CASE FOR IMPROVING WOOD DENSITY IN RADIATA PINE

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ABSTRACT

To date, most of the radiata pine harvested in New Zealand has come from untended "old crop" trees. Stands now being grown for the future will almost certainly be harvested at an earlier age than the 45 years which is current practice. This reduction in age will result in lower mean wood density compared with the "old crop", and therefore in reduced intrinsic strength for timber sawn from these stands. The relatively low proportions of outer-wood produced under these regimes may be offset in the butt log by improved timber grades obtained from pruning. Lower average wood density and larger knots in some of the upper logs can and should be compensated for by selective tree breeding to improve wood density, which is highly heritable. Machine stress grading or similar non-destructive testing is seen as an essential concomitant of such an improvement programme.

INTRODUCTION

Changes in silvicultural practices have far-reaching effects on the quality of wood produced and on the relative importance of strategies available to control wood properties. This paper examines some of the effects of reducing rotation length on the wood properties of radiata pine (*Pinus radiata* D. Don), and looks at ways of off-setting undesirable features.

The current crop of unthinned 45-year-old radiata pine is a historical accident that will not be repeated. The regimes adopted for future crops will often incorporate pruning as a means of controlling timber defects caused by large knots. They will also most likely incorporate thinning, both to eliminate malformed trees and to concentrate growth on the selected stems remaining. The precise regime adopted will vary according to location, the products required, and the management objectives. No one silvicultural regime has emerged as predominant, but all those that are being employed envisage rotation ages shorter than 45 years. One such schedule, involving early pruning coupled with thinning to waste, has been shown to be capable of yielding a high financial return (Fenton, 1972), and the economic merit of shorter rotations is very clear. Unfortunately the thinnings that will be required to stimulate diameter growth of the crop trees will also increase branch diameter above any pruned zone, depressing grade recovery from some logs in this region.

Intrinsic wood properties (e.g., the properties of clear knot-free wood as indicated

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by wood basic density which measures the actual dry-matter content of a wood sample) are also affected by growth rate and by tree age at the time of felling. Several recent studies in diverse research fields at the Forest Research Institute afford a basis for assessing the importance of wood density compared with other features affecting timber use, and for assessing our ability to modify these features by selective tree breeding and/or silviculture.

DISCUSSION

Effect of Growth Rate on Wood Density

Sutton and Harris (1973) and Cown (1974) have shown that rapid radial growth rate has a very small depressant effect on wood density within normal limits of growth. Spacing at time of planting, and thinning, therefore have little direct effect on wood density when considered over the length of a rotation. By far the most important differences in intrinsic wood properties arise from the relative proportions of corewood and outerwood formed under different regimes.

Mensurational data necessary to determine precisely the different mean wood densities resulting from different silvicultural regimes are not yet available. To derive these figures accurately, the volumes produced down each stem in each year must be known for representative trees. If the regime includes an extraction thinning, or if volume is lost through shatter at felling, the effects on mean wood density must also be considered. But, although actual examples are hard to come by, the order of reduction in density has been indicated by Cown (1974) who compared the results on the final crop element of two regimes in Kaingaroa forest. He estimated that a tree grown to 400 mm d.b.h. in 25 years would have mean wood density 8-10% lower than an unthinned tree reaching the same size over 35 years. This is mainly because the proportion of high density outerwood would be much lower in the 25-year-old tree.

The increase in wood density from the pith outwards in radiata pine is almost linear up to 25 to 30 growth layers from the pith depending on site (Harris and Nash, 1972), so that trees clear-felled at 25 years are only just beginning to produce wood of maximum density, and then only in the last-formed growth layers of the butt log. On the other hand, trees felled at 35 years have produced wood of maximum density for their particular genotype and environment for 10 years. This constitutes a zone of wood 10 growth-layers wide at the butt fading out at a level corresponding approximately to tree top height at age 10 years.

It is the loss of this dense, strong, long-fibred wood that has to be considered when assessing the effects of a shorter rotation. Although the exact reduction in density will depend on the precise nature of the regime employed, for those logs usually converted to sawn timber (i.e., butt, second, and third logs) it is certain that the younger final crops of the future will have lower wood density.

By way of partial compensation it must, of course, be conceded that rapid growth adds a relatively higher proportion of the wood of intermediate density, say 5-20 growth layers from the pith, than would be produced in unthinned stands of the same age. Also, for the pruned butt log at least, the removal of all defects caused by branches more than compensates for any loss of strength caused by reduction in density.

Effect of Early Thinning on Branch Size

Most studies to date on the effect of growing space on branch size have been made in stands planted at various initial spacings, (e.g., Sutton, 1969; 1971). These present a somewhat different picture from the branch size that will eventuate in second and upper logs when selected trees are designated for the final crop in short rotation regimes with early thinning, because branch diameter will be one of the criteria for selecting final crop trees. A true assessment of this effect must await the development of stands that have been deliberately managed for short rotations, and most are still too young to provide the final answer. Nevertheless, it is generally accepted that branch diameters in the second log will be considerably larger than those in the unthinned stands that are being harvested now. This is of particular importance when considering the production of 100 × 50 mm framing timber.

Fenton (1971) suggested an alternative method of overcoming second log branchiness by employing finger-jointing to produce framing timber. Similarly, finger-jointing was suggested to produce clear boards from factory and lower grades.

One objective of the present paper is to examine the possibility of employing machine stress grading to select framing timber with good intrinsic properties but with larger knots than are acceptable in visual grades. It will therefore be assumed that timber is machine stress graded first, irrespective of knot diameter. The possibility of finger-jointing material rejected under this system is a useful stand-by to ensure optimum utilisation.

Relative Effects of Knots and Wood Density on Stress Grades of Framing Timber

Knowles and James (1973) used visual grading and machine stress-grading to study the effects of branch size on the strength of 26-year-old *P. radiata* that had been thinned to 198 stems per hectare at age 11 years. Multinodal second logs of similar diameter and stem straightness were selected to provide a wide range of branch diameters. All logs were sawn to maximise the out-turn of 100 × 50 mm dimension, because this is the most important framing size, and strength in this dimension is more affected by knot size than that of larger pieces. In analysing the results of this study an index of strength called "mean E value" was derived for each log by calculating the weighted mean modulus of elasticity (from machine stress grade) for all pieces sawn from the log. The basic density of each piece was also considered and relationships derived for "mean E value" in terms of mean basic density and "branch size index" (Sutton, 1970) for each log. A simple straight-line relationship between the three parameters ($r^2 = 0.69$) was used to illustrate the relative effects on strength of altering either knot size or density (Fig. 1), though more detailed analysis suggested that a curvilinear function would provide a better fit ($r^2 = 0.75$). These results suggest that mean modulus of elasticity in 100 × 50 mm timber can be maintained if wood density is increased by approximately 10% when knot diameters increase by 60%.

Knowles and James (1973) concluded that further research was required on the relationship of wood strength to density and knot size, as well as the influence of factors such as log size not included in their original study. However, the important implications of their results led us to examine the question in the engineering context.

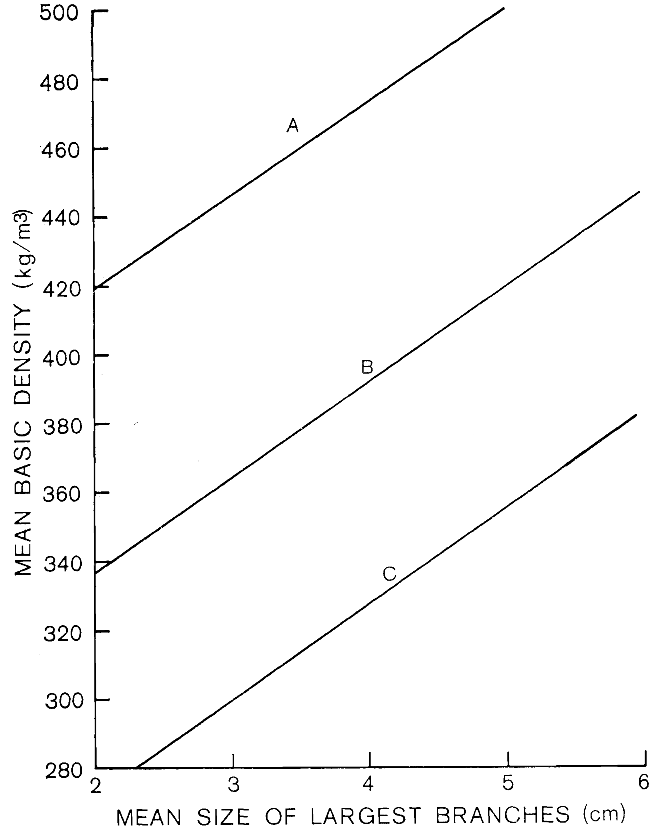

FIG. 1—Regressions of branch index on basic density to provide "mean E values" of 6.333 GPa (A), 5.011 GPa (B) and 4.184 GPa (C), respectively the highest, mean, and lowest values encountered by Knowles and James (1973).

Relative Effects of Knots and Wood Density on Structural Performance

The mean E value is a bulk property calculated from a whole log, and does not indicate the behaviour of a particular piece. For this we can refer to the well-established relationships between modulus of elasticity and modulus of rupture, with appropriate reductions for knot size and position according to values established by the American Society for Testing and Materials (1972). Slightly different values may apply to New Zealand grown radiata timber but the trends will be the same as in the examples illustrated in Fig. 2. Obviously influence of knot size is greatest in small dimensions. However in 100 × 50 mm timber a 10% increase in wood density would compensate for a 60% increase in knot diameter (from 2.5 to 4.0 cm), and would compensate for a 135% increase in knot diameter in 200 × 50 mm timber (2.5 to 5.9 cm for centre line knots). These random examples show that the capacity to offset increasing knot

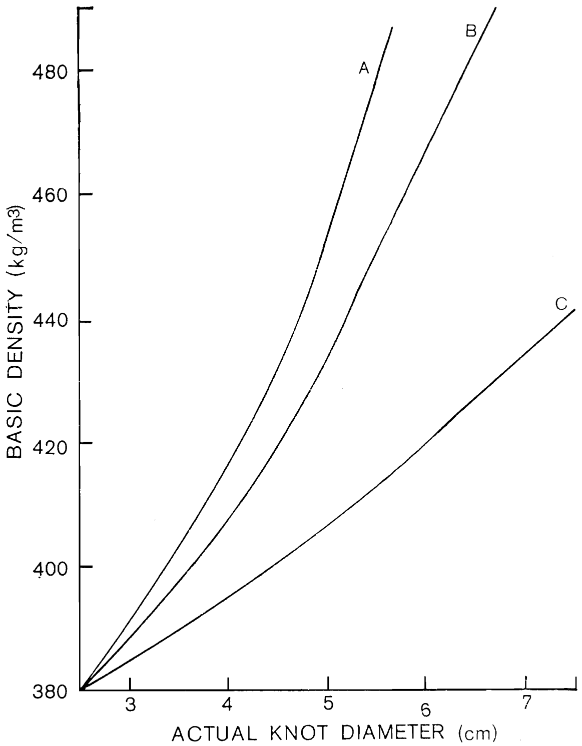

FIG. 2—Regressions of knot diameter on basic density to provide constant modulus of elasticity (and approximately constant modulus of rupture).
A: M of E = 10.687 GPa; 100 × 50 mm timber; centreline knot
B: M of E = 8.060 GPa; 200 × 50 mm timber; edge knots
C: M of E = 9.101 GPa; 200 × 50 mm timber; centreline knots.

size by increasing wood density is considerable, and that the results of Knowles and James (1973) provide useful approximations for 100 × 50 mm framing.

A further consideration is that framing timbers are usually employed in a load-sharing situation.

For wooden members subject to bending loads, such as studs, joists and rafters, stiffness is the strength factor that governs design. Stiffness is the property required also in truss members (to withstand buckling loads while loaded axially in compression) and bottom chords (to withstand bending as well as compression due to wind uplift).

The strength of a piece of timber subject to a uniform bending moment is determined by its weakest point. Deflection under load is largely dependent on stiffness throughout the length. In a load-sharing situation, where several parallel bending members are crossed by members at right angles capable of distributing the load from one member to another, the less stiff member will shed load onto its stiffer neighbours. Under a given load all members tend to be stressed to a similar proportion of their ultimate strength.

Thus the performance of a light frame structure tends to be determined by the average stiffness of the members.

Low wood density is a defect distributed along much or all of the length of a piece of timber, whereas knots can be regarded as point defects. Stress grading machines operate over a narrow span and the whole piece is graded according to the lowest reading along it. Thus, for equal improvements of stiffness grade as measured by machine, that piece which gains as a result of higher wood density will perform better in a structural situation than the piece which gains by reduction of knot size.

Effects of Density on Yields of Pulpwood

Because of the complexity of the problem, most attention has been directed in this paper towards increasing density with a view to improving stress grades in sawn timber. However, the effects of wood density on pulp yields are also very important, and, being directly proportional, are very simply estimated. They should, therefore, not be overlooked when considering the case for improving density.

Dense slabwood (outerwood) from unthinned stands aged 35 years or more is widely used in chemical pulping today to maintain important paper properties, such as tearing strength, as well as to improve pulp yields. Consequently, both quality and quantity of pulp are involved when wood density is reduced.

Selective Tree Breeding to Improve Wood Density

A preliminary assessment of a 5-year-old open-pollinated progeny test of *P. radiata* select parents (Wilcox *et al.,* 1974) provides reliable data for predicting the genetic gains that can be obtained from tree breeding to improve wood density. In fact density proves to be one of the most highly heritable characteristics examined in this study. Moreover, it exhibits no genotype x environment interaction so that selection for wood density made on one site will be equally effective elsewhere.

There is, however, a negative environmental and genetic correlation between growth rate and density, which makes it difficult, but not impossible, to optimise volume and wood density production simultaneously. Selection indices based on volume, stem straightness, branch cluster number, and density, achieved good gains simultaneously in volume and straightness, but not in density without sacrificing some gain in volume.

The genetic gain that can be achieved by selecting 1 tree in 100 for wood density is 12%. However, it would be more realistic to think in terms of selecting 1 tree in 20 for this property (which would yield 9% higher density) or even 1 tree in 10 (which would still increase density by 8%).

This possibility raises, in turn, the question as to whether selection for corewood density (as in these 5-year-old trees) has much relevance for future "intermediate" or "outerwood" production. It is true that density of corewood is poorly correlated with density of outerwood. (Harris, 1965; Wilcox *et al.,* 1974), but this purely statistical assessment can be misleading. Although wood density always increases from the pith outwards, the *gradient* of this increase is very variable. Harris (1965) illustrates this (Fig. 5, p. 19) with data for three trees from the same site. The first tree has basic density of 350 kg/m^3 at the first growth layer, increasing to 460 kg/m^3 at the 26th growth layer. The second tree starts at 310 kg/m^3 and increases to 360 kg/m^3, whereas the third tree starts at 280 kg/m^3 and yet it increases to 460 kg/m^3. Of these three trees the first would be most desirable, having relatively high density in both corewood and outerwood; the second would be undesirable because of its consistently low wood density; and the third would be equally undesirable, firstly because of its low density corewood, but also because of the steep density gradient which makes for technical difficulties in utilisation.

Thus, a good case can be made for selecting high wood density in corewood: since no instance has been recorded of any behaviour other than increasing density from the pith outwards, high density corewood would increase mean density and effectively reduce within-stem variability. For all end uses, even including mechanical pulping (Harris, 1968), the elimination of very low-density corewood would be advantageous. In particular, it could have the important effect of improving basic stresses for the species, since these are determined by the lowest 1% of results from strength tests on clear timber.

CONCLUSIONS

The salient points to be considered in relation to selective tree breeding for increased wood density in radiata pine are:

1. When compared with "old crop" unthinned stands, management regimes aimed at reducing rotation ages will reduce the mean wood density of trees harvested in the final crop. This reduction may amount to 8%.
2. Any increase in the rate of diameter growth induced by thinning may result in enlarged branches above the pruned zone which would reduce both the visual and machine stress grades of structural timber sawn from these logs.
3. Results of a pilot grade study, and also calculations based on engineering principles indicate that an increase of 10% in wood density would maintain stress grade against an increase in knot diameter of 60-100% depending on timber dimensions and the location of the knot.
4. Pulp yields and pulp quality will both be affected by a reduction in wood density.
5. Effective increases in wood density can be achieved by selective breeding using relatively low selection intensities (e.g., 8% increase in density by selecting 1 tree in 10).

The main argument against applying wood density criteria to select families in *P. radiata* progeny tests is that this would militate against maximising volume production. These grounds for objection require very careful scrutiny, including evaluation under specific regimes where there is opportunity for silvicultural selection based on vigour.

It is worth remembering that 10% increase in wood density would correspondingly increase pulp yields, even without considering pulp quality which also has an economic value. The profitability of improved stress grade resulting from increased wood density cannot be fully evaluated until the effect of new management regimes on knot dimensions above the pruned log is known. On the other hand, if it was economically sound to include branch size as a criterion for "plus tree" selection in the first place, how can highly heritable wood density be disregarded during progeny selection now that branch size, for which it compensates, has proved to be very weakly inherited?

There is one final requirement needed to justify the economics of any programme to improve intrinsic wood properties: the improvement should be capable of recognition. Machine stress grading, or some similar non-destructive testing process, is essential if improvements in wood density are to be fully utilised and made profitable for the grower. We firmly believe that the present apparent reluctance of the timber industry to accept and adopt machine stress grading will be short-lived. Technical improvements to the stress grading process, and especially the competition from alternative materials with closely predictable engineering properties, will force the timber industry to sell stress-graded timber. If the industry is unwilling to face up to this fact we need not be unduly concerned about our ability to produce framing timber, because we may not be able to sell it anyway.

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