view" is that density is of high priority for component furniture, dry structural, and plywood.

Whole-tree wood density is known to increase with tree age, and to decrease with latitude. Higher altitudes also have lower density. The reason is probably related to temperature, and in particular the length of the growing season and the ratio of latewood to earlywood, however defined. Despite these regional differences, it is worth emphasising that the differences between trees in the same stand can be even more pronounced, thus underlining the opportunities for segregation based on individual trees or logs, as well as stands.

It is widely recognised that '850' genetic stock (GF12-14 planted mainly between 1971 and 1985) is 5-10% lower in wood density than previous or subsequent material. A comparison of climbing select trees at Rotoehu (an ex-forest site) with GF14 showed a 6.3% reduction in density as a result of the '850' stock. There does not seem to be a major genotype x site interaction for wood density.

Wood density at Ngatira and Tikitere was lower than for forest sites at the same latitude and tree-age. This is partly attributable to the use of '850' planting stock and partly due to the farm site effect. Ex-farm sites have higher available nitrogen. Indeed, this is almost their defining characteristic. Work by Dave Cown and Don McConchie, the Australian Biology of Forest Growth trials, Peter Beets and by Brad Barr and Mark Kimberley has shown that high foliar nitrogen levels caused by fertilisation, or – more permanently – by a history of intensive farming, will result in reduced density. Despite earlier reports, boron fertilisation appears to have no influence on wood density.

Contrary to common perception, lower stockings result in marginally *higher* whole-tree density, because corewood occupies a similar volume between stockings (trees are largely unconstrained in growth as they fully occupy the site) but there is a greater volume of outerwood at lower stockings. Wood density has also been shown to decrease as a result of thinning, but this is likely to be the result of removal of suppressed trees that are denser than average. Were it not for this effect, enhanced tree growth following thinning is likely to increase the proportion of outerwood relative to corewood and therefore increase density in crop trees.

Stiffness

One of the main reasons for the historical concern over wood density was the supposition that it was a surrogate for stiffness. (Stiffness is more important for structural radiata pine than either strength or hardness, but all three are influenced by density). Radiata pine is disadvantaged on world structural markets by its low stiffness.

It is known that wood density alone is only a moderate indicator of stiffness, explaining 65% of the variation for clears. When microfibril angle (MFA) is added to the picture, some 94% of the variation (for clears) is explained. To be precise, the Modulus of Elasticity is directly proportional to the density divided by MFA. The contribution of these two factors to stiffness, as measured by the Modulus of Elasticity (MOE), appears to vary between juvenile wood and outerwood. Cown *et al* provided "robust" statistical evidence to indicate that both density and MFA were "very significant" in determining MOE in the juvenile wood of radiata pine, but that density had an overwhelming effect in the mature wood. They stated that this supported traditional thinking and justified past and present efforts to document factors affecting wood density in *P. radiata* and to improve the average levels through tree breeding. Also, density can be measured and predicted with precision but MFA is currently more difficult to measure and use.

It is possible to obtain accurate stiffness measurements quickly and easily on felled logs, or whole but de-limbed stems, with acoustic tools such as the Hitman or SWAT. The technology has not yet been perfected for standing trees. This development has considerable potential for maximising the potential of a resource for machine-stress-graded lumber, but has less of an application for appearance-grade material such as pruned butts. This is not to say that stiffness is totally unimportant for appearance grades, merely that it is less important.

Microfibril angle

Microfibril angle (MFA) interacts with density and grain angle to determine the stiffness, strength and shrinkage properties of wood. Although density is the most important determinant of these properties for outerwood, MFA is of greater importance in juvenile wood and the base of the stem. The stiffness of wood increases five-fold as the helical winding angle of the cellulose (the MFA) decreases from 40° to 10°. Given the short rotations that are currently employed, juvenile wood can account for a substantial part of the log volume in butt logs, and therefore MFA is critically important.

An Australian report stated: "in general fertiliser resulted in lower density, higher microfibril angle (MFA) and slightly lower stiffness". Therefore we would expect this problem to be more extreme in fertile farm sites. MFA is affected by physiological ageing (angle reduction of 1° for every year of ageing) so the problem can be mitigated somewhat by using aged cuttings.

Like spiral grain, MFA may serve an evolutionary purpose and it may be unwise to encourage across-the-board reductions in MFA for the sake of superior wood quality, while ignoring the costs in terms of growing trees. A high MFA makes for a very flexible juvenile stem, which may be advantageous in withstanding wind and snow damage in early years or at the top of the tree. A complementary evolutionary strategy is to have a low MFA in outerwood to impart stiffness. The cautious approach may be to eliminate the "outliers" (ie trees with exceptionally high MFAs) while maintaining the existing median MFA.

Longitudinal Shrinkage

There is a correlation (r^2=74%) between stiffness and shrinkage, which is important in all types of solid-wood. A Weyerhaeuser patent demonstrates that when stiffness falls below about 7.0 Gpa there is a noticeable increase in longitudinal shrinkage, a characteristic which is substantially worse in the butt log compared to the second log. Differences in longitudinal shrinkage between edges will cause boards to crook or bow. This is especially important for high value clearwood products.

Stiffness and longitudinal shrinkage appear to share a causative agent – microfibril angle. The quest to enhance stiffness in corewood by reducing MFA could conceivably create a lesser incidence of distortion in processing.

Stability in processing and in use

Distortion and stability behaviour is a complex amalgam of: drying stresses, longitudinal shrinkage differences, creep, moisture response rate, compression wood, etc. It is poorly understood at both the research and applied levels.

Stability is an issue for all types of solid wood. Wood that distorts in processing is difficult to process further, even if it comprises otherwise defect-free clearwood. Wood that distorts or moves in use reduces the functionality of the product. For example, distortion has been identified as a major reason why Swedish building contractors were converting to steel framing. Instability has been identified as a likely reason why radiata pine performs worse than species such as ponderosa pine. Given the density of the species (remembering that in general the *lower* the density the more stable) its stability is poorer than expected. The reasons are not well understood.

Compression wood

One major cause of instability and distortion is compression wood. Compression wood is a reaction to stresses in the tree, and counterbalances uneven weight loadings in the stem or crown. Radiata pine is a large-branched species (perhaps this is the price we must pay for the spectacular growth rates), a factor that may result in unusually high levels of compression wood. Also, New Zealand is a windy country, which is a major cause of stress, unbalanced crowns and leaning stems. Thinning and slope instability may compound the problem.

There is more compression wood at Tikitere compared to forest sites. This could be due to the windiness of the site and the lean of the trees (the marked butt-sweep resulted from Cyclone Alison but there was also damage from two subsequent cyclones), and by the weight imparted by the huge branches at low stockings. Compression wood tends to decrease with increasing height in the stem, indicating that the problem is particularly relevant to the all-important butt logs. Don McConchie also points out that clonal differences exist, indicating that there may be some help from altered genetics. Dave Cown has shown that compression wood is related to thinning, with the incidence proportional to the growth response from thinning. One mechanism he suggested was that thinning makes the stems more prone to windsway.

Another reason for the recent upsurge of interest in stability is the reduced dimensions of final wood products. Some products are now only 3 mm in thickness! This has major implications for a species, and for regimes, where growth rings can be 25 mm or more apart. With these product sizes, the relationship between earlywood, latewood and compression wood become very important.

Internal checking

Checking is a major cause of degrade in clearwood. It is particularly prominent in the butt log, usually does not appear until after drying, and can be invisible on the surface of the wood. Rolf Booker states that the internal checking occurs when, due to water tension forces, the earlywood with its thin cell walls contracts more that the latewood with its thicker cell walls, and the resulting tensile force in the earlywood causes it to split. Don McConchie says that checking appears to be worse on sites exposed to drought, waterlogging or frost. Drying schedules can be modified to reduce internal checking if such sites are identified in advance.

Boron deficiency is an obvious candidate as an explanation, given the well-known importance of this element in cell-wall structure and the evolution of radiata pine as a coastal species (boron levels are high in salt spray). In support of this hypothesis, checking seems to be worst at sites (like Eyrewell and Golden Downs) known to be boron-deficient. Nevertheless, a study of a boron trial at Rerewhakaaitu showed almost identical levels of checking in the control and the boron treated trees.

A possibility under active research is the elimination of checking by allowing the formation of heartwood. It appears that most checks occur within five rings of the heartwood boundary and that checks are very rare in heartwood. Thus a solution could conceivably be found by merely extending the rotation age by a few years. Heartwood heritability is relatively high, at 34% and therefore there may be possibilities via genetic manipulation. Heartwood, however, is not usually desirable for other reasons (eg colour, treatability).

Spiral grain

Spiral grain can be a major defect, resulting in distortion during processing or in use. Dave Cown states that "it has, in fact, been documented that the greatest source of drying degrade in processing young logs is twist as a direct result of spiral grain in excess of 5 degrees." Tikitere trees have higher levels of spiral grain than would be expected from trees of a similar age on ex-forest sites. There is no obvious explanation for this, except perhaps that spiral grain may be one response to wind-stress.

Before condemning spiral grain as an unmitigated evil, and attempting to eliminate it with tree breeding, it may pay to first discover its evolutionary importance. Kubler says that "Compared with straight-grained trees, spiral-grained stems and branches bend and twist more when exposed to strong wind, in this way offering less wind resistance and being less likely to break.... but the main function of spiral grain is the uniform distribution of supplies from each root to all branches, and from each branch to many roots." Total elimination of spiral grain could therefore make trees more susceptible, for example, to drought.

Resinous features

It is conceivable that resin exudation has evolved as a protective mechanism against insect attack and other injuries. Although resin pockets (the most serious form of resinous feature) are disadvantageous for human use of clearwood, they could confer benefits to tree survival in extreme conditions. Stressed trees exude resin (although the exact nature of the stress is not very clear), which may explain the high incidence in the drought and wind-prone Canterbury Plains, and in lower, more wind-exposed stockings at Tikitere. The drying effect of the wind could be more important that the exposure *per se*.

Alan Somerville has provided the definitive summary of the state of knowledge regarding resin pockets. He classified resin pockets into three types: Type 1 is contained and does not exit to the cambium. Type 2 appears to originate as Type 1 but erupts through the cambium, and Type 3 is a small defect resulting from a lesion through the cambium.

Don McConchie has now shown that there is a strong link between the level of external resin bleeding and the quantity and value of clearwood in the sawn timber. Trees prone to resinous characteristics could be eliminated at time of crop selection (typically ages 4-9) provided that a link can be established between external characteristics visible at this age and properties of the mature logs. This work has yet to be started.

Discussion and conclusions

Unpruned logs on farm sites present an intractable problem – they are particularly unsuited for structural grades, and do not have sufficient internodes for appearance grades.

Pruned logs dominate the standing value of our existing resource and may become even more important in the future as a greater proportion of the estate is planted on ex-pasture sites. Internal checking and resinous characteristics potentially compromise this value. These problems are not, however, worse on farm sites provided that stockings are reasonably high.

Characteristics of internal quality that are worse on farm sites are wood density, stiffness, longitudinal shrinkage, stability, compression wood, spiral grain and microfibril angle. These are of most importance in structural grades, but may not be so critical in appearance grades. Some of them may be resolved in the future by tree breeding or by careful siting and management, but the greatest current opportunities lie in understanding the resource and in segregating out problematic trees, stands and forests.

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