

# IMPROVING LOG AND WOOD QUALITY: THE ROLE OF THE RADIATA PINE IMPROVEMENT PROGRAMME

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## ABSTRACT

*Tree improvement of radiata pine has emphasized improvement in tree health, growth rate, stem form, and log and wood quality. Increased growth rate and better stem form will significantly increase profitability through reductions in growing costs and increases in piece size, but timber in knotty pine grades will increase at the expense of a reduction in clear-cuttings grades. Recognition of the risks and uncertainty associated with the prediction of market niche and price premiums for 30 years in the future supports the use of a simple, flexible tree improvement strategy.*

The tree improvement programme at the Forest Research Institute aims to improve the profitability of growing and processing wood from New Zealand's exotic forest plantations. Most of the research effort goes into the improvement of radiata pine, although work continues in the evaluation and genetic improvement of many other timber species.

Since the main reason for growing radiata pine in New Zealand is to make a profit from the sale of wood, tree breeders need to know the extent to which genetic improvement in log and wood quality can be profitable and should be pursued relative to other important objectives. An important corollary is the need to know which log and wood characteristics to improve, and to obtain some indication of their relative importance to the wood-using industries. In this paper I will outline the present strategy for the improvement of radiata pine, and proposals for a future strategy.

## THE RADIATA PINE IMPROVEMENT PROGRAMME Selection and Seed Orchard Establishment

Radiata pine has been grown in New Zealand for over 100 years, but intensive improvement work only began in the early 1950s with a very intensive selection of good trees in a wide-ranging survey of existing New Zealand forest stands. The emphasis in this early selection was placed on improvement in growth rate and stem form (i.e., bole straightness and light, wide-angled branching) and lack of stem cones on the lower stem. The first seed orchards were established with grafts of 15 to 25 of these selections<sup>1</sup>; since this is probably around the minimum safe number of tree genotypes necessary to avoid inbreeding in the orchard, it was possible to remove only a few of the poor parent trees on the basis of performance testing of their progeny.

The purpose of clonal seed orchards is to allow us to translate the genetic improvement (or 'gains'), from both initial selection and from selection based on progeny testing, into trees in the forest. If the seed orchards are well isolated from outside radiata pine pollen, then orchard seed will be the product of matings among improved trees only. When the orchard's seedling offspring are established in forest stands, they should exhibit genetic superiority inherited from both pollen and seed cone parents.

A second round of plus-tree selection in unimproved stands was

## OBJECTIVES OF THE FOREST RESEARCH INSTITUTE TREE IMPROVEMENT PROGRAMME IN RADIATA PINE.

- \* To ensure that improved trees have the necessary adaptability and health for successful establishment and growth on the sites available.
- \* To improve tree growth rate and stem form in order to reduce silvicultural, management, and harvesting costs and increase the profitability of growing a timber crop.
- \* To improve log and wood quality for a wide range of wood-based end products, including sawn timber, pulp and paper, and composite wood products.

undertaken in the late 1960s, and this time provision was made for applying the results of performance tests using seedling progeny. In this less-intensive selection 588 trees (or 'clones') were brought into the progeny-testing programme, but only the best 78 were retained in clonal seed orchards<sup>2</sup> after initial evaluation of their progeny. As additional progeny test information comes in, the numbers of clones in these seed orchards will be reduced to about 30 of the best of the original selections. Application of intensive re-selection in the progeny-testing phase of this second selection programme has yielded increased genetic gains relative to those achieved in the first selection.

## Short Versus Long Internodes

Selection criteria in the second selection programme were essentially similar to those in the first, except that greater emphasis was placed on a multinodal branching habit (Fig. 1). A smaller separate selection operation (of 104 clones) carried out in 1970 placed major emphasis on the alternative option of increasing the length of internodes between branch whorls — with the objective of increasing the proportion of clearcuttings grades of sawn timber output. A separate orchard has been established with the best 20 progeny-tested clones of this "long-internode" breed.

## Seed Production

Existing clonal seed orchards have been supplying commercial quantities of seed in increasing amounts since 1968. By 1990 the total New Zealand requirement for radiata pine seed (currently about 5000 kg/year) will be met from about 500 ha of clonal seed orchards. Assuming an average forest rotation of about 30 years, this means that genetically improved trees will be harvested in increasing quantities from about the turn of the century onward. By about 2015 wood from improved trees will form the predominant portion of the exotic forest resource.

## Long-term Breeding

The establishment of clonal seed orchards with highly selected progeny-tested clones is not an endpoint to the tree improvement

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<sup>1</sup> These orchards contain clones of the 850 series, and are referred to as "first orchard" in later discussion.

<sup>2</sup> These are referred to subsequently as "second orchard", and clones are of the 268 series.



Fig. 1 — Long and short internode radiata pine (BW 19166/67 Hemming)  
 L = a 2.2m internode (of clearwood) on a typical long-internode tree  
 S = a 0.5m internode on a typical short-internode tree

programme. The best of the progeny-tested trees are artificially mated with one another to generate a progressively improved breeding population. From predictions based on quantitative genetic theory, this 'recombination' and selection step is expected not only to accumulate favourable genes from both parents but also to increase the frequencies of such genes further by selecting the very best of the offspring. The improved population becomes the basis for a further round of plus-tree selection and progeny testing, in a method known to breeders as "recurrent selection". Second-generation selections have only recently been used in seed orchards, giving some idea of the long time periods involved in both the reproductive cycle of the species and in adequate evaluation of candidate trees in progeny tests. Although it will be 2030 and beyond before the offspring of most second-generation trees find their way into the New Zealand wood-using industry, the decisions regarding their genetic makeup must be made today.

#### Selection Criteria

A basic tenet of the use of selection in crop improvement programmes states that the number of selection traits emphasized should be small: the greater the number of different traits selected for, the smaller the genetic improvement in any one trait. As will be discussed, selection traits are not often independently inherited. The effect of the trade-off (in terms of number of traits selected for) is minimized when traits are favourably intercorrelated, but it is greatly exacerbated when the correlations are adverse. Therefore, the choice of selection traits is the most important decision in a tree improvement programme, either for ranking clones for seed orchard use or for ranking parents of the next breeding

population. The main emphasis in radiata pine improvement in New Zealand has been placed on six selection criteria:

- \* **Growth rate** — either for increased timber volumes and/or piece sizes (relative to unimproved stands) by a given forest rotation age, or for the same volumes or piece sizes yielded in a shorter rotation.
- \* **Stem straightness and No forking** — to increase the frequency of acceptable crop stems for pruning, leading to silvicultural cost savings in the establishment, pruning, and thinning operations (since fewer trees need to be planted and tended to obtain the necessary final crop numbers). Improved tree form of the final crop component also increases the yield of merchantable and premium grade timber relative to the total wood yield and reduces logging and processing costs.
- \* **Disease resistance** — to reduce volume growth losses resulting from needlecast diseases, thereby allowing trees to maintain normal timber yields on forest sites where disease hazard is high, with reduced costs of fungicide spray.
- \* **Branching habit**
  - (a) **Multinodal** — which leads to some reduction in knot size and an increase in yields of premium knotty pine timber grades; **or**
  - (b) **Long internodes** — which lead to an increase in knot sizes and an increase in yields of clearcutting grades of timber, independent of pruning.
- \* **Wood density** — for increases that will lead to improved yields of pulp (in relation to transport and pulping costs) and improved strength and hardness of sawn timber.

Improved stem form contributes most heavily to savings in silvicultural and establishment costs over the first 10 years of the life of a forest stand. Improved disease resistance has a similar impact on timber yields to improved growth rate, since it avoids the reduction in merchantable timber yields caused by disease. Reduced knot size (multinodal trees) and increased clearcuttings (long-internode trees) are factors of log quality that should attract price premiums when the logs are sold. Similarly, increases in average wood basic density should lead to higher dollar returns at the time of sale from the higher pulp yield/digester volumes and yields of stress-graded sawn timber that should result. Thus, selection criteria differ in their relative importance over the establishment, tending, harvesting, and marketing phases of wood production.

## IMPACT OF GENETICALLY-IMPROVED TREES ON FOREST GROWERS AND ON THE WOOD-USING INDUSTRY

### Predicted Changes in Log and Wood Quality

In what ways will the "brave new wood" from stands of seed orchard progeny differ from the product of unimproved stands under similar management? The full realization of genetic improvement will only be expressed in well-managed stands in which establishment and tending operations are carried out efficiently and at the appropriate time. Changes in log and wood quality of our first orchard stands may be barely discernible at the mill, although we predict a significant reduction in growing and harvesting costs, and higher merchantable timber volumes at the forest gate. For instance, gains in improved stem form mean that the costs of planting and tending first orchard stands will be considerably reduced if fewer stems are planted. Savings of between \$100/ha and \$200/ha in establishment and tending costs can be achieved for first orchard stands grown to clearwood regimes simply by lowering the initial to final crop stocking ratio from 5:1 to 4:1 (Carson 1986). Increases in merchantable volumes for first orchard stands under clearwood regimes may be in excess of 8% (Carson 1986). Production thinnings from first orchard stands have yielded a 12% increase in average piece size in one study (Cleland, 1985). A small reduction in mean internode length and in average knot size may affect percentages of framing and clearcutting grades of sawn timber to a minor extent. More disturbing is a predicted 5-15 kg/m<sup>3</sup> (C. Shelbourne, unpubl. data) decrease in average wood density, which will be additional to the 25 kg/m<sup>3</sup> decrease predicted by Cown *et al.* (1984) for the transition from the 'old crop' of radiata to the younger wood of 'new-crop' trees during the 1990s. Thus, wood of the first orchard crop cannot be expected to be of much improved *quality*, but it can be grown at lower *cost* to the forest owner.

As the second orchard product comes on stream, the effects of genetic changes will become much more evident. Silvicultural costs should be much reduced, forest rotations may be shorter by two years or more for equivalent volumes of timber, and many more logs of the "short-internode" type will be produced because of the emphasis placed on multinodality in selection. The effects of the first two factors should lead to substantial profits for the forest owner. Further silvicultural cost savings of between \$100/ha and

\$200/ha would result from using a 3:1 initial/final crop stocking ratio for second orchard stands, and volume increases in excess of 15% (over unimproved material) may be obtained for stands grown under clearwood regimes (Carson 1986). Wood basic density of the second orchard progeny will be closer to that of unimproved trees than the wood of the first orchard trees. There should also be moderate gains in resistance to the two major needlecast diseases (*Dothistroma pini* and *Cyclaneusma minus*). However, the greater number of logs of the 'short internode' type produced by second seed orchard stands will lead to significant changes in their sawn timber grades from the unpruned logs.

In order to predict sawn timber grade percentages for the unpruned logs using internode length data simulating a comparison of second seed orchard progeny with unimproved trees, I used the PREVAL component of the Silvicultural Stand Model (SILMOD). SILMOD was developed by the Radiata Pine Task Force to assist managers with comparisons of silvicultural alternatives (Whiteside and Sutton 1983). Results of sensitivity analyses using SILMOD are subject to numerous stated and unstated assumptions, and must be interpreted with care. For a central North Island direct sawlog regime with logs processed for maximum value, PREVAL predicted a drop from 15% to 5% in the percentage of clearcuttings grades of timber produced from unpruned logs of second seed orchard stands, and compensating increases in percentages of the knotty timber grades (Table 1).

What will be the forest industry's reaction to large decreases in relative yields of clearcuttings grades and increases in yields of knotty timber grades? There could be increased price premiums in the future for sale of timber in clear and clearcuttings grades relative to knotty grades. New Zealand Forest Service silvicultural policy is now heavily committed to the production of clearwood from large pruned logs grown under direct sawlog regimes, with the expectation of getting additional clearcuttings and knotty wood products from the unpruned logs. Why has the tree improvement programme given the industry trees with much reduced yields of clearcutting grades? There are two main reasons which are closely intercorrelated: knot size versus number of branch clusters and branch habit versus tree form and growth rate.

### Knot Size versus Number of Branch Clusters

It was discovered quite early in tree improvement research that the heritability (or the extent to which parental traits are passed on to their offspring) of branch cluster frequency is high, and therefore is easily amenable to genetic alteration. It also became evident that an increase in the number of branch clusters on the stem is accompanied by a reduction in average branch size, which could in turn lead to a reduction in knot size in the timber product. The stronger emphasis on multinodality beginning with the plus-tree selection of the 1960s was a response to an expressed preference by some end-users for a reduced knot size in framing timber and pulpwood products (see Proceedings, Improvement of *Pinus radiata* Symposium, FRI, 1966). Work of the Radiata Pine Task Force has since shown that branch size is mainly influenced by environmental factors, including both soil fertility and tree spacing. However, there is some evidence for significant additional control of branch size for multinodal trees.

**TABLE 1** — Effects of altered branching habit on sawn timber grade outturn of a direct sawlog regime grown in a Central North Island forest — rotation age 30, as predicted by PREVAL (adapted from Carson, 1987).

Tree type	Sawlog volume	Clearcutting grades		Timber grade percentages for unpruned logs <sup>1</sup>				Boards
		No. 1 cuttings	Factory	No. 1	All	No. 2	Box	
				Framing	Premium <sup>2</sup>	Framing	Framing	
Unimproved	569	4.4	10.4	19.5	34	29.6	29.1	7.0
Multinodal	569	1.0	3.8	27.5	32	34.6	25.0	8.1

<sup>1</sup> Logs are sawn for 'maximum value', and the timber price list ranks grades in order of (decreasing) value as follows: No. 1 cuttings > No. 1 Framing > Factory > No. 2 Framing > Box Framing > Boards.

<sup>2</sup> 'Premium' grade percentages are the sum of 'No. 1 cuttings', 'Factory' and 'No. 1 Framing' grades.

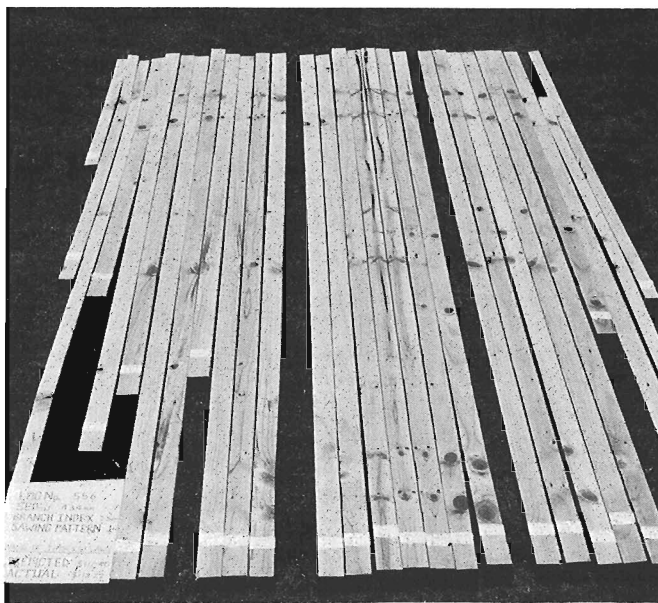
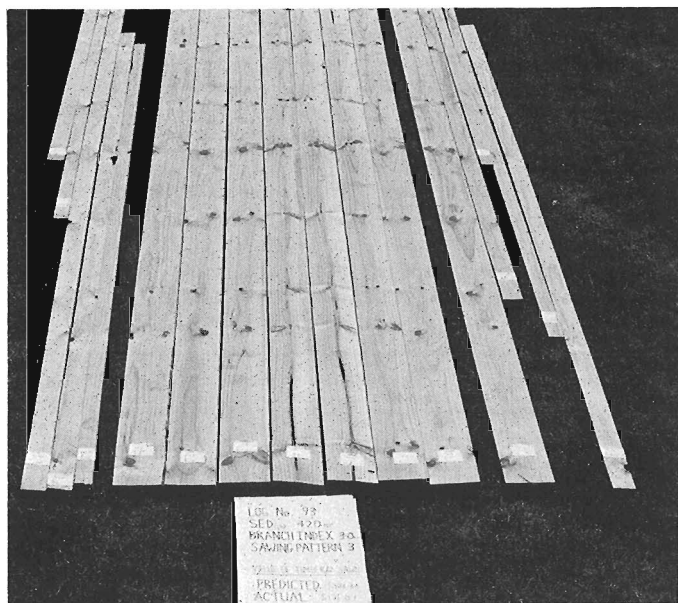


Fig. 2 Internode length changes timber grades. On left, short internodes, and on right, long internodes.

### Branch Habit versus Tree Form and Growth Rate

Another clear finding from tree improvement research is the existence of moderate-to-strong genetic correlations between branching traits and other important selection traits. Stated simply, two traits are genetically correlated if genetic change through selection for one trait tends to be accompanied by genetic change in a second, unselected trait. In radiata pine there are favourable genetic correlations between improved growth rate, stem straightness, the absence of forking, and a multinodal branch habit; the correlations are favourable in the sense that improvement in any one of these traits will assist improvement in all of the others. As might be expected, a less multinodal branch habit will be unfavourably correlated with these other traits, implying that any attempt to increase internode length tends to be accompanied by decreased growth rate and inferior stem form. In the main radiata tree improvement programme the 'easy option' has been taken of emphasizing the favourably correlated traits: improved growth rate and stem form, and a multinodal branching habit. Since there is also an unfavourable genetic correlation between improved growth rate and increased wood basic density, the emphasis on growth rate improvement has been at the cost of the ability to improve wood density.

Genetic correlations may be overcome through careful selection and breeding. Trees with long internodes and high wood density as well as acceptable growth rate and stem form can be provided by the tree improvement programme. However, in attempting to increase wood density and internode length it must be recognized that, for a similar expenditure of resources, ignoring these traits and favouring only growth and form traits would yield bigger and better-formed trees.

Thus, the existence of unfavourable genetic correlations among selection criteria makes knowledge of their relative importance critical to tree improvement strategy.

### BREEDING OPTIONS

#### Potential for Specialization of Radiata Pine Breeds

For improving radiata pine in New Zealand we have two alternative approaches. The approach to date has sought the compromise solution of providing good general-purpose timber from trees that will yield increased profits to the forest owner. If research into processing and marketing options identifies a clear need either for increasing clearcuttings grades of timber or for increasing basic wood density, then we can make some progress toward these objectives also in the 'general-purpose' breed of radiata pine. Initial gains in these traits will be moderate at best relative to gains in

growth rate and stem form traits, but breeding work should lead to greater gains in the more distant future. One way in which we could increase clearcuttings from the 'second orchard' breed above that predicted earlier would be to cull extremely multinodal clones from some of the existing seed orchards. This action, if taken now, would increase the yields of clearcuttings grades that I predicted earlier for the direct sawlog regime.

Recently we have started to explore the second alternative, which is to place selection emphasis on just one 'special-purpose' trait, while accepting limited gain in other selection criteria. Although we can probably afford to retain more than one special-purpose breed, it must be clear that the more options we pursue, the greater is the cost of resources expended. Large gains in internode length are expected from progeny of a seed orchard of long internode clones. We are currently well placed to advance a special-purpose breed for increased wood density, and we are also about to plant an orchard of clones with improved resistance to the needle blight *Dothistroma pini*.



Fig. 3 Controlled pollination at Amberley seed orchard to produce large quantities of seed of known parentage (photo FRI).



## Impact of New Techniques of Plant Multiplication

Recent development of techniques for mass propagation of young pine seedlings should facilitate production of a wide range of radiata breeds with special characteristics. Using techniques of controlled pollination on a large scale (Fig 3) it is now possible to produce moderate quantities of seed of known parentage; by intensive selection of both parents for a special-purpose trait much larger gains are possible than can be obtained from the progeny of a conventional clonal seed orchard. New techniques of multiplying seedlings as 'nursery cuttings' will extend the control-cross seed, enabling large areas of forest to be planted to one special-purpose product. The application of both mass control-pollination and nursery cutting techniques should be a much more flexible, cost-effective option than is the traditional clonal seed orchard approach for producing special-purpose trees. These techniques will be equally effective in capturing the genetic gain available from the very best crosses among general-purpose trees. Control of the pollen parent removes the risk of 'foreign' pollen contaminating a poorly isolated orchard and prevents inbreeding within the orchard, leading to greater realization of genetic gain.

## ROLE OF LOG AND WOOD QUALITY IMPROVEMENT

To turn again to the title of this paper, we must ask what is the role of the tree improvement programme in terms of improving log and wood quality.

\* *Genetic improvement gained from the existing programme will benefit forest owners in terms of lower growing costs.* However, we do not know what prices the wood-using industry will pay for the **quality** of the wood product, or indeed whether all the wood produced will find a market.

\* *Log and wood quality traits are much more strongly influenced by silviculture (e.g., choice of site, pruning, thinning, rotation length) than by genetic manipulation.* Silvicultural manipulation can be used either as an **alternative** to genetic manipulation (e.g., lengthening the rotation to increase average wood density), or to **complement** genetic manipulation (e.g., late thinning of stands of multinodal trees to obtain additional control of branch size in unpruned logs). The impact of genetic changes in log and wood quality could be minimized (or negated) by inappropriate silvicultural decisions.

\* *Special-purpose breeds need specific planning and silviculture if maximum genetic gains are to be achieved.* Using the example of our existing long-internode breed, appropriate silviculture might include choosing sheltered, fertile sites, relatively high (e.g., 6:1) initial to final crop stocking ratios (to allow adequate culling of poorly-formed trees), pruning to only 2.4 m height (since trees of the long-internode type begin producing long clears from about height 3 m in most forecasts), and delayed final thinning (both to obtain some control of upper log branch size and to allow for an effective silvicultural selection of trees with long internodes).

Forest planning, management, harvesting, and wood processing will need to reach a high level of co-ordination and sophistication if genetic improvement in log and wood quality traits of special-purpose breeds is to be realized in the harvested wood. There will be additional costs to the forest grower and wood user in attaining these desired goals.

\* *Most forest owners may prefer to plant general-purpose radiata pine breeds.* It is likely that few special-purpose breeds will be used in future owing to:

- uncertainties about the existence of future markets for wood of specific quality, given the effects of competition from other suppliers, and the possibility of product and substitution, **and**
- uncertainties about the size of wood price margins (or stumpages) paid to forest owners, who will be the principal risk-takers.

## IMPLICATIONS AND CONCLUSIONS FOR A TREE IMPROVEMENT STRATEGY

If prediction of markets for forest products 30 to 40 years hence is characterized by such high risk and uncertainty, what form should our tree improvement strategy take?

1 **There need be only a few special-purpose radiata breeds:** It has recently been decided to follow a simple approach of concentrating effort on a few options that offer high potential returns (Shelbourne *et al.* 1986). The option of growing stands for high percentages of clearcuttings will be accommodated by the long-internode breed. Trees for forest sites with particular limitations (e.g., high risk of *Dothistroma pini* defoliation) or for situations requiring emphasis on wood quality traits (e.g., high wood density), can be easily obtained from subdivisions of a versatile general-purpose radiata pine breed. The main principle being followed in this strategy is to build on the substantial gains already made in improved growth rate and stem form traits each time a breed for special-purpose use is created.

2 **The main plank of the tree improvement programme will continue to be a general-purpose radiata breed:** The second orchard breed offers a tree type with wide site tolerance, superior vigour and stem form, and moderate resistance to the two major needlecast diseases. It will be suitable for most silvicultural regimes requiring high yields of either pruned clearwood, or structural timber grades (including housing poles). It will assist in improving the quality of pulpwood obtained from most silvicultural regimes. Future breeding in the general-purpose breeding programme will concentrate on continued improvement in the tree health, growth rate, and stem form characteristics of the second orchard breed, while not allowing average wood density to decrease.

3 **Great additional flexibility is possible in future breed production options by placing major emphasis on developing the techniques of controlled pollination and subsequent vegetative multiplication:** These techniques will enable cuttings of a new breed to be deployed within as little as five years of identifying a demand for it, whereas the conventional seed orchard approach would take a minimum of about 15 years to provide an equivalent number of seedlings. Flexibility will be further increased through the development of quick screening techniques, in order to avoid the long delays involved in the field testing phase of breed production.

In conclusion, the strategy for the continued improvement of radiata pine should rely on both simplicity of objectives and flexibility of operations to meet the challenge of supplying trees for future forests. Genetic manipulation of the species to supply markets for specific log and wood quality traits, although important, is likely to remain secondary to the objectives of improving tree health, growth rate, and stem form. However, early identification of market trends will greatly assist effective planning of the tree breeding programme.

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