A new impetus for radiata pine breeding – identifying the opportunities

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Abstract

Improved radiata pine genetics continues to offer considerable potential to increase forest production, improve log characteristics and wood properties, and confer improved resistance against pests and diseases. Past contributions have been notable and played a very large part in making radiata pine the key resource of the forest industry in New Zealand. The current strategic thrust of the New Zealand forest industry is to increase productivity, profitability and disease resistance with the aim of doubling export earnings over the next 10 years. This timeframe is too short for tree breeding and genetics to make any significant improvement, but over the longer term this will be the main generator of future productivity and profitability.

There are many opportunities for improving performance and they are described and discussed. The focus on developing gain in key traits of interest will continue, and although percentage gain may increase, the impact on the industry is dulled by the long timelines for development followed by the length of a commercial forest rotation which collectively may be up to 50 to 60 years. Shortening the breeding and deployment cycle by half (15 years) by the introduction of forward selection, the utilisation of genomic selection, and improved deployment processes can deliver a net present value (NPV) three times greater than that achieved by genetic gain alone. An increased focus on gain per unit time offers considerable opportunity to deliver increased profitability. Downstream, the exploitation of genetics by environment interactions has the potential to deliver further significant benefits. All of these developments should help to transform tree breeding and see it become more commercially targeted and responsive.

Background

Genetic improvement of radiata pine has played a very large part in making it the key resource of the forest industry in New Zealand. The early impacts were made in the 1950s and 1960s, with the selection of superior trees in the forest leading to significant increases in growth, stem-form and market acceptability. These characteristics were developed further over the years with the establishment of clonal nurseries and the successive transition from open to controlled pollination processes for seed production. In the late 1980s, the GF Scheme was introduced as a rating system for genetic gain in growth and form to be used for identifying seed quality in the market place. By this time planting stock was available offering gain of some 30% in volume, and an increase in merchantable stems from 45% in unimproved stands to 70–80%. The benefit of genetic improvement to forest growers was obvious.

The intensification of tree breeding that commenced in the late 1960s coincided with a major thrust to optimise plantation management practices and target both a direct sawlog (short rotation) regime and the production of 'clearwood'. The result was an over-focus on increasing volume growth which led to loss of wood density. Although high-value pruned logs were produced, the overall log harvest was characterised by low strength unstable wood which lost competiveness in world commodity markets. In response, there was a realisation of the importance of wood properties in tree breeding, and of the necessity to manage all traits of commercial value. In the late 1990s, the GF Plus scheme was introduced to fulfil this purpose.

The 1990s also constituted a major period of change for science in New Zealand which had serious repercussions for forest genetics and the forest industries at large. Science capacity decreased, the operating environment became commercially competitive, government research funding for tree breeding was severely reduced, and industry assumed responsibility for all tree breeding research and the GF Plus scheme under a company structure – the Radiata Pine Breeding Company (RPBC). Activity was maintained at a very low level for some five years until an industry-government research consortium was established in 2005.

This partnering with government, which has developed further over the years, together with effective relationships with research providers and international collaborators has now created a renewed energy in tree breeding and genetics. This is timely, since the forest industry has developed a pan-sector research strategy with the main aim of increasing profitability and improving sustainable forest management, and introduced an industry-wide commodity levy to fund research and other key non-competitive activities of the industry. Tree breeding and genetics is recognised as having the potential to make a major contribution to the overall research and innovation strategy.

The strategic vision of the radiata pine industry

The primary aims of industry are to increase sustainable production and profitability, and to reduce the impact of pests and diseases. To achieve these outcomes the industry strategy follows a multi-pronged approach with the core elements being genetic improvement, better forest management, more robust biosecurity – all contributing to the key outcome of greater acceptability for downstream processing and markets.

The aim of industry, as articulated in the NZ Woodco Strategy, is to double the projected earnings of radiata pine wood exports by 2022 from $6 billion to $12 billion. This timeframe is too short for genetics, and to a large extent forest management, to have any influence since the forests supplying the raw material are already past mid-rotation. All improvements must therefore come from activities such as wood segregation, new and improved processing and manufacturing, new products and marketing. Ongoing improvement to secure and grow increased business activity over time will result from developments in genetics and forest management, with genetics offering the opportunity for continuous improvement. From a pan-industry perspective, a portfolio approach covering major intervention points along the forestry value chain will create a continuum of short, medium and long-term responses to drive and maintain international competiveness.

Increasing volume

Conventional tree breeding is a very long-term activity which results in a slow transfer of genetically improved planting stock to commercial forests. The breeding and deployment cycle for getting newly-created untested germplasm to the forest can be as long as 30 years. Add to this the 27 to 30-year growing rotations of radiata pine, it can thus take up to 60 years before the benefits of genetic improvement can impact the market place. With these timelines, it is of little surprise that there have only been three to four generations of improvement since breeding research commenced in the early 1950s. The good thing is that there is a lot more improvement to exploit; the bad thing is that response times to date have denied rapid development and uptake. Developments in clonal forestry offer a more responsive pathway, but uptake across the industry has been slow. The current research interest in shortening the breeding and development cycle, together with the potential introduction of genomic selection, illustrates the increased interest to speed the breeding and deployment process.

The major challenge for tree breeding is to place it as an investment within the realms and timelines of a market-driven business proposition, rather than as a long-term strategic investment made more on faith than hard business information. No single technological advance is going to provide the answer. Rather, it will depend on a portfolio of integrated technologies all targeting a common outcome.

Opportunities for improvement

Increasing gain in target traits

The primary focus of the radiata breeding programme for many years has been to seek improvement in those traits that increase the value of harvested logs. Volume growth has always been a pre-eminent target since gains are readily translated into financial values. However, the experience from the clearwood and direct sawlog regimes clearly demonstrated that the pursuit of volume should not be made at the sacrifice of wood properties. Currently, RPBC seeks improvement in volume, density and corewood stiffness (the main drivers of product and market acceptability), with the caveat that any gain in one trait must not result in a loss in the other. Non-key traits are selected in production population crosses as part of the deployment process. This opportunity is business as usual.

Value from wood property improvement

The financial impact of improvements in volume are readily calculated since volume is a key driver of returns from log sales. Financial benefits associated with wood properties are less easy to calculate, with some being related with performance thresholds of products and thus having no prescribed value unit by unit. In other instances, the performance of the product may depend on multiple wood property traits. There is currently a market failure for wood property improvement at the point of log sales. Processors and manufacturers benefit from improved wood properties but do not pay a premium for them. Gaining a better understanding of the relationship between product performance, wood properties and market values will do much to overcome this situation and provide higher return to forest growers. This opportunity is best answered from a marketing perspective and represents 'money on the table'.

Improved selection

At the front end of the process for deployment of improved genetics is the selection of parents with desirable traits for crossings. Selected traits will differ depending on the end-market use of the target crop. The use of predictive tree crop models helps to place a financial value for wood products, but the markets are some 30 years ahead and markets and values are therefore very uncertain. Choosing genotypes for crossing with the highest breeding values (BVs) for desirable traits assumes no change in the economy or the market. An improved strategy now being considered is robust selection where good mid-level performers are selected that show little variability across broad economic and market scenarios. They are low-risk selections for the future that will still deliver good performance. Integral to making the best selections is the accuracy of BV estimation. Recent improvements made through the introduction of advanced mathematical computation and statistical analysis have upgraded BVs, and further advancements are now being made by factoring in the impact of site variables and GxE interactions. Improved selection will increase the quality of crosses made and get the best genotypes into production and increase gain in desirable traits.

Genomic selection

Standard BVs are estimated from phenotypic data which is the direct (or indirect) measurement of the trait expressed in the new crosses at about age seven to eight years. Measurements take time, can be difficult to make, and may be costly. On the other hand, genomic-based breeding values (GeBVs) are calculated by matching DNA markers (that are related to established phenotypic information of traits) against the DNA of unrated seedlings in the nursery. GeBVs can be calculated in the first year of seedling growth and eliminate the need, and time, for standard phenotypic testing and assessment. An additional benefit of genomic selection is that multiple traits can be assessed simultaneously on SNP panels which is a marked contrast to phenotypic assessments where traits are assessed one by one. Genomic selection is a new technology leading step change across animal and plant breeding, with possibilities for significant financial gains. The adoption of genomic selection will underpin the introduction of forward selection.

New radiata elites ready for clonal propagation for genomics training population

Forward selection

Conventional tree breeding utilises backward selection to identify new genotypes for the production population. This involves measurement of traits in selected crosses at age seven to eight to confirm expected gains in target traits, followed by a further (next generation) round of crosses and testing to ensure gains are maintained. Progeny from the first set of crosses are then chosen for improved seed orchard stock. Forward selection uses information from assessment of the first round of crosses to choose nursery stock, thus reducing the breeding and deployment cycle by at least seven to eight years. The introduction of forward selection has a marked impact in reducing the timelines for breeding and deployment, improving financial returns and adding urgency to the development of new germplasm.

Exploiting genetics by environment (GxE) interactions

The two responses to GxE of interest to forest growers are:

- Change of ranking in performance of genotypes across sites
- Stable performance of genotypes across all sites.

The influence of GxE on genetic performance differs between the various traits, for example, volume is sensitive to GxE and rankings can change across sites whereas the ranking for density is relatively stable. Since volume is such a driver for economic return, exploitation of GxE to produce improved performance attracts attention.

Current work with BV assessment and calculation has demonstrated that GxE is widespread for volume across the forest estate. Cluster analysis groups sites of similar GxE characteristics, and it has been shown in preliminary work that the selection of high-performing genotypes within a cluster can raise volume production by up to 15–20%. The potential for increased gains is obvious, but before GxE can be exploited commercially they need to be validated and sites must be fully described with environment parameters. From a commercial perspective, exploiting GxE has the potential for optimising genetic performance across sites and delivering additional financial returns from the production population.

Genotypes which have stable rankings across sites, and whose relative performance is not affected greatly to changes in environment, must also be of interest to forest growers. They offer consistency of performance across sites, align well with the requirements of robust selection, and may offer stability of performance over time with the potential onset of climate change. From a commercial perspective these stable genotypes offer certainty to growers, but this is likely to be at the cost of maximising the productivity of the site.

Speeding the breeding and deployment process

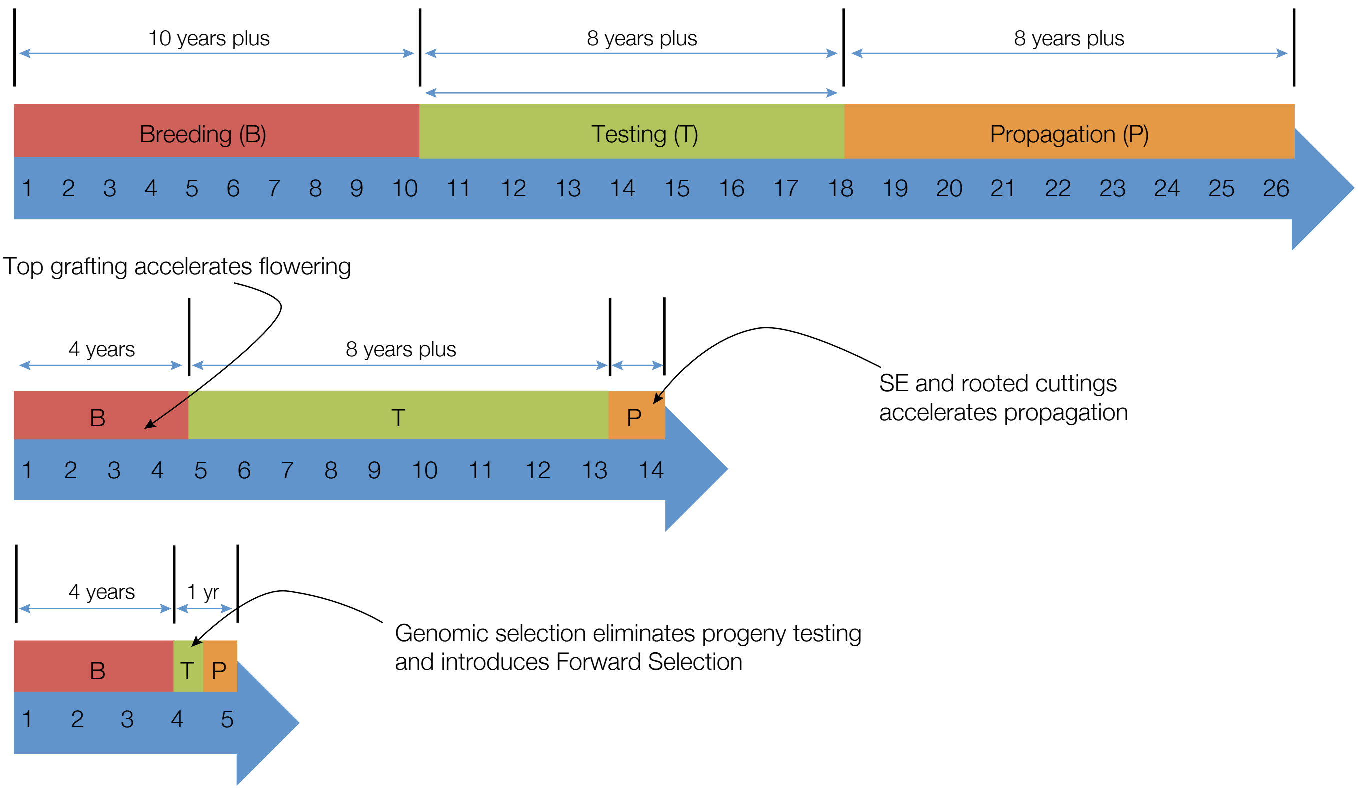
In broad terms, radiata pine tree breeding has concentrated on increasing the genetic gain in selected traits as the primary mechanism of providing returns to shareholders. Increases in GF Plus ratings over time have largely been the measure of success. However, from a financial perspective perhaps a more beneficial approach is to increase genetic gain per unit time by shortening the breeding and deployment cycle. Currently, the breeding and deployment timeline can be up to 30 years, which is then followed by a further 28 or so years for the growing process before log sales. A gain of 20% in volume at harvest, together with a shortening of the breeding and deployment cycle by 15 years, would deliver a three-fold financial return compared with the same volume gain and no reduction of the breeding and deployment timeline.

By comparison, what would be considered an exceptional gain of 100–150 m^3/ha in volume would result in only a 20–30% gain in NPV. A 15% reduction in the breeding timeline is already within our sight, and future reductions will potentially deliver a breeding and deployment cycle as low as 10 years. In combination with early flowering in radiata pine, the timeline may be reduced to less than five years, currently considered to be a possibility for *Pinus elliottii*. The financial impact of this would be dramatic.

Propagation and deployment

The long timelines for deployment experienced with conventional breeding and deployment processes result mainly from the time required to assess new crosses in progeny trials through phenotypic measurement and evaluation, the utilisation of backward selection, and the time to bulk up new germplasm and establish commercial seed orchards. The introduction of genomic selection, forward selection and embryogenesis, together with stool bed and cuttings technology or clonal propagation, represents a faster pathway for deployment.

Impact of Integrated Genomic Selection on Breeding and Deployment Timelines



(after Matias Kirst, University of Florida)

Better prediction and proof of genetic performance over time

Tree breeding and the production cycles of forestry are so long, and the factors influencing production at harvest so wide and variable, that accurate prediction of performance at the end of the process is very difficult, if not impossible. Radiata pine forests are grown across the length and breadth of New Zealand over a range of soil types and topographies, all of which have an influence on the properties of wood at rotation. Individual sites can also be extremely variable. Greater knowledge of environmental variables and GxE, improvements in trial designs and measurements, and a greater understanding of age-age correlations, for example, will do much to raise understanding of variability and increase the ability to make better predictions.

The benefits of genetic improvement may also be negated by poor forest management. Weed growth during establishment, poor silviculture, plant disease and the unforeseen climatic event or other environmental impact can all significantly reduce genetic gain. In reality, genetically improved planting stock gives the developing forest the potential of better performance, but it requires good management and husbandry to be realised. Thus the importance of genetics, environment and silvicultural GxExS interactions. All of the above issues contribute to the additional difficulty in clearly demonstrating certainty of return on investment from tree breeding and genetics where proof is required in the commercial estate. If this proof is forthcoming it may be possible to capture the increased value of forests, even of young pre-inventory forests, on the balance sheets of forest-growing companies. This must be of interest to the asset ownership companies whose time horizons for investment are likely to be less than that of a single rotation.

Proof of genetic gain is difficult to demonstrate. Visual comparisons between trials are unsatisfactory because of trial designs utilising single tree plots, demonstration plots can be useful but they lack statistical validity, and comparing neighbouring commercial stands can be confounded by site and environmental variables. Best estimates of genetic gain are obtained from large plot trials with a wide range of genotypes of different genetic improvement (e.g. a wide range of GF Plus ratings). Recent research at Scion on genetic gain in radiata pine to incorporate in growth and yield modelling systems has demonstrated a gain of some 20% in volume between unimproved (e.g. GF Plus 7) and highly improved (GF Plus 26) stands. This work is now being validated. Another recent and outstanding demonstration in proof of genetic gain is seen in the change of GF Plus ratings for density since 2000. Following the loss of density arising from the push for large increases in volume from the 1970s onwards a concerted effort was made in breeding to regain losses. The average GF Plus rating for density in the production population increased from 16 to 24 by 2014. Over this period volume ratings remained constant at GF Plus 22. This was a remarkable achievement since density and volume are negatively correlated.

Priorities for action

The quick overview above demonstrates a series of different approaches to increase financial returns from tree breeding. Obviously, it is not possible to implement all opportunities simultaneously and priority should be given to those which offer the best potential for improvement at an acceptable level of risk for achievement:

- The outstanding conclusion is that *speeding the breeding and deployment cycle* will have a much larger impact on increasing financial gain than the pursuit of increased gain in target traits. The RPBC is already responding to this opportunity through the introduction of 'integrated genomic selection', which combines forward selection, genomic selection and improvements in vegetative propagation. These developments are considered to be of low to medium risk and have the potential to be operational within the industry in the next five to 10 years. Results will be a more rapid turnover of generations and a faster transfer of improved genetics in to the commercial forest estate.
- Supporting technologies which can be developed in parallel are the continued improvement in *BV calculation, better selection and increased gain in target traits,* which will remain the key activity in the supply of germplasm to the industry.
- The *exploitation of GxE* is more future-orientated as there is a longer research and development pathway required. Current work in BV development that incorporates GxE, improving trial design to understand influence of site variables, and a current PhD study to gain more precise understanding of the environmental and climatic variables that delineate important environmental groupings will all contribute to establish the underpinnings for a developmental programme.
- A further long-term opportunity would be to *shorten the time to flowering* of radiata pine, which would have a dramatic impact on breeding and turnover of generations.

Conclusions

In recent years, the RPBC has attempted to bring a greater degree of market responsiveness to the breeding of radiata pine. Developments are now more financially driven than scientifically driven, but not at the expense of science quality – and the science challenge often increases! Improved genetics have large contributions to make to the industry, but they must be timely and supported by a good value proposition. There is still much to do, but hopefully we are going in the right direction.

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