# GENETIC IMPROVEMENTS FROM A RADIATA PINE SEED ORCHARD

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ABSTRACT

Three yield trials now 10 to 12 years old have shown that Australia's first radiata pine (**Pinus radiata** D. Don) seed orchard has produced genetically improved stands. Orchard seedlots produced about 20% more total wood volume, with about twice as many trees of excellent stem and branch quality, than a control seedlot representing not only the population from which the trees in the orchard were selected but also typical commercial seed of the 1960s.

## INTRODUCTION

The suitability of radiata pine for industrial forestry is attested by its planting on more than 2 million ha in New Zealand, Chile, Australia, Spain, and South Africa, supporting the manufacture of many wood-based products. Among the softwoods planted as exotics it probably has the largest plantation area.

Although radiata pine grows useful wood quickly on a range of sites, nevertheless it has a number of imperfections: it has a tendency to fork, many trees are crooked, the branches are often steep, thick, and long, and nodal swellings are common on the first 2 or 3 m of stem. All these deficiencies are exaggerated when initial spacing is wide. The corewood, which has a large gradient in density from pith to about the tenth ring, is too weak for some structural uses and for some grades of paper.

Many of these deficiencies can be improved by the skilled silviculturalist's adjustments of initial stocking, pruning, thinning, fertilising, choice of site, and age of felling. For further improvement, such as better branching on widely spaced trees, and for the control of those pests and diseases for which spraying or biological control is not possible, an obvious solution is breeding of genetically improved varieties.

The main request from forest managers to radiata pine breeders has been for improved stem and branch quality. Managers have given lower priority to wood quality but this attitude would soon change in the face of a glut of radiata pine, when manufacturers could demand wood with the qualities best suited to their requirements. There would then be pressure on tree breeders to give higher priority to wood quality.

This paper gives results achieved in radiata pine breeding in Australia in the last 25 years, illustrated by the genetic improvement obtained from the earliest clonal seed orchard.

## TALLAGANDA SEED ORCHARD

Australian research on genetics of radiata pine started in 1938 when M. R. Jacobs established trials in which rows of plants grown from cuttings from several trees were compared (Jacobs 1939). The genetic variation demonstrated in these trials (Fielding 1953) led J. M. Fielding and A. G. Brown to commence a practical breeding programme in the early 1950s. In 1957 they established the Tallaganda seed orchard with the co-operation of the Forestry Commission of New South Wales (Fielding 1964; Brown 1971).

The Tallanganda orchard was the first radiata pine seed orchard in Australia and one of the first of any tree species in the world. The orchard was planted at 6.1 × 6.1 m with 1020 grafts or rooted cuttings of 30 plus-trees. These trees had been selected for their large size, straight stems, and good branching habit in plantations more than 20 years old near Canberra. The orchard occupies an area of 4 ha well isolated from other radiata pine.

Seed collections commenced in 1966 and since then more than 1000 kg of seed has been harvested and used to plant nearly 10 000 ha of plantations near Canberra, Bombala, and Tumut. Wood grown from Tallaganda seed is now reaching pulp mills as first thinnings.

### Trials of Tallaganda Seed

Three trials planted near Canberra in 1969, 1970, and 1971 are now old enough to give an indication of the improvement to be expected at harvesting age from the use of orchard seed. These trials meet a number of important requirements: (i) the designs are statistically adequate to detect small differences, (ii) there was minimal variation in nursery and establishment conditions, (iii) the seed came from an orchard old enough to provide a normal commercial seedlot, (iv) there is an appropriate control seedlot, (v) at the time of assessment the trials were old enough to permit the results to be related to rotation age with reasonable confidence.

The 1969 trial is on deep sand at Jervis Bay and the other two are on clay loam at Tallaganda State Forest. Details of the trials are given in Table 1. In each trial trees raised from commercial-scale seed collections at Tallaganda seed orchard (the "orchard" seedlot) were compared with trees raised from seed from 200 randomly chosen, seed-bearing trees in 7-year-old Canberra plantations. This "control" seedlot represents not only the population from which the trees in the orchard were selected but also much of the Australian commercial seed of the 1960s. Seed of similar genetic quality, or worse, is still being used for some Australian plantations.

### Genetic Improvement Achieved

*Growth:* The plots established from the orchard seedlot have grown faster than those from control seed (Fig. 1). Basal area is probably the best measure of the differences in growth because diameters of all trees were included in the calculation. (It was not practicable to measure the height of all 2000 trees in the three trials as many of the trees were over 16 m in 1981.) The improvement in basal area per hectare of orchard trees compared with the control was 22, 11, and 20% at 12, 11, and 10 years (Fig. 1).

TABLE 1—Establishment details of three yield trials near Canberra, comparing the orchard and control seedlings

| Trial number | 1049 | 1051 | 1052 |
|---|---|---|---|
| Location | Jervis Bay | Tallaganda | Tallaganda |
| Soil | deep sand | clay loam | clay loam |
| Rainfall (mm) | 1110 | 1240 | 1240 |
| Year planted | 1969 | 1970 | 1971 |
| Orchard age when seed collected (yr) | 10 | 11 | 12 |
| No. replicates | 6 | 14 | 80 |
| No. trees/plot | 100 | 72 | 5 |
| Initial stocking (stems/ha) | 1700 | 1900 | 1700 |
| Fertiliser* (g/tree) | 113 | 113 | 85 |
| Fertiliser (kg/ha) | 190 | 215 | 145 |
| Predominant height at 10 yr, all plots (m) | 12.6 | 13.4 | 12.2 |

* Fertiliser was a pelleted ammonium phosphate mixture ('15 30') containing N 15%, P 13%, K 0, S 10%.

Volume per tree was calculated based on a sample of tree heights in the two older trials and on all trees in the 1971 trial (No. 1052). Total volume per hectare was calculated from the diameter of all trees and predominant height. Improvement in volume per tree was 29, 9, and 25% respectively (Fig. 1) and in volume per hectare 22, 9, and 16%.

*Stem and branch quality:* The orchard seedlot also produced trees of better stem and branch quality than the control (Fig. 1). In each trial the trees were assessed for presence of forks, and scored for stem straightness and branch quality (score 1 to 5, 5 best). The proportion of trees with a score of 4 or 5 for both stem straightness and branch quality, free of forks, and of above-average diameter was determined. Such high-quality trees are sought when marking for thinning and retained for the final crop. The proportion of these good trees in the orchard plots (Fig. 1) was 7% in both the Tallaganda trials and 12% at Jervis Bay. The proportions in the control plots were 3, 3, and 7% respectively. (In general, tree form was better at Jervis Bay than at Tallaganda.)

*Wood quality:* The only measurement made yet in the field trials to determine whether wood quality of trees of orchard origin is different from that of controls was a preliminary estimate of wood density with a torsiometer (Nicholls & Roget 1977) which showed no significant difference between orchard and control in Trial 1052 at 8 years. Little difference is expected because selection intensity for wood properties of the original plus-trees was too low to be effective. Selection against low density high spiral grain, or short fibres was only by culling the worst tree in 10 for each character.

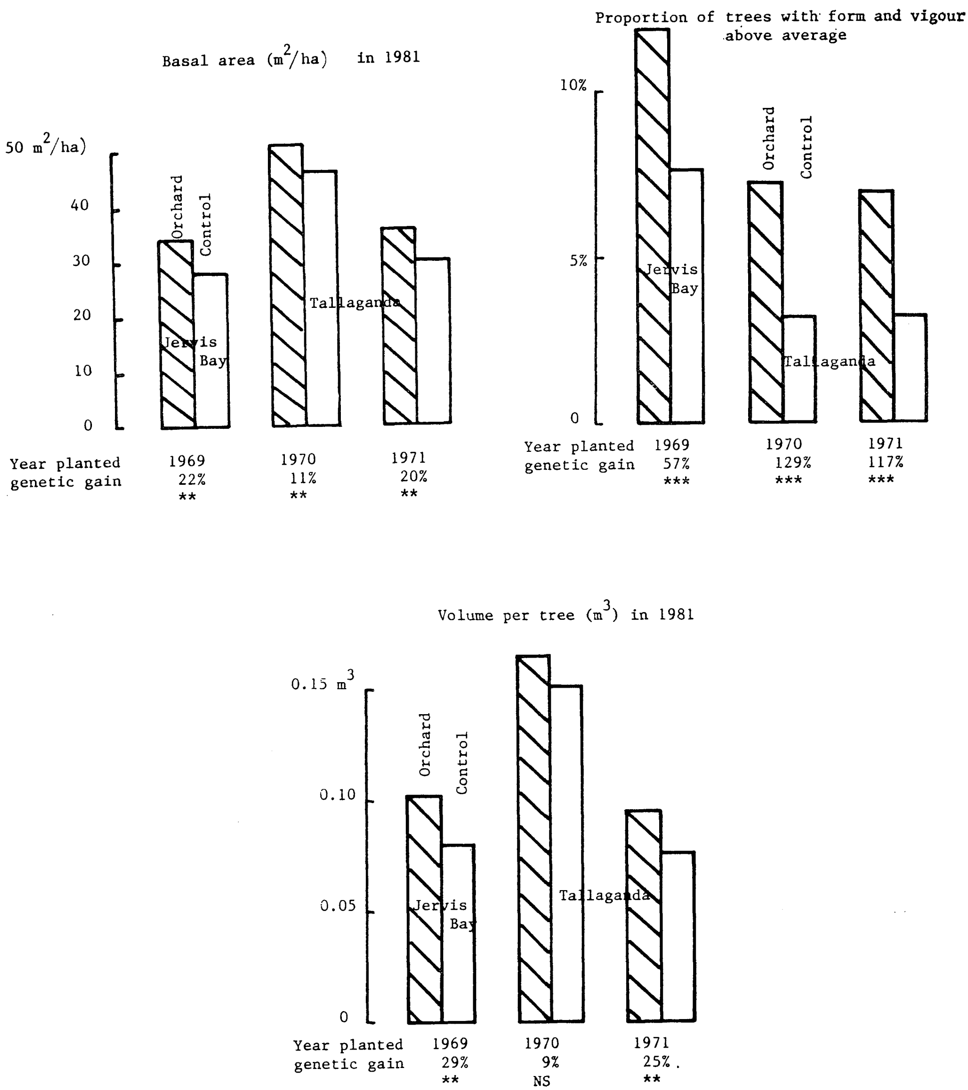


FIG. 1—Comparison of seed orchard and control seedlots in three yield trials, planted 1969, 1970, and 1971 at Jervis Bay and Tallaganda, showing the percentage genetic improvement in basal area per hectare, volume per tree, and proportion of trees with both excellent form and above-average vigour (*** p = 0.001; ** p = 0.01; NS not significant)

## DISCUSSION

The genetic improvement realised from Tallaganda seed is attributable to the relatively straightforward breeding method of intensive phenotypic selection of plus-trees followed by mating among the clones in the orchard. The differences between control and orchard seed are such that the initial phenotypic selection must have been effective in identifying superior genotypes.

The 4 ha of seed orchard at Tallaganda was followed by 340 ha of clonal orchards of similar design in other parts of Australia in the next 15 years.

The first yield trials to monitor progress in radiata pine breeding were established in 1965 near Traralgon, Victoria. Three control seedlots (two local and one New Zealand) were compared with an "orchard" seedlot, a mixture of several control-pollinated crosses of Golden Gully seed orchard clones. This mixture was used because the orchard did not produce seed in commercial quantities until 1968 (Pederick & Brown 1976). The trials are on two contrasting sites. One site has infertile sand and low rainfall and the other has relatively fertile clay loam and higher rainfall. After 15 years the trees from the orchard seedlot were superior in terms of volume and of stem and branch quality on both sites (J. N. Cameron pers. comm.).

In the two trials near Traralgon and the three near Canberra the growth advantage of the orchard seedlots has been maintained with age and in some cases increased. Several other Australian yield trials planted between 1969 and 1976 will be producing results in the next few years as they reach sufficient age (Pederick & Griffin 1977).

The upper limits to genetic improvement of radiata pine in the next few decades can be seen in some of the currently used plus-trees which are outstanding in several characters (Fig. 2). Growth rate will be improved only up to the limits set by availability of nutrients, water, and other environmental factors; even the narrowest crowned radiata pine is likely to grow long, coarse branches in the open; and a uninodal tree with small branches would not have enough needles to grow fast.

Given two or three more generations of selection and seed orchards, or a break-through in rejuvenation of old trees, whole forests of trees of at least the standard of the best of today's plus-trees could be obtained.

The quickest changes will be made with the help of mass vegetative reproduction, which offers much larger improvements in stem and branch quality than can be obtained from the first generation of seed orchards. However, despite successful planting of rooted cuttings in Australia and New Zealand for 40 years the technique has not reached commercial-scale application.

As well as the opportunity provided by vegetative propagation to mass-produce unusual individuals, an unexpected additional improvement has been found in an 8-year-old trial of cuttings from seedlings. In 1973 rooted cuttings from 2-year-old seedlings of crosses between plus-trees were planted for comparison with 1-year-old seedlings of the same families. In 1981 the growth rate of seedlings and cuttings was similar but branching of the cuttings was much superior. The additional improvement attributable to the greater physiological age of the cuttings compared with the seedlings can be appreciated by considering data for two characters listed in Table 2. The first three lines of Table 2 are from 8-year-old trees in Trial 1052 which contains 259

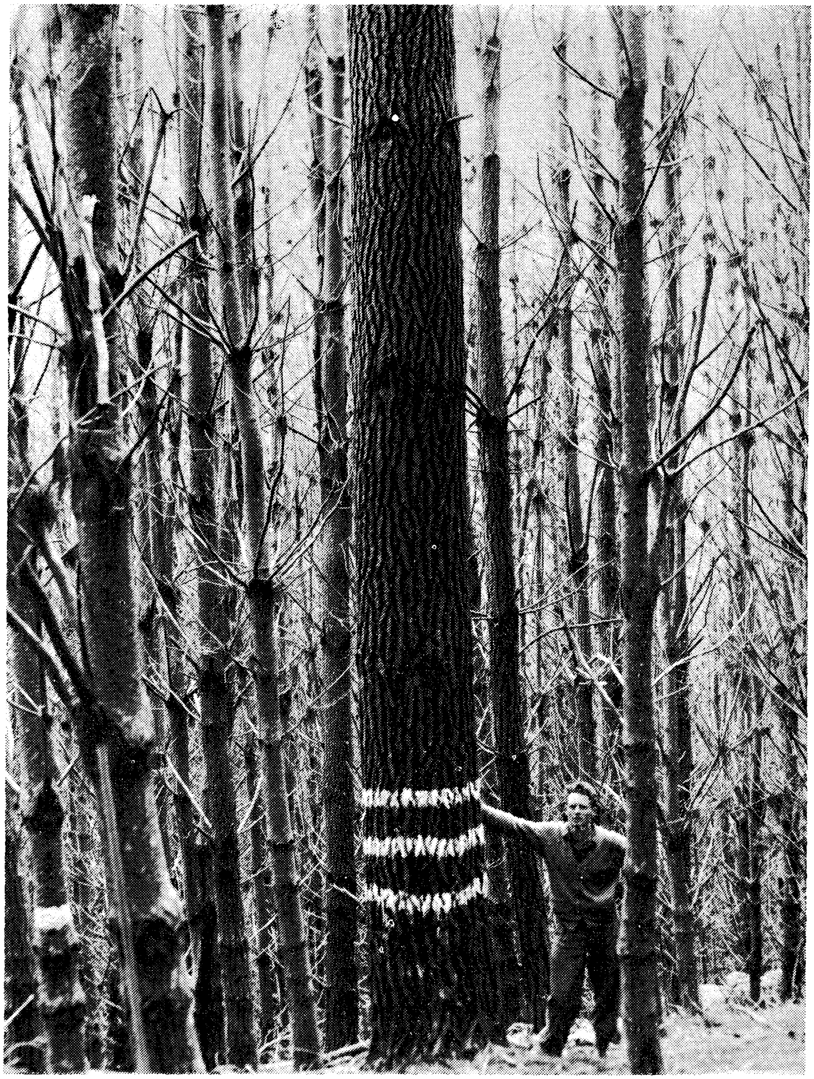

FIG. 2—One of the best plus-trees of radiata pine. It was selected in 1953 for outstanding vigour, straight stem, and light multinodal branching in a 1927 plantation of N.Z. Forest Products Ltd at Atiamuri. Height at 27 years was 41 m and diameter 69 cm. The average diameter of dominants in the surrounding 0.4-ha plot was 40 cm. Grafts of this tree are in several New Zealand and Australian seed orchards.

control-pollinated families as well as the orchard and control seedlots referred to earlier (Table 1). The last two lines of Table 2 are from 8-year-old trees in part of Trial 1063 planted at Tallaganda in 1973 with cuttings and seedlings of three families which performed well in Trial 1052.

TABLE 2—An example of genetic improvement achieved in number of whorls per year and in branch quality through seed orchard seed and cuttings

| Source of planting stock | Whorls/yr | | Branch quality | |
|---|---|---|---|---|
| | No. | % gain | Score | % gain |
| "Control" seedlings | 1.67 | 0 | 2.80 | 0 |
| "Orchard" seedlings | 1.70 | 2 | 2.98 | 6 |
| Control-pollinated seedlings, best 10% in Trial 1052 | 1.90 | 14 | 3.31 | 18 |
| Control-pollinated seedlings of three good families | 1.90 | | 3.30 | |
| Cuttings from 2-yr-old seedlings of the same three families | 2.30 | 38 | 3.67 | 31 |

The number of whorls of branches per year is an objective metric assessment. The branch quality score is a more subjective summation of angle, thickness, spacing, and frequency based on a 1 to 5 score, 5 being best.

Increase in number of branch whorls was only 2% through the seed orchard, 14% if only the best families were used, and 38% with cuttings. These cuttings have 2.30 whorls per year compared with 1.67 in the control. That more improvement is possible can be seen from the occasional tree in plantations with four whorls per year. Branch quality score improved by 6% through the seed orchard, 18% if only the best families were used, and 31% with cuttings. In spite of this improvement, some trees among the cuttings still had steep thick branches and there was room for further improvement.

It might be argued that fertilisers can produce greater improvement in growth or that genetic improvement is in the ability to tolerate Australia's impoverished soils. However, it should be remembered that the three trials near Canberra were fertilised and that genetic improvement was in addition to a response to fertiliser. Genetic improvements accumulate over generations and fertiliser responses do not. Furthermore, fertiliser costs increase in proportion to the area planted but tree breeding costs do not.

During the last 20 years about five professional and 10 supporting staff have been employed each year on radiata pine breeding and genetic research in Australia, approximately half of the time on practical breeding. Allowing A$100 000 as half the salaries of these 15 people at 1981 rates, plus about the same amount for overheads and materials, the annual cost of radiata pine breeding (excluding research) has been of the order of A$200 000 per year.

An adequate account of the cost-effectiveness of tree breeding requires more detailed analysis than will be given here. If the volume advantage of about 20% at 10 to 12 years persists to rotation age as 20% more harvested wood, the benefits can be considered as either:

(a) a larger harvest at the usual rotation age,

(b) the same yield from a smaller area, or

(c) the same yield from a shorter rotation.

In Australia about 70 000 ha were planted with orchard seed between 1970 and 1981. If these plantations are producing 3 $m^3$/ha/yr more wood (20% of 15 $m^3$/ha/yr) worth A$10/$m^3$ royalty, the current value of the extra growth would be of the order of A$2 million per year. The extra value increases each year as the proportion of the plantation estate planted with orchard seed increases.

In addition to the value of a larger total volume of wood, improved form is also valuable. Trees with straighter stems, better branching, and fewer forks will lead to the harvesting of a greater proportion of the total volume and less waste in the forest, cheaper delimbing and debarking, higher sawn recovery, and more of the higher-priced sawn grades. The sum of these small genetic improvements could approach the extra value of improved total volume.

However, the present seed orchard approach to genetic improvement seems unlikely to mass-produce seed to establish plantations of fast-growing, fine-branched, narrow-crowned trees until at least the third generation of seed orchards are in production, after the year 2010.

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