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Progressing Radiata pine breeding in Australia

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Abstract

Many factors affect the success of a tree improvement program with the most important being the breeding objective that aims to improve the profit of the forest enterprise. The STBA has developed new breeding tools for data management, and TREEPLAN® genetic evaluation, and is working towards capturing more innovations. The Juvenile Wood Initiative recognises that reductions in rotation length have an impact on the quality of wood produced and we aim to reduce the amount of juvenile wood produced in a tree and improve the quality of that wood. The Breeding Objectives project seeks to establish an economic index for radiata pine that is based on the traits that directly influence the profits of its industry members. Surveys conducted in individual STBA member companies are the bases of models that link biological traits with solid wood production systems to determine which traits have greatest influence on profit. Improved knowledge of genotype by environment interactions will be used to more accurately define regionalised production zones, so that differences in genotype performance between regions can be taken into account in TREEPLAN®. It is recognised that the ability to demonstrate realised gains in operational plantations is vital, although this can often be difficult. Recent results from a series of gains trials established across Australia and New Zealand in 1988 illustrate this point. The adoption of a dynamic rolling front strategy means that breeding values of individual genotypes will change from year to year as new data accumulates

Keywords: *Pinus radiata*, breeding strategy, TREEPLAN®, breeding objective, juvenile wood, realised gains, GxE.

Introduction

Growing radiata pine (*Pinus radiata*) in Australia has a long history with the earliest introduction of the species occurring in the early 1850s (Anon, 2005) with commercial plantings commencing in the late 19th and early 20th centuries in different states. In the 1950s separate breeding programs were developed by a number of state-based organisations although some early crossing efforts were achieved collaboratively through the Research Working Group body. These efforts culminated in the formation of The Southern Tree Breeding Association Incorporated (STBA) in 1983 as an industry body responsible for continuing genetic improvement of the species on behalf of four foundation members from the Green Triangle region in South Australia. Subsequently STBA membership has broadened to include organisations from across Australia and New Zealand. Currently the STBA has twenty members with ten breeding and five research members active in the radiata pine tree improvement program.

Many factors affect the success of a tree improvement program. One of the most important is the breeding objective which should aim to improve the profit of the forest enterprise. Site characteristics and management practices in combination with the economic and financial environments in which an enterprise operates will determine the optimal germplasm that should be deployed on a site or in a region. Different enterprises may require customised breeding objectives to ensure tree improvement and deployment decisions are optimal.

Breeding Strategy

The history of the radiata pine breeding strategy since the formation of the STBA has involved constant change and improvement, particularly over the last five years. In particular the STBA recognised it needed a set of technical tools for use in its tree improvement programs to overcome identified bottlenecks. With the increasing availability and wider use of BLUP-based software packages to perform genetic analysis and to predict breeding values (Jarvis *et al.* 1995) came a recognition of the difficulties associated with genetic analysis and management of a large number of progeny trials, particularly given the range of sites, pedigrees and statistical designs involved. Strategy revision and tool development in the STBA's radiata pine breeding program have taken place in parallel with its national program in *Eucalyptus globulus*. These tools have enabled the adoption of best practice genetic technologies resulting in more efficient and cost effective programs. However, tree improvement takes time and it will only be through a long-term commitment to breeding that full benefits will accrue to the STBA membership.

Tool development

There are three basic tools that are crucial to effectively managing an advanced tree improvement program. They are (i) a data management system, (ii) a genetic evaluation system, and (iii) a crossing and deployment management system. The STBA has recently developed and implemented data management (STBA-DMS), and TREEPLAN® genetic evaluation systems (Kerr *et al*. 2001, 2002; McRae *et al.* 2004). Coupled with these must be a commitment by industry to provide personnel and resources at a level that enables the operational work of a program to be fully effective. The STBA-DMS and TREEPLAN®, which have been running in a production environment for three years have both proven invaluable for managing the radiata pine genetic resource. The STBA-DMS efficiently manages progeny trial data, making information available across the internet for day to day management purposes and also provides structured data for genetic evaluation by TREEPLAN®. The STBA-DMS also holds the results from TREEPLAN® runs which are also available across the internet for use by STBA staff and member companies. A crossing and deployment management system has been identified as the next major requirement of the STBA.

Know your species.

Recently, Dr Bruce Zobel, when reviewing what is important in a breeding program stated that "knowing your species" is among the highest on the list (Zobel, 2004). While the STBA now has a suite of tools at its disposal, the benefits from their use will only be maximised if they are "fed" information that is appropriate to the species being improved. This includes: flowering biology, stem and crown morphology, pests and diseases, internal wood structure, silvicultural response patterns, and economic information related to harvesting and processing. Overlying these is the influence of genotype, since it is only through the exploitation of genetic variation at a number of levels that improved breeds, more suitable to purpose, will be developed. Where information is missing it will be a sound knowledge of the species that allows predictions to be made with the best chance of being right.

Juvenile wood

Growth rate improvements in radiata pine over the first two generations of breeding, in combination with improvements in silvicultural practices, have contributed to a decrease in rotation age in Australia from around 40-45 years to 27-30 years. One effect of shorter rotations is increased amounts of juvenile wood in harvested logs and as a result wood quality will decline due to poorer wood properties – lower density, shorter fibres, lower cellulose content, and higher incidence of knots. The STBA in partnership with CSIRO, the Queensland Department of Primary Industries Forestry (QDPIF) and the Forest and Wood Products Research and Development Corporation (FWPRDC) is currently working on the “Juvenile Wood Initiative” project. This project aims to increase the value of Australia’s pine wood production by reducing the amount of juvenile wood produced in a tree (decreasing the age of transition from juvenile wood to mature wood) and/or by improving the quality of the wood (for example, increasing the inherent stiffness of the juvenile wood).

An early goal of this project was the sampling of basic density in six progeny trials that form the core of the STBA radiata pine breeding program. By June 2004 the STBA had sampled over 7000 cores from these trials and incorporated the results into the most recent TREEPLAN® genetic values. This represents a significant improvement in the amount of density data on which breeding values are calculated and will have an immediate impact on the ability of members to select genotypes for deployment with improved quality.

Breeding Objectives

The most important aspect of a tree improvement program is the definition of the breeding objective. Ideally the objective will be clearly defined in economic terms and based on traits that are under genetic control and influence profit. Currently the STBA’s radiata pine breeding program is based on the improvement of four primary breeding objective traits – harvest volume, whole-tree density, stem form and branching (Powell *et al.* 2004). These are combined in an index that allows the STBA and its members to select genotypes based on their predicted overall genetic merit.

In partnership with CSIRO and FWPRDC, the STBA is working on the definition of breeding objectives based on the traits that directly influence profit for its members. Not surprisingly, results are showing that a significant proportion of future genetic progress is more likely to come from improving wood quality traits such as stiffness than from higher growth rates (Wu, 2004). STBA members have been surveyed and individual company models built that link biological traits with products from solid wood production systems (tree growing to processing) to determine which traits have greatest influence on profit. The ability to put a dollar value on individual tree traits is a major advance for the breeding program. It is now possible for individual members to select genotypes for deployment based on customised breeding objectives that take into account their own production systems and cost structures.

The project is also studying correlations between traits measured at an early age and at later age (clearfall). Good estimates of these correlations will indicate how reliably we can select for breeding objective traits at early ages (6-7 years) in progeny trials. Initial indications are that wood property traits have both higher heritabilities and higher correlations with the same trait measured at clearfall, compared with growth traits. Thus it should be possible to improve wood properties by using early age data, capturing genetic gain much earlier.

Progress in this project is of key importance to the STBA. By having objective data on the traits of commercial importance in the breeding objective (those affecting profit), and by establishing the relative importance of each trait in the objective, tree improvement programs will be able to maximise genetic gain into members plantations.

Strategy revision

The early history of the STBA program was documented by Boomsma (1997), who reported on the strategy revisions done through the 1980s and the early 1990s. On the basis of this strategy breeding values were predicted (White *et al*. 1992ab) and crossing work carried out in the early 1990s. This led to the establishment of a large number (30) of progeny trials in 1996 and 1997 which now form the basis for much of the advanced generation breeding effort for radiata pine in Australia.

In recent years it has been recognised that significant changes in the strategy are needed to increase the rate of genetic progress. The STBA has and continues to modify its tree improvement strategy for *Pinus radiata* in response to the developments discussed above to ensure the rate of genetic advance increases and is adopted by members.

Some of the specific changes being adopted are

- Single breeding population - discrete nucleus and main breeding populations are not retained. Nucleus breeding was largely developed for animal breeding situations which are different from those found in *P. radiata*.
- Rolling front breeding - Discrete generation breeding, a component of the past strategy, leads to an inefficient use of resources and reduced gain. A rolling front will lead to greater gain through operational efficiencies, increased selection pressure, earlier adoption and use of elite genotypes for breeding, ease of infusing new material, reduced risk, and better account of GxE. TREEPLAN® genetic evaluation has facilitated the adoption of rolling fronts.
- Independent breeding sub-lines will continue, at least in the short-term. This aids in managing inbreeding and ensures deployment populations are outcrossed. The size of the breeding population can be reduced and effective population size managed better with adoption of selection and mate allocation genetic algorithms.
- Separate deployment 'breeds' will be developed with two sub-lines per breed. Initially this will include multi-purpose, high-growth and *Phytophthora* resistant breeds. The definition of other breeds, for example, Pitch canker, *Dothistroma*, and *Essigella* etc., will occur as needed.

Where to?

Despite the significant improvements of recent years there are a number of issues likely to impact on the long-term success of the program.

Genotype by environment interaction (GxE)

Genetic (breeding) values for radiata pine in Australia are currently predicted using regionalised target production zones (Figure 1). This enables differences in genotype performance between regions to be taken into account and is one of the first steps in developing customised breeding objectives for different members and/or regions. However, the basis for defining regions is likely to change as knowledge of the species improves and more information becomes available from trials with common pedigree across sites. Part of a project to enhance the TREEPLAN® system is examining GxE in more detail and come up with clearer recommendations for defining regions.

Figure 1. Regions (after Wood *et al.* 2001) used in defining *P. radiata* production zones used in TREEPLAN®.

Realised gains – where are they?

To encourage ongoing investment any breeding program must not only be able to deliver predicted gains to its investors, but it must be able to demonstrate them in operational plantations. This is often difficult in the case of tree improvement programs for a number of reasons – effects of unknown GxE, longevity of trees and the length of time it takes for a testing scheme to deliver stable information. The results from genetic gains trials are also often considered to be "out-of-date" by the time results are available since they no longer represent the improved material being planted operationally. Regardless, they are useful for demonstrating to managers that gains from investment in breeding are real and worth pursuing relative to other forms of investment.

A series of gains trials established across Australia and New Zealand in 1988 illustrates the point (Low *et al.* 2003). The performance of twenty common seedlots from three countries (Australia, New Zealand and South Africa) on eight Australian and two New Zealand sites was compared. Results showed that growth differences among seedlots across sites were not significant despite significant differences between seedlots within most sites. There was however a highly significant GxE interaction across trial sites. From single site analyses it was noted that New Zealand seedlots performed best on the New Zealand sites and Australian seedlots generally performed better on Australian sites.

The significance of this issue is not lost on the STBA. Managers need to have justification for expenditure on breeding and it is important that objective information is forthcoming. It is timely for the STBA to examine the role of genetic gains trials in supporting the radiata pine breeding program by both (i) reviewing and collectively analysing data from genetic gains trials planted in the past, and (ii) determining the way forward with new trial designs that are able to detect smaller differences between seedlots, and/or validate predicted breeding values.

Chasing the leaders!

The adoption of a rolling front strategy combined with the ability to run TREEPLAN® on a regular basis requires a change in the way that growers use breeding values. Under a dynamic strategy with overlapping generations it is likely that breeding values of individual genotypes will change from year to year as new data accumulates. Better genotypes will be identified more frequently. With discrete generations, breeding values will remain static for much longer periods, perhaps for a full generation, but gain is lost. This distinction needs to be understood when making deployment decisions, i.e., the establishment of seed orchards, family or clonal stool beds etc. Tree improvement programs take the population forward and thus, the subset comprising the "current top 20" selections will be somewhat dynamic. The length of time individuals are used in the deployment population will be finite, since they will eventually be superceded as new deployment choices are made.

Table 1 shows the levels of gain that can be expected from selecting among the best trees based on the latest TREEPLAN® run. Good progress has been made, with the best progeny in the third generation clearly superior to earlier generation selections.

Table 1. Mean TREEPLAN® breeding values for Breeding Objective traits. (percentage increase/decrease over base in parentheses).

	INDEX	VOLUME	DENSITY	BRANCH	STEM
Base Productivity		500 m^3/ha	400 kg/m^3	3.5	3.5
First-Generation (889 selections)	17.07	12.29 (2)	-2.2 (-1)	0.03 (1)	0.02 (1)
Second-Generation (569 selections)	50.98	32.27 (6)	-3.74 (-1)	0.08 (2)	0.13 (4)
Third-Generation (340 selections*)	148.35	82.55 (17)	-12.44 (-3)	0.46 (13)	0.2 (6)
Overall Average	30.39	20.19 (4)	-1.93 (0)	0.07 (2)	0.04 (1)
Top 20 trees selected on INDEX	220.81	134.10 (27)	-17.04 (-4)	0.70 (20)	0.12 (3)
Top 20 trees selected on VOLUME	199.81	155.97 (31)	-28.35 (-7)	0.34 (10)	0.17 (5)
Top 20 trees selected on DENSITY	-24.07	-29.41 (-6)	45.18 (11)	-0.02 (-1)	-0.09 (-3)
Top 20 trees selected on BRANCH	123.12	11.54 (2)	-7.41 (-2)	1.13 (32)	-0.28 (-8)
Top 20 trees selected on STEM	90.75	26.87 (5)	-3.17 (-1)	-0.05 (-1)	0.92 (26)

* - simulated third generation

Conclusion

The STBA radiata pine breeding program has recently been modernised with new tools and strategies established. This process will continue over the next few years as results from current research projects are incorporated into operational activities. This will result in a program that efficiently supplies members with objective information that allows them to maximise the return on their investment in tree improvement. Through the application of these improved tools and a commitment to breeding in the longer term, the rate at which benefits accrue over time should begin to accelerate as germplasm is cycled more quickly through the breeding program. Strategy revision will keep the program focused on the important traits that directly influence profit and improved knowledge of GxE interactions important to the species will enable the targeting of an additional level of gain especially when making germplasm deployment decisions.

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