Successful varietal forestry with radiata pine in New Zealand

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Abstract

Varietal forestry (sometimes termed clonal forestry) can be defined as the commercial production and deployment of plants of field-tested, individual genotypes (clones or varieties) of forest tree species. The varietal forestry programme managed by Forest Genetics Ltd (FG) with radiata pine is one of a few such successful programmes with pines worldwide, and has been built on over 60 years of R&D in breeding and propagation. Clonal varieties offer substantial additional benefits to forest growers when compared with commercial seedlots produced in both open-pollinated and control-pollinated seed orchards. Although cloning technologies for pines have been available for over 30 years, a reliable and cost-efficient varietal development and delivery system for radiata pine has only recently been perfected.

Introduction

Varietal forestry is defined as the commercial production and deployment of plants of field-tested individual genotypes (clones or varieties) of forest tree species. One of the key enabling technologies to achieve varietal forestry has been the ability to store frozen pine tissue cryogenically, and thereby to maintain its juvenile growth habit for the necessary 8–10 year field testing period. Comprehensive field testing is then carried out over the full range of forest sites and regions, and for a range of growth and yield, log and wood quality, and disease and other screening traits. Once the field screening results are 'in', the best few varieties are selected and rapidly multiplied for woodlot and plantation growers using a combination of tissue culture and stoolbed amplification techniques.

These production varieties are then established in validation trials and stands, such that the production programme receives a stream of feedback that enables further selection and fine-tuning to occur. Figure 1 shows the sequential process that FG uses for the development of production varieties. These methods provide cost-efficient commercial production that has enabled the business to maintain a small staff, with relatively low capital requirements.

Market challenges

As with most new technologies, varietal forestry has thrown up numerous challenges. Clonal varieties are sold into a finite New Zealand market for radiata pine plants, where they compete with relatively inexpensive seedlings grown from open-pollinated clonal seed orchards, as well as both seedlings and rooted cuttings developed from controlled crosses among progeny-tested radiata pine breeding parents. The New Zealand radiata pine market currently requires 45–50 million plants per year, largely for the re-establishment of harvested stands by large plantation forest growers.

Other landowners, including Maori, farmers and rural investors, have been periodically involved in plantation establishment. However, unsupportive local and national government policies are currently constraining further forestry investment by these groups. The recent spike of new ETS-related planting has diminished as a result of over-supply of cheap carbon credits from Europe. However, a recovery is possible if supply stabilises and the value of NZUs can be restored to at or above $10/tonne of CO_2.

Attributes of varietal forestry

While varietal forestry has most of the same attributes as forestry with conventional seedlings, there are some important differences including:

- Varietal treestocks are supplied as rooted cuttings, rather than as seedlings. The varietal plants produced from cryopreserved tissue are variously termed as somatic seedlings or 'emblings', and are identical genetic copies of the embryo that was first extracted from seed and frozen. These emblings supply the nursery stoolbeds from which branch tips are harvested and set, and grown on for a year, resulting in the rooted cuttings grown for deployment in plantations
- Compared with seedlings, varietal cuttings exhibit some of the attributes of a more physiologically-mature plant including:
  - A more erect form with a narrower crown, arising from increased apical dominance (i.e. where the terminal leader grows more vigorously than do competing side branches)
  - Less stem malformation, which in part is due to the greater apical dominance and in part to selection for improved form
  - Longer and greener needles, and developed branch buds versus rosettes of juvenile needles at the branch tips
  - Since varieties are clones, each derived from a single embryo, any differences among trees within a variety are almost entirely due to environmental influences, rather than their genes.

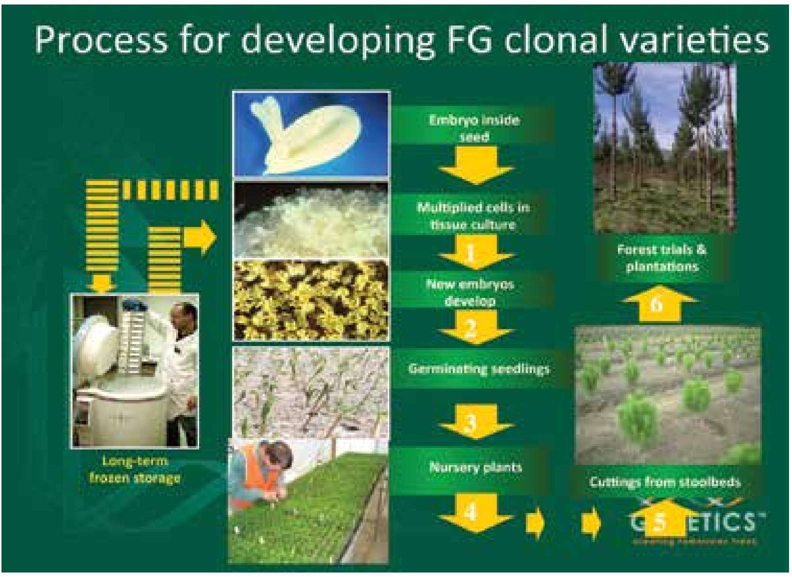

Figure 1: The process for developing clonal varieties

Recognising these differences, clonal varieties can be managed in a similar manner to other seedling and cutting treestocks. The most important consideration is the nature and amount of genetic improvement that can be expected from them.

Customer focus

The business model for developing a varietal forestry business requires the combination of a strong customer focus, and a clear strategic vision with rigorous review and prioritisation of technical goals. Forest growers in New Zealand are typically reliant on revenues from the sale of their trees as stumpage or as logs, and there are relatively few companies with vertical integration into wood processing and end-product markets. As such, growers are usually most concerned with achieving improved log volume and quality, as well as remediating the various physical and biological risks associated with growing a crop to the point of harvest – all to be achieved at a reduced cost, if possible.

The main differentiating factor among forest grower customers is the relative emphasis they give to either a structural or appearance-grade product, although there can be a number of next-level considerations below this broad division. In general, growers of structural timber tend to maintain higher initial and final crop stocking levels and to favour genetic improvements in growth rate, log quality (i.e. less sinuosity and sweep, and leader malformation), and increased timber strength and stiffness. For growing appearance-grade timber, growth rate and log quality are still considered important, but wood quality traits that lead to reduced wood defects are more likely to be preferred. For example, increased dimensional stability on drying, and reductions in the amount of compression wood, and/or in numbers of resin pockets etc. Where there is a disease hazard that can be addressed through genetic selection, for instance Dothistroma resistance, growers will seek improvement in these traits as well.

Risk management

Risk management issues are often of critical interest to forest growers, particularly when they are faced with new technologies like cloning. Since clones represent a new paradigm, there is a need to discuss and respond to legitimate questions relating to the potential for any increased risk to forest growers. Principal among these is the issue of genetic diversity, and fears that a genetic monoculture may predispose a plantation to infection and damage caused by plant pathogens and insect pests.

Long crop rotations, combined with extensive management practices, expose forest plantations to a larger risk window of exposure to pests and diseases relative to that for annual crops. It is appropriate to address concerns about physical and biotic agents that might selectively damage some genotypes versus others, and to do this by maintaining an appropriate level of genetic diversity. For radiata pine, as yet unknown pests and diseases causing defoliation and/or stem canker are probably the biggest concern. However, in terms of the degree to which such risks relate to any reduced genetic diversity:

- Both the Radiata Pine Breeding Company (RPBC) breeding programme and the FG varietal programme actively select for resistance to known diseases, and for crown and stem health in general
- Genetic diversity can be managed across the plantation estate, and over time, as well as on a clone-by-clone basis. For most New Zealand growers, their estate of radiata pine will comprise a very diverse genetic mosaic of stands of seed orchard and other origin for many decades to come
- Within a stand, risks associated with diminished genetic diversity can be reduced by planting mixtures of clonal varieties
- Radiata pine may have no genetic resistance to some pest and disease threats, and damage from these will not be prevented by managing genetic diversity.

Most current growers of clonal varieties are comfortable with deploying relatively low numbers of varieties (i.e. less than 10) in a given year, and deployment of 15–20 varieties is considered safe by some larger companies. Almost invariably, the clonal varieties are deployed as single-genotype stands versus as varietal mixtures, although the genetic gains will be similar in either case. Greater uniformity among trees in stands of single clonal varieties may, however, offer some additional benefits in silvicultural management, particularly for optimising pruning and clear-cutting yields through having a more uniform branching habit. Single-clone stands will also enable growers to track varietal performance during the life of the stand, which should assist in the ultimate marketing of the forest crop, as well as providing crucial feedback to the varietal screening process.

Another concern often expressed by forest researchers, and less often by forest growers, relates to the perception that varietal forestry will in some way represent a risk due

to the potential for genotype-by-environment (G-by-E) interactions to reduce treestock performance in either growth rate or other traits. The concept here is that genotypes that have either natural or selected adaptation to a specific set of growing sites may perform differently relative to other genotypes when grown on other sites. The differences, or the G-by-E, can be expressed as either a change in genotype rankings between sites, or as an overall increase or decrease in the differences among genotypes (the genetic variance). The concern as it relates to varietal treestocks would be that the genetic gains estimated for selected varieties from their performance at some locations may not be expressed in another location.

In our view, G-by-E should not be of concern to growers of FG varieties since:

- The varieties have all been developed from very good progeny-tested parent trees identified in the RPBC breeding programme
- The FG varieties have themselves been tested and selected as good all-round performers from trials established over a wide range of New Zealand and Australian forest sites
- Of the traits FG improves its varieties for, only growth rate has been shown to have the potential to be strongly affected by G-by-E, and FG places substantial emphasis on validating the growth rate of selected varieties in customer plantations.

Rather than being an issue for concern, G-by-E when managed wisely can instead offer benefits to forest growers through a process we term genotype-site matching (GSM). The benefits from GSM arise from a better matching of the genetic characteristics of selected varieties with a grower's site conditions and log product objectives. One example is with the large additional gains in wood strength and stability that can be made by matching clonal varieties selected for their high wood density to sites, which are capable of yielding more valuable log grades than could otherwise be achieved.

This could be through growing high-wood-density varieties on sites with naturally-low wood density, as is the case in more elevated regions in the Central North Island and in the Southern South Island, in order to produce structural grade timber as an alternative to growing sawlogs for either appearance-grade timber or as export logs. On any New Zealand site there are selected FG varieties that can provide increased average wood density at or above 60 kg/m^3. This increase, when combined with improved growth rate and stem form, will provide growers with the potential for a broader range of market options for their logs.

Technical challenges

Since cloning of radiata pine has not previously been commercialised, FG has faced a number of technical challenges in developing an effective production system. FG's earlier reliance on CellFor, Canada to assist with growing emblings from cryopreserved tissue ended with CellFor's demise, and FG had to quickly respond by importing the key cryopreserved tissues and setting up its own lab near Rotorua to take over this work. The previously researched 'proof of concept' tissue culture propagation methods had to be greatly extended to improve yields and plant quality for field-proven genotypes. Also new research has been undertaken to deal with the specific problem of recalcitrant clones (i.e. varieties that do not propagate well in either the lab or in subsequent nursery stages).

In parallel with optimising the varietal production methods, FG has been actively developing an advanced generation of improved varieties. This has been done through creating new varieties from crosses among the best clones already in production, while also bringing in infusions of new genes from the RPBC and other progeny-tested parents.

Cloning of the RPBC breeding population becomes an exciting new prospect and, when combined with the application of genomic selection, represents the next stage of improvement of radiata pine. FG are collaborating with the RPBC and Arborgen to bring the most advanced RPBC breeding population candidates into cryostorage as clonal varieties that will be screened by the RPBC in the genomics selection process, and backed up by routine field testing. Highly-improved clonal varieties developed from this project will contribute to future plantation gains for the sector, both from their use as tested seed orchard parents and as commercial varieties.

Benefits and opportunities

What kind of gains can forest growers expect from growing clonal varieties? As already mentioned, FG's focus has been on improvement in growth rate, log and wood quality, and Dothistroma resistance, and we are being successful in making gains in all these traits. Table 1 illustrates genetic gains from block plantings of three selected clones in Kaingaroa Forest, compared to GF-rated controls. While the clones differ from one another in their performance for growth and wood quality (i.e. wood density and corewood stiffness), it is evident that all three clones have performed substantially better than either of the open-pollinated orchard and control-pollinated seedlot controls, which performed similarly to one another in this trial to age nine.

Table 1: Kaingaroa Forest Genetic Validation Trials (mean of 70 trees assessed at age 9)

	DBH (cm)	Height (m)	Stiffness (Gpa)	Density (kg/m^3)
OP controls – GF19	20.7	12.6	5.7	324
CP controls – GF24–30	20.6	12.5	5.9	318
Clone A	21.6	14.2	7.9	373
Clone B	23.6	15.1	8.1	345
Clone C	22.1	13.9	8.1	368

Wood density of radiata pine is known to vary widely across New Zealand sites (e.g. average wood density on Northland sands may be as much as 100 kg/m^3 greater than for a similar-aged stand in Southland). However, numerous studies have shown that the genetic rankings for wood density do not vary much, if at all, across sites in New Zealand and Australia.

A number of FG selected varieties can add as much as 60 kg/m^3 to the average wood density at any site. In the example of genotype-site matching mentioned previously, for growers on cold sites either in Otago/Southland or the Central North Island this provides an opportunity to grow timber meeting structural timber grade specifications, rather than being obliged to produce only either pruned clearwood or export logs.

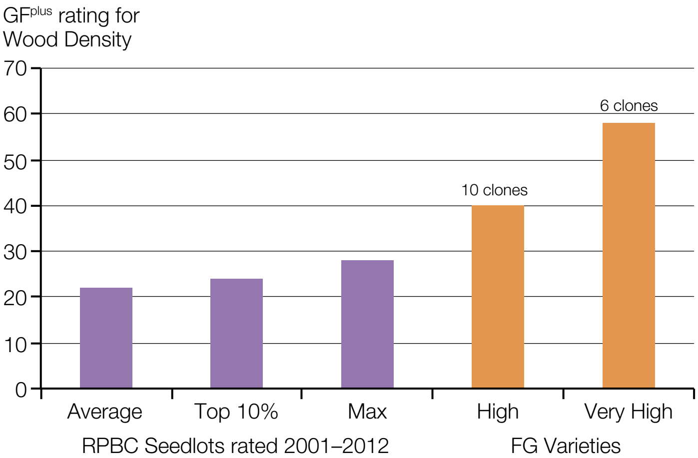

Figure 2: Seedlots rated for wood density by GFPlus from 2001–2012 versus FG varieties

Figure 2 illustrates the much higher GFPlus ratings for wood density that have been estimated for these FG varieties, compared to the best alternative CP seedlots planted between 2001 and 2012. Increased wood density confers greater strength to sawn timber and also contributes to improved dimensional stability of wood on drying. In addition, the combined increased growth rate and wood density that has been achieved in some FG varieties makes these an attractive option for growers seeking increased carbon credits from their plantations, since they can be expected to provide gains in CO_2/tonne of up to 30% over the rotation.

Many of these same varieties are also substantially improved for corewood stiffness (i.e. associated with increased bending strength of timber), and gains of 2–3 GPa are typical as can be seen in Table 1.

Finally, a number of our selected varieties also have excellent resistance to Dothistroma as illustrated in Figure 3. This knowledge can be used to guide clients in their planting decisions on high-hazard sites for Dothistroma.

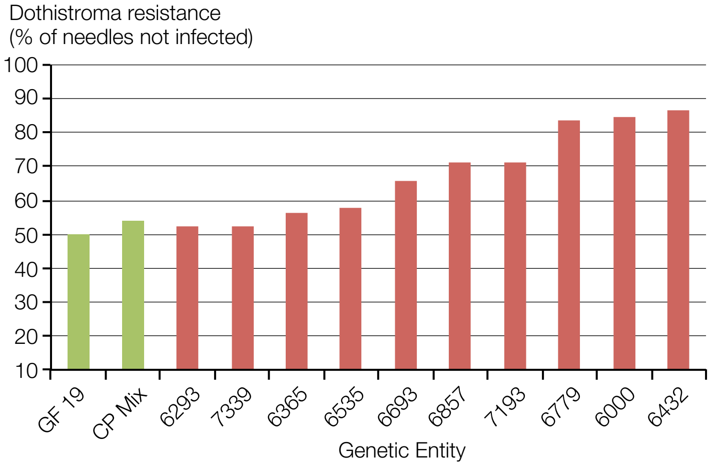

Figure 3: Mean Dothistroma resistance at 54 months

Another differentiating feature of varietal radiata pine is the ability it provides to incorporate improvement in all of the above traits in the same set of production varieties. This is because while some traits of radiata pine (such as growth rate and wood density) are negatively correlated in seedling plants, varietal selection enables relatively uncommon correlation-breakers (i.e. with high values in all traits) to be identified and supplied for deployment.

Conclusion

FG is providing New Zealand forest growers with the option of growing new radiata pine varieties that can add substantial value to forest plantations, while also reducing some of the risks posed by disease and physical damage. Closer integration of goals with forest growers has provided the varietal programme with additional opportunities for realising gain, through the ability to:

- match genotypes to site conditions and economic objectives
- track varietal performance into commercial plantations, and
- respond much more rapidly to the resulting feedback compared to seed-based programmes.

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