WOOD DENSITY OF RADIATA PINE: ITS VARIATION AND MANIPULATION

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SYNOPSIS

Within-tree and between-tree variations in wood density of radiata pine are described. The main factors which influence the variations are discussed and their effecis compared.

Large variations can be attributed to climatic and site factors which are unchangeable, whereas silvicultural treatments have only a minor effect on wood density under New Zealand conditions. Selective breeding for wood density could significantly alter both absolute density levels, particularly in the corewood, and total densiy variation within stands. However, the current emphasis on stem morphology and vigour precludes the inclusion of wood density as a prime criterion for selection in improvement programmes. It is concluded that, in general, technological innovations will remain the chief means of improvement in the properties of sawn timber and wood products for some time to come.

INTRODUCTION

Radiata pine (*Pinus radiata* D. Don) has unrivalled vigour of growth on most sites, and its timber is suitable for a wide range of products. Because of these qualities, it seems destined to remain economically by far the most important timber species grown in New Zealand. With the current trend towards shorter rotations and more intensive silviculture (Fenton and Sutton, 1968), it is important to ensure that management practices do not adversely affect wool properties.

Wood properties are influenced by all conditions of growth, whether these are natural, such as climate, or under the control of man. Although the effects of climate are largely immutable, foresters can exercise some control over wood properties through silvicultural practices (Fielding, 1967) and by selective breeding (Zobel, 1971). This note examines the relative influences of these processes on one wood property of radiata pine to determine whether any significant gains in this direction can be effected in New Zealand.

Wood density is the property which will be used as an example because of its close correlation with timber strength (Dadswell and Nicholls, 1959; Elliott, 1970) and pulp yield

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and quality (Kleppe, 1970), and because it is widely held by wood technologists to be the single most important wood variable (de Zeeuw, 1965). According to Panshin *et al.* (1964), the relationship between wood density and timber strength is expressed by:

$$S = K\,(D)^n$$

where S is any of the strength properties, K is a constant, D is density, and n is an exponent which depends on the strength property being considered. For compression parallel to the grain, n is about 1.0, for modulus of rupture about 1.25, and for compression perpendicular to the grain, around 2.25.

VARIABILITY IN WOOD DENSITY

The sources of wood density variation in tree crops can be considered in two categories. These are within-tree variation and between-tree variation.

Within-tree Variation

Regular patterns of wood density are found within stems of radiata pine (Fig. 1). At all height levels, density increases gradually from the pith outwards to the bark. The term "corewood" embraces the low-density wood in the vicinity of the pith, but its extent cannot be precisely defined as its properties are not solely dependent on density. For example, corewood also characteristically contains short cells with high microfibril angles and, as a consequence, often exhibits excessive longitudinal shrinkage (Harris and Meylan, 1965). The most severe spiral grain is also frequently found within a few rings from the pith (Harris, 1969). However, low wood density is the main cause of the poor strength properties and reduced pulp yields associated with corewood (Einspahr, 1972).

The wood-using industry as a whole would benefit from a decrease in the influence of corewood (Zobel, 1966).

Between-tree Variation

The range of wood densities encountered in trees of the same age and crown class growing in an apparently uniform environment is very wide (Nicholls and Dadswell, 1965). Corewood values ranging from 270 to 360 kg/m^3 were recorded in 6-year-old trees by Harris (1966a), and in the outer wood of 35-year-old trees the highest values were frequently 50% greater than the lowest values on any one site (Harris, 1965).

FACTORS AFFECTING WOOD DENSITY

Three main groups of factors are known to influence wood properties either directly or indirectly:

(1) Site and soil (climate, altitude, latitude, soil characteristics).

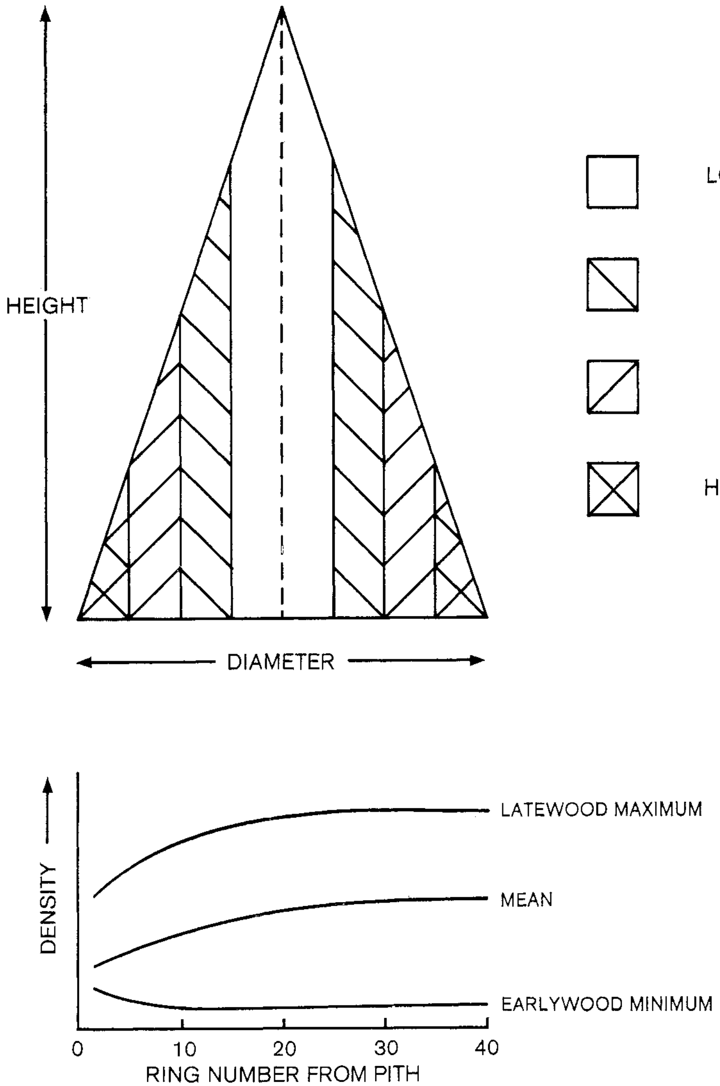

FIG. 1: *Distribution of wood density within stems of radiata pine.*

(2) Silviculture (spacing, thinning, pruning, fertilizers, rotation).

(3) Genetics (variability and heritability of wood density).

Site and Soil

In practice it is difficult to separate the effects of climate and site as they often interact. For example, high-altitude sites tend to be cold and windy. Climate and site together determine the limits of growth of any species.

Harris (1965) found that variations in outer wood density were closely correlated with mean annual temperatures ($r = 0.94$) but that the corresponding relationship for corewood was considerably weaker ($r = 0.56$). A detailed study of climatic effects (D. S. Jackson, pers. comm.) showed wood density to be positively correlated with late summer and autumn temperatures. Summer and autumn rainfall also contributed to higher densities.

Altitude and latitude have been shown to have a strong influence on wood density in New Zealand (Harris, 1965). Outer wood density decreases with increasing latitude at a rate of about 10 kg/m^3 per degree and with increasing altitude at about 15 kg/m^3 per 100 m. Between the extreme northernmost sites (35° S) and extreme southernmost sites (46° S) there are differences in density of 25 to 30%.

Like climatic factors, the nutrient status of the soil is an important variable which can affect wood density. Forest sites deficient in nutrients are uncommon in New Zealand, but a prime example is Riverhead Forest in Auckland Conservancy where trees can stagnate and die owing to lack of phosphorus. On sites of low natural fertility, such as occur in parts of Nelson Conservancy, deficiencies can be exaggerated by poor management. Cown (1972a) found that some of the symptoms attributed to deficiency (Appleton and Slow, 1966) are a direct result of over-stocking.

The radial variation in wood density on mineral-deficient sites differs from that on other soils in that there tends to be a very rapid increase from the pith outwards for about 10 growth rings (Cown, 1972b). Figure 2a demonstrates this while Fig. 2b shows the effect on the diameter/density relationship. Produce from deficient sites tends to be of high density owing to the longer rotations required to reach a given size (in the absence of corrective treatment) and the higher corewood density levels. Differences of up to 20% in mean density might be expected between final crop trees on deficient and "normal" sites.

Silviculture

Several studies have investigated the effects of silvicultural treatments on wood density in New Zealand (Cown, 1971, 1972b, 1973a, b; Sutton and Harris, 1973).

Growing space and wood density have been shown to be only weakly related within normal limits of growth. Wide planting and thinning can both contribute to temporary production of lower density wood, but over the length of a rotation this effect is minimal. Their greatest influence on density is an indirect one arising from a shortening of the rotation age. It has been calculated (Cown, 1973b) that a crop grown to a dbh of 400 mm in 25 years will have a mean density of 8 to 10% lower than an unthinned crop reaching the same size over 35 years.

Under intensive silviculture the effects of pruning on timber grades will more than compensate for any loss in clear timber

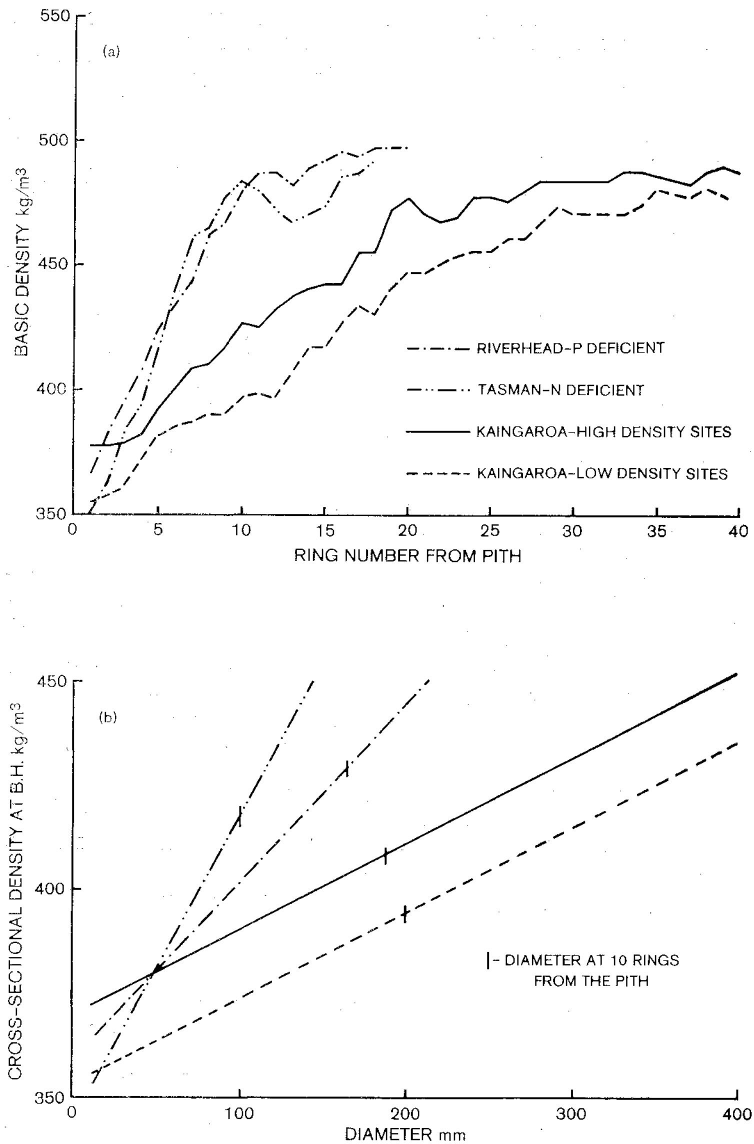

FIG. 2: *Density trends at breast height and their effect on the density/diameter relationship.*

strength within the pruned zone. Severe pruning also tends to promote slightly higher density wood for a few years immediately after treatment, but this has a negligible effect on tree mean density (Cown, 1971, 1973a).

The effects of fertilizers on radiata pine wood density have been exetnsively studied on naturally deficient sites. It has been demonstrated that, where volume increment has been significantly increased, there is often a temporary decrease in density of up to 10% (Harris, 1966b; Cown, 1972a, b; and unpublished data). It appears that the effect of fertilizers is to reduce wood density to the level which would be expected on non-deficient sites.

The results of trials in which more than one stem level was sampled indicate that the effects of silvicultural treatments on wood density are greatest in the lower stem and may be negligible within the crown (Cown, 1973a, b).

Genetics

It was mentioned earlier that wood density in radiata pine is extremely variable within stands, and this variability is maintained under different site and silvicultural conditions. The extent to which the observed values can be attributed to inheritance depends on the influence of environmental factors within crops. Growth rate and wood density are not closely related (Harris, 1965) and thus local environment is unlikely to have much effect on density.

Recent work has shown that inheritance of wood density in radiata pine is very strong (Shelbourne *et al.*, 1972; Burdon *et al.*, 1972). Shelbourne *et al.*, predicted that corewood density could be increased by 15% by selecting phenotypes at an intensity of 1 in 10 followed by progeny testing and reselection of the best 10% of clones. Greater gains could be achieved by selecting more intensively.

The relationship between corewood and outer wood density levels within individual stems is not strong (Harris, 1965), so that selection for high corewood density would not necessarily result in correspondingly high outer wood values. Increase in corewood density might nevertheless reduce extreme radial density gradients.

DISCUSSION AND CONCLUSIONS

A disadvantage of wood as a raw material is its extreme variability compared with man-made competitors such as steel, concrete, and plastics. Most of the inherent variation in properties arises from a combination of the within-tree pattern of density development and the large between-tree component. Any reduction in the total variation could increase the cost-effectiveness of the timber industry.

The effects of climate and site cannot be controlled, so that manipulation of wood density in tree crops must be through either silviculture or selective breeding. Radiata pine silviculture in New Zealand is geared to producing large volumes of timber economically from short rotations, and does not allow sufficient flexibility for control over wood density. Even if a small degree of control were possible by employing different treatments, this would not alter the between-tree variation present.

Work in New Zealand has shown that wood density of radiata pine is highly heritable and that very significant changes can be brought about by intensive selection of desirable phenotypes. An increase in corewood density would be far more effective in upgrading quality than improvement in outer wood density, and this could have the additional benefit of reducing within-tree variation. However, the desirability of including wood density in tree improvement programmes depends on economic considerations and the current priorities given to stem form and vigour rule out the possibility for some time to come (I. J. Thulin, pers. comm.). Selection for wood density could only be justified in the case where there existed a single end use for radiata pine timber with stringent wood quality requirements. So far, this situation has not arisen in New Zealand.

In the foreseeable future, it is more likely that progeny in breeding trials will be screened for undesirable rather than desirable wood properties, and a small proportion rejected on this basis, if necessary. Thus conventional seed improvement methods offer little scope in the alteration of wood density.

The increasing use of rooted cuttings, on the other hand, does present a good opportunity to manipulate wood density, since the total genetic variance can be exploited and because clonal material exhibits maximum uniformity in properties. Selection of parents with high-density corewood would result in progeny with superior strength properties, minimal between-tree variation, and possibly reduced within-tree variation. It will, however, be several rotations before vegetatively reproduced plants make up more than a minor part of the annual planting programme (Thulin, 1969).

The current economic constraints on the flexibility of silvicultural and tree breeding methods mean that the forester can do very little to influence the intrinsic properties of radiata pine such as wood density. In integrated industries where uniformity of the raw material is preferred, traditional or improved methods of log segregation will remain an important part of the process. The development of new techniques for detecting defects in round timber could increase the efficiency and quality of log conversion, and the practice of stress-grading can go a long way towards ensuring uniformity of strength properties in sawn timber.

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