Using economics to match genetics to site types and end products in pine and eucalypts

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The use of genetically improved trees in plantations is an effective way of lifting the productivity and quality of the forest resource for use in processing of solid wood, and pulp and paper products. The challenge for tree breeders is to identify improved genetic material which is suited to particular production environments and processing systems. This means its value must be described not only in genetic terms, but also its economic worth must be calculated depending on end use. Objectively comparing genetic material in breeding and deployment programs, which may be at different stages of development and with performance data from a range of sources, requires the use of advanced statistical methods and efficient data management systems.

The Southern Tree Breeding Association (STBA) runs national tree improvement programs in Australia for Pinus radiata and Eucalyptus globulus. These cooperative programs resulted from the amalgamation over time of a number of previously independent breeding programs begun by private companies, state and federal government agencies. Each of these programs brought genetic resources with associated data and information to the national cooperative. Combining the large amounts of data collected at different times and from many locations presented some technical challenges for the STBA and its partners. In recent years, the STBA has developed a suite of innovative software tools that have allowed it to overcome some of these challenges, which continue to confront tree breeders internationally.

Economic objectives

The objective of the national tree improvement programs is to breed and select genetic material with improved biological characteristics for traits of commercial importance. The STBA uses economic indices to describe the genetic worth of trees in the breeding and deployment populations. Bio-economic models, discounted cash flow analysis and risk analysis provide methodologies for establishing what may be important at the estate level to guide breeding for a species when more than one trait is of importance. For example, for P. radiata destined for a structural timber market, harvest volume (MAI m³/ha), branch size (cm), stem straightness or sweep (mm/m), and timber stiffness (GPa) are the commercially important traits which we are trying to improve. For E. globulus which is destined as chips for a pulp and paper market, the objective traits are harvest volume (m³/ha), wood basic density (kg/m³) and pulp yield (percent). Economic weights, derived from the bio-economic models, and used in profit indices to yield net present value for the breeding objective are now routinely used by the STBA, its members and associates in the national tree improvement programs to guide breeding and deployment decisions. Every tree has unique characteristics for each trait of importance and the use of economic indices allows breeders to consolidate this performance information into a single economic value. All trees can then be objectively compared and ranked on their potential end use value.

National databases

The STBA and its partners work with multiple species. A large amount of biological data has been collected on many trees over decades of breeding for these species. This data is collected for a range of purposes for use in tree improvement and associated research. The STBA developed and uses the web based DATAPLAN system to manage information, as well as to facilitate access by its breeders, researchers and other industry personnel. Data and information from organisations in Australia and Sweden for the breeding populations of P. radiata, E. globulus, E. nitens, P. sylvestris, P. contorta, Picea abies and Betula pendula, and other emerging species, are increasingly being consolidated in DATAPLAN. Data from 27 different programs is currently represented, with observations on more than 1.5 million different genotypes (trees), 15,600 families, and includes 26 million records on trees from 1240 field trials. New data and species are continually being added to the system. Development of the DATAPLAN software tool and the consolidation of data in national
and species wide databases has been a significant step forward in organising data and pedigree for use in genetic analysis.

**Genetic analysis**

The TREEPLAN system is a software tool that has been developed in the 2000s for the genetic analysis of tree breeding data on a species wide or global basis and uses best linear unbiased prediction (BLUP). All performance data collected in hundreds of trials over years can now be combined in national evaluations using full pedigree and the most advanced statistical methods.

For example, a recent TREEPLAN run for *P. radiata* included data for some 290,000 genotypes (genetically different trees) tested in 152 field trials. Breeding and total genetic values were predicted in a multi-variate analysis (across generations, locations, traits and age classes) for 27 measured traits. These selection criteria traits were then converted into four commercially important breeding objective traits (harvest volume, branch size, sweep, and timber stiffness) at rotation age.

For *E. globulus*, a recent TREEPLAN run included data for 230,950 genotypes measured across 130 field trials. Genetic (and breeding) values for volume growth, density and kraft pulp yield were predicted and combined into profit indices (marginal gain in net present value) with appropriate economic weights applied to each harvest age trait. The superiority of improved genetic material is benchmarked against an unimproved baseline (native CSIRO collection). As an example, trees grown from CP seed of the top 1000 trees ranked on $Index should be about $1960 NPV more profitable, faster growing by 54.4 m³/ha (26.5%), 21.97 kg/m³ (4.1%) more dense and with slightly improved pulp yield. Although gains for individual traits can be much higher if we ignore other breeding objective traits, trees with the highest growth rates, or density, or pulp yield will not maximise overall profit for an industry producing fibre for pulp and paper processing.

Different companies use different economic indices as their cost structures and revenue streams vary. This means the genetic values and economic indices must be tailored to the particular situation.

TREEPLAN allows for the objective comparison of trees and genetic material for breeding and deployment, as all the data is included in the one analysis, and is weighted according to its relevance for a particular situation. Results are reported on a regional basis, to ensure potential genotype by environment interactions are included and the best genetics is identified for each situation. The TREEPLAN software is a joint initiative of the tree and livestock industries. This ongoing collaboration allows innovation to be developed with application across multiple plant and animal species. TREEPLAN has global utility being suitable for use in other species and programs. For example it has been adopted by Skogforsk in Sweden for its national evaluations in Scots pine, Norway spruce, Lodgepole pine and Silver birch. It has the utility to combine data across different programs while retaining focus on local environmental conditions and processing systems. For example, it provides us with the technical capability to do a joint analysis across Australasia using all data from the Australian and New Zealand tree improvement programs for Radiata pine.

**Matching genetics to site types**

Knowledge of genetic and economic merit is important for selection and mate allocation in the breeding program. It is also important for decision making in deployment activities of seed and plant production, as well as matching improved genetics to particular environments. A recent study in *E. globulus* demonstrated that the genetic value of a seedlot changes according to the targeted site type. By matching available seedlots, each with their array of different genetic values, to specific site types resulted in an increase in marginal profits of more than $250 net present value per ha compared to mixing the seedlots and distributing them evenly across planting sites managed by the same company within a region of Western Australia. Innovative software tools like SEEDPLAN are being used to deliver these types of outputs to industry. Managing relatedness to avoid the adverse effects of inbreeding depression is a challenge for advanced generation breeding programs aiming to optimise gain for the breeding objective, as the best genotypes are often related. MATEPLAN software is important for managing risk associated with population fitness across generations of breeding.

Innovative software tools like DATAPLAN, TREEPLAN, MATEPLAN and SEEDPLAN are contributing significantly to enhanced genetic gain per unit time in the national breeding programs. These tools are also providing flexibility for the breeders while delivering operational efficiencies.
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18 November 2010 Rotorua
23 November 2010 Albury

STBA Group

Southern Tree Breeding Association Inc.

Cooperative tree improvement programs

Pinus radiata program
Eucalyptus globulus program
Other projects and species

PlantPlan Genetics Pty Ltd
Service contracts
Important ingredients:

Economic objectives to describe the financial performance of improved genetic material

Genetic material with genetic variation for traits of commercial importance

Data and information to describe genetic material for particular situations

Characterise target production environments and processing systems

Tools to summarise information and match genetic material to site types

Efficient propagation systems

How do we breed, select and deploy improved genetics for particular production environments and processing systems?

\[ P = G + E + GE \]
It’s an economic decision rather than a biological one

Economics is central to our decision making:

Economic indices are used to describe the genetic worth of trees (individuals, clones, families or seedlots)

Bio-economic models, discounted cash flow analysis and risk analysis are methodologies for determining what’s important at the estate level when more than one trait is important
We use economic objectives:

*Pinus radiata*
\[ NPV$ = w_1 \text{GROWTH} + w_2 \text{BRANCH} + w_3 \text{SWEEP} + w_4 \text{STIFFNESS} \]

*Eucalyptus globulus*
\[ NPV$ = w_1 \text{VOL} + w_2 \text{DEN} + w_3 \text{KPY} \]

*Eucalyptus nitens*
\[ NPV$ = w_1 \text{VOL} + w_2 \text{DEN} + w_3 \text{KPY} + w_4 \text{BRANCH} + w_5 \text{STRAIGHTNESS} \]

**Pine sawn timber production**

*Pinus radiata*
\[ NPV$ = w_1 \text{GROWTH} + w_2 \text{BRANCH} + w_3 \text{SWEEP} + w_4 \text{STIFFNESS} \]

Customised weights *(forest grower, processor, integrated)*
Flexible for each company *(deployment)*

Other traits: Drought, Dothistroma, Pine aphid, Pitch canker and *Phytophthora pinifolia*
Changing environments and carbon?
Breeding and deployment values (NPV$)

$2740
$752
$960
$2290
-3250

DATAPLAN® is a tool

Web based (working since 2001)
Stores trial data, pedigree and other information
Stores results (genetic values and profit indices)
Breeders, researchers and industry are on the same page
Facilitates genetic analysis (organises data and pedigree)
Ability to share (but not show) data for joint analysis
Security of data and IP
Transparency and transferability
DATAPLAN

8 main species
27+ programs
1357+ trials
2.04+ million genotypes
32.8+ million measurements

*Pinus radiata* 243 (’00s)
*Eucalyptus globulus* 173
*Eucalyptus nitens* 149
*Pinus sylvestris* 161
*Picea abies* 85 (275)
*Pinus contorta* 9 (22)
*Betula pendula* (55)
*Pinus mariana* 1
*Eucalypts mixed* 515
*Solanum tuberosum* 6+
*Pinus pinaster*
*P. elliottii* and *P. caribaea* hybrids
*E. smithii*

TREEPLAN® is a tool

BLUP software that allows genetic analysis of data on a species wide or global basis

Predicts breeding and other genetic values (clonal and SCA) using all data and full pedigree

We can benchmark genetic material of different origins if data is included in the same analysis

Results reflect the amount, quality and relevance of the data

Fits optimal statistical models (across generations, locations, traits and age-classes)

It’s flexible
TREETRAN® is a tool

It has enabled us to amalgamate data collected in different programs over time using different protocols (STBA programs).

Gunns and Forestry Tasmania (and partners) share data for a species wide analysis in *E. nitens*.

The result is more genetic gain for each program, and they still compete by not seeing each others data or results.

It gives us the technical capability to do a joint industry wide analysis using all trial data from the Australian and New Zealand (and other) programs for Radiata pine.

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![Graph showing improvement in marginal profit ($NPV) over time for the best 1000 genotypes (trees) based on the national economic objective for a vertically integrated industry.](image)
Marginal improvement in MAI (m³/ha/yr) over time for the best 1000 genotypes (trees) based on the national economic objective for a vertically integrated industry.

**P. radiata TREEPLAN 2010 results are based on data from trees in 154 field trials.**

Marginal reduction in Branch Size (cm) over time for the best 1000 genotypes (trees) based on the national economic objective for a vertically integrated industry.

**P. radiata TREEPLAN 2010 results based on data from trees measured in 154 field trials.**
Marginal reduction in Sweep (mm/m) over time for the best 1000 genotypes (trees) based on the national economic objective for a vertically integrated industry

Marginal improvement in timber Stiffness (Gpa) over time for the best 1000 genotypes (trees) based on the national economic objective for a vertically integrated industry
P. radiata TREEPLAN 2010 - Average $NPV of the best 1000 genotypes by generation, region and discount rate based on data from 154 field trials

Marginal profit per ha ($NPV using a discount rate of 6%) for a vertically integrated industry growing and processing forestry products

Marginal Profit ($NPV) using different Discount Rates

TREEmEPLAN E. globulus 2010

$Index Values of Generations and Top 1000 individuals over time
SEEDPLAN® is a tool in the making

We have all this information, but how do we use it to match genetics to different site types and end products?

We recognise that orchards are made up of trees with different genetic values for a range of traits

The value of a seedlot is not the same for all sites

More segregation of seedlots is needed

Characteristics (environment) of target planting sites need to be identified

SEEDPLAN is a tool

Growers want to put the right seedlot in the right stand

We need to know the production system

Understand the key bio-economic drivers of profit

Characterise the G

Understand the E and GxE effects on mean and variance of important traits

We need to align our seed and plant production systems with site types

SEEDPLAN is about information management and optimisation
An example:

- 1576 ha established
- 20 site types and 156 seedlots

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cost (m)</th>
<th>Cost ($/ha)</th>
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<tbody>
<tr>
<td>Even allocation</td>
<td>$2.25</td>
<td>$1425</td>
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<tr>
<td>Optimal allocation</td>
<td>$2.93</td>
<td>$1861</td>
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<tr>
<td>Extra NPV</td>
<td>$436</td>
<td>$436/ha</td>
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MATEPLAN is a breeder’s tool
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