Hybrid and clonal eucalypts for saline land. Current progress and where to from here?

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ABSTRACT

The XYLONOVA Research and Development Program commenced in 1996 with the aim of developing salt tolerant eucalypt hybrids for establishing commercial plantations on saline and waterlogged land. The program's primary objective was to combine the salt tolerance and timber characteristics of *E. camaldulensis* with the growth rate, wood quality and form of *E. grandis* and *E. globulus*. To date 1333 novel varieties have been developed.

Field trial results at Mt Scobie in northern Victoria under conditions of saline irrigation (10 dS/m), high watertable levels and medium to heavy clay soils, indicate potential for growth rates at least equal to that expected under conventional non-saline forestry systems, with individual trees exceeding 10m and variety means exceeding 8.5 m height at two and a half years of age.

This paper reports the results of current field trials, discusses the prospects for commercial plantations in saline environments.

KEY WORDS

Stress tolerance, salt tolerance, eucalypt hybrids, clonal forestry, tree breeding

INTRODUCTION

With the accumulation of knowledge on the hydrological basis of salinity, much has been written on the need to re-afforest large areas of salt-affected catchments to achieve hydrological control on the level necessary to restore groundwater balance and substantially impact on rising salinity trends. Hatton (2000) has estimated that up to 70% of some catchments may need to be re-forested, while the joint ACF-NFF (2000) statement on salinity has proposed the need to re-forest 20 million hectares of the Murray Darling. Generally viewing trees in low-rainfall, salt affected areas as not economic, opposition has been voiced over the enormous costs of such an undertaking, and concern raised over the social and economic consequences of replacing farming systems with trees solely for environmental benefit (eg, Tuckey, 2000).

The successful application of trees as a socially acceptable, financially achievable and economically sustainable tool on a scale necessary to achieve a meaningful environmental impact virtually dictates, in most situations, that such forests provide economic returns at least equal to that of the farming systems they are replacing. In the majority of catchments affected by salinity, where rainfall is generally less than the 650 mm limit to conventional forestry, and where groundwater reserves are often saline, the objective of achieving economically viable forestry production presents a significant challenge.

On a world scale, the two most important plantation eucalypt species are Flooded Gum (*E. grandis*) and Tasmanian Blue Gum (*E. globulus*) (Klemarewski *et al*., 2000). Both are desirable for their high growth rates, good stem form and commercially desirable wood properties. However, both are poorly adapted to saline and low-rainfall areas. Conversely, species such as River Red Gum (*E. camaldulensis*) that are adapted to a broad range of conditions including saline soils and low-rainfall, have good wood properties, but are relatively slow growing and have relatively poor stem form. Among the 700 odd eucalypt species, no serious options exist for a species capable of providing the growth rates necessary to attract investment capital in areas that are moderately saline, waterlogged, or at the margin (450 to 650 mm rainfall) of land currently considered suitable for commercial forestry.

Based on the expectation of combining the complimentary traits of fast growing, commercially important species with broadly adapted, stress tolerant species, the XylonovA program embarked on a combined cross-breeding and biotechnology program to produce hybrids of *E. camaldulensis* with *E. grandis* and *E. globulus*. The program also involved the development of management practices to optimise productivity in stressed environments. The cross-breeding component of the program has to date generated over 1300 hybrid clones which are currently in trials across Australia. The results of these trials and prospects for commercial forestry on saline lands are described in this paper.

MATERIALS AND METHODS

Hybrid Pedigrees: Eleven full-sib, F_1 hybrid families were constructed, comprising combinations of three *E. camaldulensis*, three *E. globulus* and two *E. grandis* parents. The *E. camaldulensis* parents were selected on the basis of proven salt tolerance and above average growth and stem form in replicated clonal trials in Victoria and Western Australia. The *E. grandis* parents were selected on the basis of early growth and form in an irrigated provenance trial at Shepparton in northern Victoria, and *E. globulus* parents were chosen on the basis of growth, for and wood quality for pulp production.

Field trials: The first field trial of 217 XylonovA hybrids from six families was established at Mt Scobie near Kyabram in northern Victoria in October 1998. *Design:* This trial is an incomplete block design with single-tree plots and 5 replicates per treatment. It is established on an ex-pasture site that had become too saline for continued pasture production due to rising soil salinity that reached 8 to 12 dS/m ($EC_{1:5}$) prior to planting with XylonovA trees. The trial forms part of a salinity control experiment testing conjunctive water use as a form of integrated on-farm salt management. The trial is located within the draw-down zone of a groundwater pump, and is used to dispose of the saline water extracted by the pump. Irrigation with low-salinity water continues on the surrounding dairy pasture. *Soil type:* The predominant soil type in the trial area is a Goulburn Loam (a grey-brown loam from 0-12 cm, with a subsoil of yellowish-brown medium to heavy clay) (Skene and Poutsma 1962). A tongue of Congupna Clay (grey, gilgaied clay of less than 10 cm, with a heavy clay subsoil) extends across the bottom of the trial associated with a drainage line. *Management:* The site was irrigated with fresh water for five months following establishment. In the second irrigation season, groundwater was shandied 1:1 with channel water to achieve an EC of 5 dS/m. The third irrigation season commenced in October 2000, with groundwater at 10 dS/m being applied directly to the trial. Irrigation with 10 dS/m groundwater will continue in future irrigation seasons. *Climate:* The area receives a mean annual rainfall of approximately 465 mm, and mean annual evaporation is around 1606 mm. Applied irrigation provides approximately 400 mm of rainfall, bringing the annual total to 865 mm. *Site conditions:* Watertable depth measured in piezometers at either end of the trial is between 0.5 and 1.05 m, and groundwater salinity varies between 7.5 and 8.5 dS/m. Soil core samples show a variation across the site in the trend of ECe with depth in the profile. At two sampling locations, ECe was approximately 7 dS/m near the surface, increased to between 10 and 12 dS/m at 0.5 m, then declined again to between 4 to 5 dS/m at 1 to 1.5 m depth. In contrast, at the third sampling location, ECe remained at a relatively constant level of around 4 to 5 dS/m throughout the profile to 3 m. Soil pH ranges between 6 to 7 at the soil surface and increases to between 7.5 to 8.1 at 0.5 m, and varies between 7.7 and 8.8 with increasing depth in the profile to 3 m.

A second, more comprehensive field trial of nearly 600 clones from 10 families was established near Deniliquin in southern NSW in October 1999. Four other trials were planted in 1999. Of note among these is a trial planted in September by Forestry SA on a 550 mm dryland site near Naracoorte in South Australia. In collaboration with industrial companies, government organizations and private landowners across temperate and sub-tropical Australia, a further 27 trials were established in 2000 and 42 trials in 2001. The design for these trials is predominately 5 tree line-plots x 4 replications. Number and composition of clones varies between sites, with substantial clone overlaps between sites to permit across site analysis, and investigation of clone by site interaction. The various site conditions sample geographic location; salinity (up to 15 dS/m); soil type; rainfall (450 to 1200 mm); rainfall season (summer/winter); irrigation (irrigated/not irrigated); alkalinity/acidity and elevation, and a range of management conditions. Results reported herein will focus largely on the Kyabram trial.

RESULTS

Table 1 illustrates substantial gains in yield were achieved by the hybrids over their pure species parents in the Mt Scobie trial at 30 months. For the *E. camaldulensis x E. grandis* hybrid, the mean stem volume of all clones (unselected) is 56% greater than the mean stem volume of the two pure species parents. Selection of the top 10% of clones increased this yield gain to 146%. For the *E. camaldulensis x E. globulus* hybrid the volume gain is more pronounced, with the mean stem volume of all clones being 143% greater than the mean stem volume of the pure species parents. Selection of the top 10% of clones increased this yield gain to 363%.

Table 1: Mean height diameter and stem volume of hybrids and pure species in the Mt Scobie trial at 30 months in comparison to their pure species parents.

	Mean Height		Mean Diameter		Mean Stem Volume	
	(m)	% gain over mean of parents	(cm)	% gain over mean of parents	(dm^3)	% gain over mean of parents
E. cam. x grandis (All clones)	6.5	18%	6.0	21%	10.4	56%
E. cam. x E. grandis (Top 10%)	7.7	39%	7.4	50%	16.4	146%
E. cam. x E. grandis (Top Clone)	8.2	48%	7.9	59%	19.0	185%
E. cam. x E. globulus (All clones)	6.0	22%	5.5	33%	10.5	143%
E. cam. x E. globulus (Top 10%)	8.3	68%	8.0	92%	20.1	363%
E. cam. x E. globulus (Top Clone)	8.1	64%	8.4	103%	22.3	415%
E. grandis parental mean	6.1		5.6		8.9	
E. globulus parental mean	4.9		4.1		4.2	
E. camaldulensis parental mean	4.9		4.2		4.4	
Overall Trial Average	6.3		5.8		10.2	

Early results also indicate the potential of the hybrids for fast growth rates on low-rainfall dryland sites, raising the possibility for their deployment in recharge, as well as discharge sites. In a trial established by Forestry SA on a low-rainfall (550 mm/yr) dryland site in September 1999, incorporating a set of 20 randomly selected *E. camaldulensis x E. grandis* clones replicated with 15 ramets in each of two blocks, the mean height was 1.68 m. The highest clone mean for height (mean of 30 ramets) was 2.05m, and the tallest individual tree was 3.45 m. Overall survival was in excess of 95%. Results from other trials have shown the hybrids to exhibit high survival and promising early growth across a wide range of locations, environments and site conditions.

The hybrids also appear to display resistance to attack by Autumn Gum moth, a serious pest of pure *E. globulus* plantations. A challenge to hybrids in the Mt Scobie trial by Autumn Gum Moth at around 20 months of age and again at 32 months led to severe attack of pure *E. globulus* controls, with little or no damage to either hybrid type. Preliminary investigation appears to link this resistance to a higher leaf specific weight and lower concentrations of particular leaf extractives, however, this remains to be more fully investigated.

DISCUSSION

Hybrid productivity: The exploitation of heterosis has been one of the major successes of plant breeding in the 20th Century (Cooper and Merrill, 2000). The results of this study indicate the potential for a similar revolution in the adaptation and improvement in performance of eucalypt forestry for stressed environments through inter-specific hybridisation, and the incumbent capacity to exploit and re-package the wealth of natural genetic variation available among the inter-breeding species of this genus.

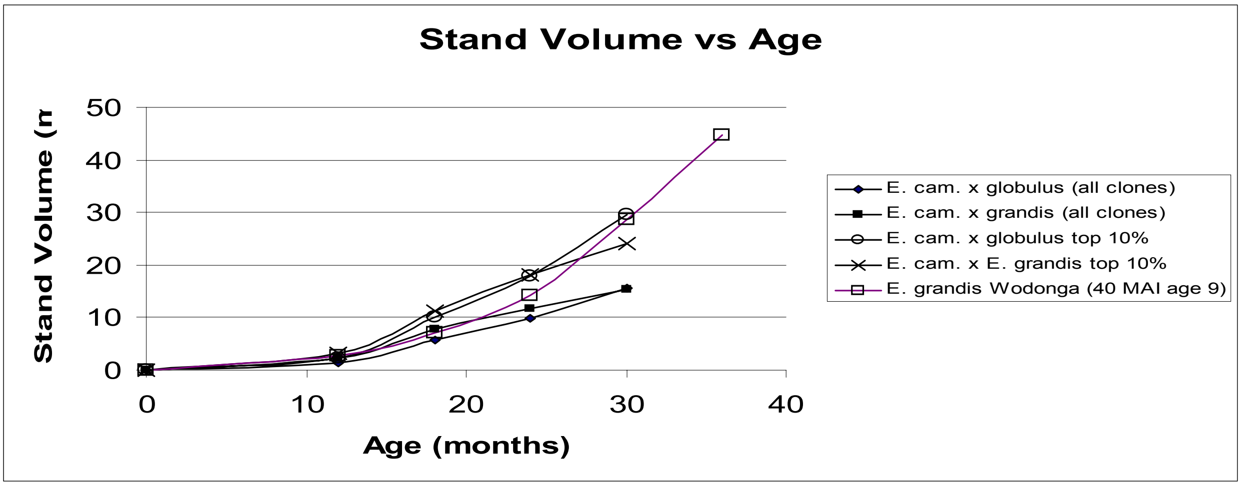
The Kyabram trial site presents soil conditions that would typically be considered stressful for growth of non-halophytic tree and crop species, viz: shallow watertable (0.5 to 1.05 m) leading to problems with root zone aeration; moderately saline groundwater (7.5 to 8.5 dS/m) having direct osmotic and toxicity impacts; saline soil conditions at the soil surface (ECe 4.7 to 7.1 dS/m) and in the active rootzone area

(ECe up to 12d S/m at 0.5 m), again having osmotic and toxicity impacts; medium to heavy clay texture restricting root penetration, soil aeration and plant water availability; and high sub-soil pH (7.5 to 8.8 at 0.5m and below) leading to problems with nutrient availability. These site conditions are typical of many saline degraded areas of the Murray-Darling Basin, and present conditions unsuitable for agricultural crops which are typically restricted to soils of less than 2 dS/m (Ghassemi *et al*., 1995).

Under the stressful conditions of the Mt Scobie site, significant heterosis is displayed by both hybrid types relative to their respective mid-parent means. For stem volume at 30 months, the gain in the mean performance over the mid-parent mean was between 56% for the *E. camaldulensis x E. grandis* hybrids and 143% for the *E. camaldulensis x E. globulus* hybrids. The practical implication of this result is that an increased level of timber production can be achieved in the hybrids under shallow saline watertable conditions compared to naturally occurring pure species. However, this alone is not adequate justification to support commercial adoption of the hybrids unless the absolute growth rates exceed a minimum, commercially viable level.

Figure 1 compares the mean performance of the two hybrid types, and the mean performance of the top 10% of clones from each hybrid against the actual growth achieved by an effluent irrigated stand of pure *E. grandis* on a high quality site at Wodonga under non-saline conditions. The high site quality *E. grandis* stand achieved a maximum growth rate of 40 m^3/ha/yr at age 9. This is well above the threshold of around 20 to 25 m^3/ha/yr generally revealed by economic modelling as a threshold level of productivity for many forestry investments, and the rate of 30 m^3/ha/yr targeted in many forestry investment prospectuses for *E. globulus* on higher rainfall (>650 mm) non-saline sites. It is difficult to confidently predict rotation age yield from early age measure data of the Mt Scobie trial. However, assuming the growth rate of the hybrids continues to follow the same trend as exhibited to date, then they might be expected to achieve a commercially attractive harvest yield when grown under poor quality site conditions.

Figure 1: Growth curve of stand volume at Mt Scobie (m^3/ha) for the mean of all *E. camaldulensis x E. grandis* and *E. camaldulensis x E. globulus* hybrids, and for the top 10% of clones for each of these hybrids. The accumulation of stem wood on a per hectare basis is compared to the growth curve for a non-saline, effluent irrigated stand of *E. grandis* at Wodonga which achieved a maximum MAI of 40m^3/ha/yr at age 9 (Data supplied by Tom Baker, CFTT). The shape of the growth curve for the hybrids reflects the relatively faster growth rate in summer when temperatures are warmer and water-tables on the trial area fall, and the relatively lower growth rate through winter when temperatures are cool and the watertable rises to within 0.5 m of the land surface.



Opportunities for Plantation Development

Trees and other deep rooted perennials are widely recognised as having a key role in salinity control. This application is for both reduction of groundwater recharge and direct treatment of discharge sites to reduce salt runoff into rivers and streams, and to return degraded land to productive use. However, for trees to exert an appreciable effect on regional groundwater tables, planting must be carried out on a large scale. Current targets for the MDBC salinity reforestation bank are in the order of 1.5 million hectares within the 500 to 800 mm rainfall zone or just 4.2% of the land area of this zone. This will require an enormous capital investment, estimated at $17 billion over the next 50 years. Funding for such investment from the public purse is undoubtedly impractical and economically unsustainable. As such, it is paramount that the investment in plantations of deep rooted perennials for salinity control provides a commercial return in order to sustain and encourage the scale of capital investment required.

The relatively low rainfall of the region requiring re-afforestation compared to traditional forestry areas, the wide variability in seasonal conditions and the occurrence of salinity and waterlogging, all present significant challenges to the establishment of commercial plantations. Improvements in productivity achieved by Saltgrow hybrids under stressed environmental conditions should enable commercially viable growth rates to be achieved in the key areas requiring re-forestation. Current projections are that Saltgrow hybrids can achieve harvestable logs of up to 50 cm diameter in 20 to 25 years. Further improvements in clonal selection may reduce this period, while developments in sawmilling technology may reduce optimum log size to 35cm, and allow use of thinnings as small as 20 cm top end diameter for products such as high value flooring.

The establishment of plantations for the dual role of environmental benefits and commercial production requires a clear focus to ensure development of forest resources that are suitable for the target product. This in turn requires consideration of the markets for alternative product options, transport costs, production costs and processing costs. With the exception of the oil mallee project in Western Australia, previous programs to establish trees for salinity control and other environmental benefits, particularly the National Heritage Trust, have been piecemeal, sort term, lacked product and resource focus, and have generally used inferior species incapable of producing a cost competitive raw material. The consequence of such programs is that they have failed to achieve the scale required to support any viable processing industry, or to produce a resource capable of generating any commercial return.

Fortuitously, the need for large scale re-forestation to control salinity is fully consistent with the requirement for development of a critical resource mass to supply any industry based on processing of wood and fibre products. While hardwood sawmilling operations (currently based exclusively on native forests) can operate on a resource of as little as 5,000ha (RIRDC, 1996), an internationally competitive softwood sawmill requires a minimum resource base in the order of 38,000ha (RIRDC, 1996). It is likely that a similar scale of resource will be required to support hardwood mills based predominately on new plantation timber resources, and that such mills will need to be integrated to produce a range of products that fully utilise the wood fibre entering the mill gate.

A critical consideration in any timber based operation is the impact of transport costs on the return to the grower. While this varies with local road conditions, 150 to 200 km is typically considered the maximum economic haul distance. The 500 to 800mm zone of the Murray-Darling Basin is beyond the economic haul distance to coastal ports to be viable for production of woodchip, hence, any resource developed in this region needs to focus on local processing of high value products, and needs to consider additional manufacture and value adding. Given the scale of afforestation required, these products need to have international commodity markets, and production cost needs to be competitive on the world market. While products such as charcoal may be high value, they are essentially niche markets, and would be likely to suffer dramatic oversupply and price decline from an estate of 1.5 million hectares. Conversely, with declining supplies of hardwoods from native forests in Australian and Asia (RIRDC, 1996), regional demand, particularly for appearance grade timbers for furniture, joinery and finishing timbers is growing (Margules, 1996). Across the Asia-Pacific region, a decline in timber exports across the board and a increase in net imports is projected. Japan will remain the largest net importer, followed by Thailand and Taiwan. By 2010, China is expected to be a major net importer of sawn hardwood (Margules, 1996). Integrated timber processing operations would also utilise residues for products such as biomass energy generation, which in turn will contribute to meeting Australia's renewable energy targets.

The establishment of plantations for salinity control to create critical scale resource catchments capable of supporting world class timber processing facilities, while at the same time delivering environmental services, will have significant flow-on benefits. It will lead to creation of new regional industries and jobs in forestry contracting, timber harvesting, sawmilling and value added processing. This in turn will have flow-on benefits to service and support industries, and provide a diversified source of income to landholders, either through lease payments on land or participating in the returns from tree growing. The net environmental and economic benefits for a single 20,000 ha resource catchment is estimated in the magnitude of $23 million. This ignores the social benefit arising from the arrest of rural decline, stimulation of new regional jobs and industries, and the maintenance or improvement in farm productivity and sustainability.

CONCLUSION

Trials with *E. camaldulensis x E. grandis* and *E. camaldulensis x E. globulus* hybrids have demonstrated a clear benefit of hybrid breeding and clonal selection to exploit the inherent natural variation among inter-breeding species of the genus *Eucalyptus*. The hybrids developed in this program have achieved substantially greater mean stem volumes than their pure species parents at two and a half years of age, and an absolute level of volume growth which indicates the potential to achieve commercially attractive growth rates in saline, waterlogged and low-rainfall environments. This development in turn, raises a very real prospect of achieving productive and commercially viable utilisation of saline land resources. It is this capacity to generate commercial returns that is necessary to effect the paradigm shift necessary to achieve the scale of tree planting required to address the problem of salinity.

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