

Breeding salt and drought-tolerant eucalypt hybrids: Economic returns from environmental problems.

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ABSTRACT

Remediation of agricultural landscapes affected by salinity requires modification of land use practices to re-establish water balance at the catchment scale. Forest plantations established throughout the landscape, from recharge to discharge areas, have the potential to play an important role in this regard given their deep rooting habit, high perennial water use and low leakage of rainfall below the rootzone relative to annual crops. However, areas affected by salinity in Australia often present environmental conditions challenging to commercial growth. In 1996, the XYLONOVA R&D Syndicate commenced a collaborative breeding program to combine the salt and drought tolerance of *E. camaldulensis*, with the growth rate, stem form and wood properties of the commercial species *E. grandis* and *E. globulus*. These hybrids exhibited heterosis under saline irrigated conditions, with the mean stem volume of hybrids at 85 months exceeding the best pure-species parent by 96 to 122%. Gains in stem volume based on the mean of a commercial selection of hybrid clones ranged from 157 to 236%. Gains were more modest under non-saline, medium to low rainfall conditions (531 to 707 mm/yr). Hybrid population means were similar to alternative pure-species, but the hybrids were more stable across sites. Gains in mean stem volume from selection of the top 10% of hybrid clones over the best performing pure-species ranged between 27 and 30%. The opportunity for commercial plantations of improved eucalypt hybrids integrated with agriculture in medium to low rainfall areas to address salinity and sustainability is discussed.

INTRODUCTION

Planted forests offer the potential to address many environmental issues including salinity, greenhouse and loss of biodiversity. Across Australia, salinity currently affects over 5.6 million ha. Without intervention, the area of salt-affected land in Australia is projected to increase to 17 million ha by 2050, of which over 13.6 million ha or 80% is agricultural land (NLWRA, 2000).

Dry-land salinity is generally believed to result from clearing of native deep rooted perennial vegetation and its replacement with annual crop and pasture species. This vegetation change, and the associated decrease in plant water-use, leads to an altered water-balance and rise in groundwater tables, ultimately bringing salt stored deep in the soil profile to the surface. Commercially driven tree production systems developed for large areas of the current crop and pasture zones of the Murray Darling Basin form one of the three principle areas of on-ground action recommended to halt the spread of salinity and loss of native biodiversity in Australia's land and river systems (Stirzaker *et al.*, 2000). However, in the majority of catchments affected by salinity, where rainfall is generally less than the 700 mm limit to the majority of plantation forestry sites in Australia (Anon., 2005), and groundwater reserves are often saline, the objective of achieving economically viable forestry production presents a significant challenge.

The XYLONOVA Research and Development Program commenced in 1996 with the aim of developing salt and drought-tolerant eucalypt hybrids that could be used to establish commercial plantations under medium to low rainfall conditions, and on saline and/or waterlogged land. The program's primary objective was to combine the salt and drought tolerance plus timber characteristics of *Eucalyptus camaldulensis* Dehnh. with the growth rate, wood quality and stem form of *Eucalyptus grandis* Hill ex Maiden and *Eucalyptus globulus* Labill. To date a total of 1333 hybrid clones have been developed, and over 150 trials and 300 separate planting sites have been established across Australia.

This paper reports on the results of a sub-set of these trials grown under two different landscape conditions. Results are reviewed in the context of opportunities for commercial plantations integrated with agriculture in medium to low rainfall areas, with the aim of addressing salinity, carbon sequestration and sustainability. In addition, the potential for partnerships among land-rich, cash-poor farmers, catchment management authorities seeking to invest in public good projects that enhance environmental sustainability, and private investors seeking commercial returns is also discussed.

MATERIALS AND METHODS

Hybrids

Two types of hybrids were produced – *E. camaldulensis* × *E. grandis* (6 full-sib families) and *E. camaldulensis* × *E. globulus* (4 full-sib families). Parents were chosen from tested clones of *E. camaldulensis* selected for salt tolerance, growth rate and stem form, and individual trees of *E. grandis* and *E. globulus* selected for growth rate and stem form. Each parent was used in 3 – 5 hybrid crosses.

Site and trial descriptions

Site-type 1: Shallow saline watertable with saline irrigation

The first hybrid screening trial was established at Mt Scobie, near Kyabram in northern Victoria in October 1998. It comprised 217 clones from two hybrid types: *E. camaldulensis* × *E. grandis* (2 families) and *E. camaldulensis* × *E. globulus* (4 families). This trial was established using a randomised complete block design with five replicates, and a single irrigation treatment using pumped saline groundwater. Clones were mostly represented by a single tree in each replicate, however, due to plant availability, some clones were represented by fewer than 5 replicates. The parental species *E. globulus* and *E. camaldulensis* were represented by an average of 4 trees in each replicate, while *E. grandis* was represented by an average of 13 trees per replicate. The source of *E. globulus* and *E. grandis* were open-pollinated seedlings of the parent trees to the hybrids, while two clones were used for the *E. camaldulensis*, one being the main parent to the *E. camaldulensis* × *E. grandis* hybrids, the other being an unrelated clone.

The site formed part of a salinity control experiment testing conjunctive water use as a form of integrated on-farm salt management. The trial was located within the draw-down zone of a groundwater pump and was used to dispose of excess saline water extracted by the pump. Irrigation with low salinity water continued on the surrounding dairy pasture.

The trees were located in an area which had become too saline for continued pasture production, with an average soil salinity in the upper 60 cm of 7 to 19 dS/m ($EC_{e,calc}$). Soil texture within the trial area was a medium to heavy clay throughout the profile to a depth of at least 3 m. Soil salinity ($EC_{e,calc}$) was measured as the estimated electrical conductivity (EC) of a soil saturation paste extract (EC_e or EC_{se}), determined by multiplying the measured value of a 1:5 soil:water solution ($EC_{1:5}$) by a correction factor corresponding to the sample's field texture (Slavich and Petterson, 1993).

The site was irrigated with fresh water during the first five months following establishment. In the second irrigation season (October 1999 to March 2000), groundwater was diluted 1:1 with fresh water to achieve an EC of 5 dS/m. From the start of the third irrigation season (October 2000) and for all subsequent irrigation seasons, the site was irrigated with undiluted groundwater at 10 dS/m. Irrigation with saline water exposed all trees to the same level of salinity.

Mean annual rainfall in the area (Kyabram) over the period of the trial was 416 mm (range 280 to 530 mm), and mean annual evaporation was 1680 mm. Applied irrigation provided the equivalent (not allowing for evaporation) of 280 to 890 mm/yr of rainfall (average 595 mm/yr), bringing the total annual water input (rain plus irrigation) to 1010 mm (range 750 to 1280 mm). Average watertable depth across the site varied between 0.3 and 1.5 m.

Site-type 2: Medium to low rainfall, non-saline recharge sites

In August 2000, six research trials were established as a sub-set of a series of 50 species evaluation trials for non-saline, medium to low rainfall areas of New South Wales. With limited prior information for the target regions, the pure-species in the sub-set of six research trials were selected as “best bets” based on wood properties, growth rates, suitability for the rainfall zone and proven success in similar rainfall zones in other

areas of Australia (Barton and Parekh, 2006). *E. camaldulensis* hybrids were included based on promising early results from trials on saline sites, and the expectation of a common physiological basis of tolerance to salinity and drought, both involving tolerance to osmotic stress.

The six trials were established in conjunction with Forests NSW on the western slopes of NSW along a cline from winter maximum rainfall areas in the south (2 trials), through uniform rainfall areas (2 trials), to summer maximum rainfall areas in the north (2 trials). Long term average rainfall across the six sites ranged from 530 to 710 mm. Other key climatic data are summarized in Table 1.

Each trial comprised 84 hybrid clones from two hybrid types (29 *E. camaldulensis* × *E. globulus* and 55 *E. camaldulensis* × *E. grandis*), plus five unimproved pure-species. Pure-species and provenance source (in brackets) used in the winter rainfall trials were: *Eucalyptus cladocalyx* F. Muell. (Marble Range); *Eucalyptus camaldulensis* (Albacutya); *Eucalyptus sideroxylon* A. Cunningham (West Wyalong); *Corymbia maculata* Hook. (Curryall SF); and *Acacia mearnsii* de Wild. (North Bungendore). In the intermediate and summer rainfall trials, *E. cladocalyx* and *C. maculata* were replaced by *Eucalyptus argophloia* Blakely (Queensland) and *Corymbia variegata* F. Muell. (Richmond Range). At the taxa level, trials were established as a randomised complete block design using 72 tree plots (12 trees × 6 rows) with an internal 40 tree measure plot (10 trees × 4 rows). Within hybrid plots, clones were arranged as 3-tree line plots of 20 un-replicated clones per plot plus 4 replicated check clones (included in each plot of each replicate), giving a total of 84 clones per trial. The same set of 84 clones was used in each of the 6 trials. This design was adopted to provide a fixed clone set at the taxa level, but permit screening of a large number of clones.

All six trials were established on non-saline recharge areas where rainfall not used by annual crops and pastures drains past the rootzone. Over time, this leakage may contribute to a rise in the watertable and lead to salinity outbreaks in downslope areas. The re-establishment of trees in recharge areas aims to prevent deep drainage to the watertable, preventing or limiting the spread of salinity.

Statistical analysis

Statistical analyses of volume data collected in the seven trials (one trial on the first site-type and six on the second site-type) were conducted in ASREML (Gilmour *et al.* 1999) using a mixed-model separately for each trial. Replicate effects were fitted as fixed effects, while all other effects included in the statistical models were fitted as random factors. Due to differences in trial design and layout, different models were fitted to the Mt Scobie (site-type 1) trial and the remaining six trials. At Mt Scobie, the following model was fitted:

$$y_{ijkl} = \mu + R_i + G_j + C_{jk} + \varepsilon_{ijk}$$

where, y_{ijkl} is the j^{th} clone (or tree) within the k^{th} group, in the i^{th} replicate, and ε_{ijk} is the residual. Groups correspond to each of the parental species included as controls, plus each of the two hybrid combinations (i.e. *E. camaldulensis* × *E. grandis*, and *E. camaldulensis* × *E. globulus*). Separate estimates of the variance with group, were fitted for each group. The same statistical model was fitted for the remaining six trials (site-type 2) except that we added a random effect for sets within replicates. Group and

clonal means (Best Linear Unbiased Predictions, BLUPs) were used to compare differences between the pure-species controls and selected clones.

Site-type 1: Heterosis for stem volume at 85 months under saline conditions was investigated by comparing the population mean of all clones in each hybrid type with their pure-species parents (*E. grandis*, *E. globulus* and *E. camaldulensis*).

The potential gain in stem volume growth at 85 months from selected commercial sets of each hybrid type relative to their pure-species parents was also compared. For this purpose, 7 clones of *E. camaldulensis* × *E. globulus* and 6 clones of *E. camaldulensis* × *E. grandis* occurring in the trial were grouped and treated as two separate taxa. The selected clones were not necessarily the top ranking clones in the trial, but had been selected based on their consistent performance across a larger series of trials.

Means for both sets of analyses were compared using Fisher's Least Significant Difference test. (Note, as all trees of pure *E. globulus* had died by 85 months, there were only four taxa available for comparison in each analysis – two hybrid taxa and two pure-species parents).

Site-type 2: The 84 hybrid clones tested across these 6 trials were first ranked on mean stem volume growth at 57 months. As there were relatively few standard commercial clones in these trials, the top 10% (8 clones) were identified and treated to reflect a commercial group selection. The mean performance (mean of the BLUPs for each clone) of this select hybrid group for mean stem volume at 57 months was then compared to average performance of the pure-species (i.e. group mean from ASREML). Means were compared using Fisher's Least Significant Difference test.

RESULTS

Site-type 1: Shallow saline watertable with saline irrigation

The mean stem volume at 85 months for the population of all genotypes of both hybrid types was significantly greater ($p \leq 0.05$) than the mean stem volume for the best pure-species (Table 2a). Among the hybrid types, the mean stem volume of *E. camaldulensis* × *E. globulus* clones was significantly higher than that of the *E. camaldulensis* × *E. grandis* clones. For the *E. camaldulensis* × *E. grandis* hybrid, mean stem volume of all clones was 96% greater than that for the best of its two pure-species parents (*E. grandis*). For the *E. camaldulensis* × *E. globulus* hybrid, mean stem volume of all clones was 122% greater than the best pure-species (*E. grandis*) and 133% greater than the best performing parent to this hybrid (*E. camaldulensis*).

The mean stem volume at 85 months of the select commercial set of each hybrid type was also significantly greater ($p \leq 0.05$) than the mean stem volume of the best pure-species (Table 2b). Mean stem volume of the commercial set of *E. camaldulensis* × *E. globulus* hybrids was significantly greater ($p \leq 0.05$) than that for the commercial set of *E. camaldulensis* × *E. grandis* hybrids. For the commercial set of *E. camaldulensis* × *E. grandis* hybrids, mean stem volume gain over the best pure-species parent (*E. grandis*) was 157%. For the commercial set of *E. camaldulensis* × *E. globulus* hybrids, mean stem volume gain over *E. grandis* was 236%, and 253% over the best performing parent

to this hybrid (*E. camaldulensis*). Growth curves for the various species and groupings of hybrid taxa are illustrated in Figure 1.

Survival of the select *E. camaldulensis* × *E. globulus* and *E. camaldulensis* × *E. grandis* clones was 100%, compared to pure *E. globulus* (0%) and pure *E. grandis* (20%) (Table 2b). In contrast to pure *E. globulus* and *E. grandis*, survival of pure *E. camaldulensis* was 100%. Average survival across all clones of each hybrid type was 75% for *E. camaldulensis* × *E. globulus* and 90% for *E. camaldulensis* × *E. grandis* (Table 2a).

Site-type 2 Medium to low rainfall, non-saline recharge sites

The selected hybrid group comprising the top 10% of genotypes performed significantly better ($p \leq 0.05$) than the top ranked pure-species in both the winter maximum rainfall and the uniform and summer maximum rainfall trials (Table 3a and b). Mean stem volume of the select hybrid group in the winter maximum rainfall trials was 30% greater than that of the best pure-species (*C. maculata*), and was 27% greater than the best pure-species in the uniform and summer maximum rainfall trials (*E. sideroxylon*).

DISCUSSION

Genetic improvement of *Eucalyptus* for commercial productivity in medium to low rainfall and saline site conditions.

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 work indicate the potential for a similar revolution in eucalypt hybrids for forestry in stressed environments. In this study, inter-specific hybridisation has permitted exploitation and re-packaging of natural genetic variation available among inter-breeding eucalypt species to achieve substantial improvements in adaptation and productivity.

The Mt Scobie trial site presents soil conditions that would typically be considered stressful for growth of non-halophytic tree and crop species: shallow watertable (0.3 to 1.5 m) leading to problems with root zone aeration; moderately saline groundwater (average of 11.2 dS/m); and saline soil conditions in the active rootzone ($EC_{e_{calc}}$ 7 to 19 dS/m for 0 to 60cm) having direct 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 ≥ 0.5 m) leading to problems with nutrient availability. These site conditions, typical of many saline degraded areas of the Murray-Darling Basin and the Shepparton Irrigation Region in particular, are unsuitable for agricultural crops which are typically restricted to salinities of less than 2 dS/m (Ghassemi *et al.*, 1995).

Under the stressful conditions of the Mt Scobie site, significant heterosis was displayed by both hybrid types relative to their respective parental species, with mean stem volume gains of 96 to 133% (Table 2a). In addition, both hybrid types appeared to display partial dominance for survival at 85 months, with 90% survival for *E. camaldulensis* × *E. grandis* and 75% for *E. camaldulensis* × *E. globulus*, against expected means of 60% and 50% respectively (Table 2a).

Selection of a set of commercial clones increased the potential gain in a deployment population further to between 157% and 253% (Table 2b). The practical gain in survival of this commercial set is equal to that of the high parent, with both hybrid types recording 100% survival at 85 months (Table 4b).

These results indicate that, under the type of saline conditions presented at Mt Scobie, the hybrids appear to combine the complimentary traits of the parent species (*E. globulus* and *E. grandis* – faster growth but lower salt tolerance; and *E. camaldulensis* – slower growth but higher salt tolerance). The practical implication of this result is the potential for increased timber production from these hybrids under shallow saline watertable conditions compared to the pure-species.

Similarly, the NSW recharge site trials which span a rainfall range of 530 mm/yr to 710 mm/yr, present rainfall conditions below that typical of the majority of plantation forestry sites in Australia (Anon., 2005). For forestry purposes, low rainfall in southern Australia is defined as 400 to 600 mm/yr; medium rainfall as 600 to 800 mm/yr, and high rainfall as >800 mm/yr (Harwood and Bush, 2002). Salinity in eastern Australia predominately occurs in the 400 to 700 mm rainfall zone. As such, species suitable for commercial re-forestation of recharge areas of saline catchments need to be both drought tolerant and water-use efficient to grow well in moisture limited conditions. The results of the NSW dryland salinity trials indicate that clonal selection among the hybrids can deliver productivity gains of 27 to 30% relative to pure-species under medium to low rainfall conditions. This gain, achieved from a relatively small pool of 84 genotypes, could potentially be increased by selection from a larger population. Importantly, the best performing hybrids from this relatively small set displayed greater across-site stability than the pure-species. Although changes in rank among hybrid genotypes and pure-species occurred between sites, each individual select hybrid outperformed the best pure-species on un-weighted mean performance across all sites. This stability of individual genotypes translated into the select hybrid set having a significantly better average performance across all six sites than the best pure-species.

Together, the Mt Scobie and NSW recharge trial results indicate that *E. camaldulensis* hybrids display a broad spectrum of stress tolerance, stable performance across a wide range of site conditions, and are able to achieve high rates of growth relative to other commercial eucalypt species in medium to low rainfall and saline areas. These three attributes make these hybrids a viable option for integrating commercial forestry into agriculture – one of the key actions required to address salinity. Maintenance of this productive advantage to harvest maturity will be necessary to realise these gains. Prior work with medium to low rainfall forestry has demonstrated the feasibility of growing trees to maturity by managing tree stocking to balance plantation water demand with soil water availability (Moore, 2000). Similarly, recent work modelling the growth of these same *E. camaldulensis* hybrids on sites with shallow saline watertables has identified combinations of soil conditions and management factors that will allow productivity on saline discharge sites to be sustained (Dale *et al.*, 2006).

Maximising the benefits and minimising the impacts of commercial-environmental plantations.

In contrast to production forestry in higher rainfall areas, forestry aimed at delivering both wood products and environmental services in medium to low rainfall areas will require the targeted re-introduction of trees as a mosaic in the rural landscape. The first level will require plantations of adequate scale to be established to reduce groundwater recharge, utilise discharge and intercept lateral flows in order to comprehensively address hydrological imbalances resulting from prior land use changes such as conversion of natural woodland to annual crops (Taylor *et al.*, 2002).

At the second level, the work of van Dijk *et al.* (2004) indicates that plantation development will need to be targeted to those sub-catchments of river systems that maximise the positive benefits of plantations on overall catchment health (reduced land salinisation and movement of salt, nutrient and sediment into streams), and minimise potential negative effects (reduced streamflow volumes and reduced inflows of low salinity water which may lead to increased salt concentrations in river systems with negative impacts on native biodiversity).

The scale of forestry required to address salinity.

The Murray Darling Basin Commission Salinity Reforestation Bank envisaged the need for targeted establishment of around 1.5 million hectares within the 500 to 800 mm rainfall zone – 4.2% of the land area of this zone – for plantations to exert an appreciable effect on regional groundwater tables in the Basin. This scale of planting would require an area rivalling Australia's existing plantation resource in high rainfall areas (Anon, 2005). The associated scale of capital investment, and the trend of natural resource management agencies to leverage limited public funds with private investment will often dictate that such forests provide economic returns in order to encourage and sustain capital investment.

In light of this requirement for commercial viability, other specialty timber genera not considered in the NSW trials, but with reasonable growth rates and high stress tolerance for medium to low rainfall and saline areas such as *Casuarina obesa* (Safstrom, 2002) could also be considered for genetic improvement and plantation development. However, an important consideration for any species is the market size for its products and capacity for product utilisation on a large industrial scale. Some inroads have been made in this direction with Mallee species for biomass energy (Enecon, 2001), but few existing tree products rival the global market for roundwood of 1.7 billion m³/yr in 1995, projected to increase to 2.3 billion m³/yr in 2045 (Jaakko Poyry, 1999).

Improvements in productivity achieved by *E. camaldulensis* 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 *E. camaldulensis* hybrids can achieve harvestable log size of at least 40 cm diameter in 20 to 25 years (requiring a diameter growth rate of 1.6 to 2.0 cm/yr). This target growth rate has been exceeded in many other trials (unpublished data). Further improvements in clonal selection may reduce this period, while developments in sawmilling and veneering technology may reduce optimum log sizes and rotation lengths.

Fortuitously, the need for large scale re-forestation to control salinity is fully consistent with the requirement for development of a critical resource size to supply an industry based on processing of wood and fibre products. While hardwood sawmilling operations (currently based on native forests) can operate on a resource of as little as 5,000 ha (RIRDC, 1996), an internationally competitive softwood sawmill requires a minimum resource base in the order of 38,000 ha (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. 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.

A further benefit of large scale plantations integrated with agriculture, in addition to providing salinity benefits together with commercial timber, is the flow-on benefit to rural communities. Such plantations can be expected to create 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 by participating in the returns from tree growing. The environmental and economic benefits from a single 20,000 ha resource catchment managed over a period of 40 years, has been estimated to have a net present value in the magnitude of AUD \$23 million (using a discount rate of 8%). This does not include 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.

Potential for partnerships between farmers, catchment management authorities and private investment

The scale of reforestation required to address salinity will require significant capital investment. The proposed 1.5 million ha Murray Darling Basin Commission Salinity Reforestation Bank envisaged an investment of AUD \$17 billion over 50 years. Full funding for such projects from catchment boards and natural resource management agencies, even where economic returns are attractive, is undoubtedly impractical. At the same time, the task is unlikely to be achieved by land-rich, cash-poor farmers, the custodians of the land on which re-introduction of trees is required, given the long investment periods to realize returns from forestry. This opens the opportunity for partnerships between catchment authorities, landholders and investors able to absorb the cash-flow profile of forestry investment, where most expenses are incurred at the start of a rotation and returns at the end.

From such partnerships, each party stands to gain significantly. Farmers can provide the land on which re-introduction of trees is required to achieve benefits to downstream land managers, water users and native ecosystems. At the same time farmers making land available for tree planting may benefit from lease fees, giving them certainty of annual income from a portion of their property, or alternatively through sharing the profit of the timber crop, as well as direct on-site benefits of tree establishment including: shade and shelter for stock; windbreaks for crops, pastures and stock; habitat for natural predators - allowing reduced insecticide use; and direct return of degraded land to productive use. Catchment management authorities, mandated with repair and improvement of the natural resources within their jurisdiction, benefit from the ability to leverage limited government funds with private investment in public good projects that enhance environmental sustainability. In turn, this will allow them to achieve a larger scale of land-use change than they could with public grant funds alone. Finally, private investors receive long-term returns from harvesting of timber products, with risk and cost reduced by public co-investment interested in purchasing the public good environmental benefits. Corporate investors may also enjoy the goodwill of facilitating public good environmental works and stimulating rural economies.

CONCLUSIONS

Improvements in productivity achieved by *E. camaldulensis* hybrids under saline and medium to low rainfall environments should enable commercially viable growth rates to be achieved in the key areas requiring re-forestation for salinity abatement in Australia.

The scale of re-forestation required to address salinity is consistent with the scale of plantation required to supply timber processing facilities that are competitive on a world scale. Significant opportunity exists for private investors to partner with natural resource management agencies in projects with commercial and environmental benefits.

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Table 1: Key climatic data for medium to low rainfall, non-saline recharge trials (Australian Bureau of Meteorology, <http://www.bom.gov.au/climate/averages/>).

Station	Mona Vale	Tuffnell Park	Lui Station	Winston Park	Silsoe	Emerald Hills
Nearest meteorological station	Wagga Airport	Junee	Mudgee	Molong	Quirindi	Gunnedah
Trial latitude and longitude	35°12', 147°30'	34°57', 147°39'	32°39', 149°50'	32°49', 148°43'	31°39', 150°40'	30°52', 150°06'
Rainfall seasonality	Winter	Winter	Uniform	Uniform	Summer	Summer
Av. Ann. Rainfall (mm)	584	531	675	707	685	619
Decile 1 Rainfall (mm)* ¹	418	367	430	467	458	377
Lowest Min Temp (°C)	-6.3	-5.0	-8.3	-8.8	-6.7	-5.6
Highest Max Temp (°C)	44.8	46.1	42.2	42.3	41.8	43.3
Days <0°C	22.1	24.8	38.5	66.4	31.1	9.8
Days > 35°C	18.2	18.2	13.3	12.5	19.6	22
Annual Evap. (mm)	1825	1825	1752	1825	1934	1934

¹ Decile 1 rainfall means that there is a 10% chance that the annual rainfall will be at or below this figure.

Table 2: BLUP means for mean stem volume (dm³ per tree), significance of differences between means (P = 0.05), stem volume gain relative to the best pure-species (%), and survival (%) for: (a) the hybrid population means (after thinning) of *E. camaldulensis* x *E. globulus* (54 genotypes) and *E. camaldulensis* x *E. globulus* (106 genotypes) compared to control species *E. grandis*, *E. globulus* and *E. camaldulensis*; and, (b) the grouped commercial clone selections of *E. camaldulensis* x *E. globulus* (7 genotypes) and *E. camaldulensis* x *E. grandis* (6 genotypes) compared to control species *E. grandis*, *E. globulus* and *E. camaldulensis*, for the Mt Scobie trial. There is no significant difference between taxa groupings with the same letter.

(a) Comparison of pure-species with hybrid population means (after thinning), Mt Scobie.					(b) Comparison of pure-species with commercial clone selections of each hybrid taxa, Mt Scobie.				
Species	Mean stem volume (dm³)	Significance (p ≤ 0.05)	Relative gain (%)	Survival (%)	Species	Mean stem volume (dm³)	Significance (p ≤ 0.05)	Relative gain (%)	Survival (%)
<i>E. globulus</i>	0	a	-100%	0%	<i>E. globulus</i>	0	a	-100%	0%
<i>E. camaldulensis</i>	29.5	b	-5%	100%	<i>E. camaldulensis</i>	29.5	b	-5%	100%
<i>E. grandis</i>	31.1	b	0%	20%	<i>E. grandis</i>	31.1	b	0%	20%
<i>E. camaldulensis</i> x <i>grandis</i> (pop'n)	60.8	c	96%	75%	<i>E. camaldulensis</i> x <i>grandis</i> (selects)	80.0	c	157%	100%
<i>E. camaldulensis</i> x <i>globulus</i> (pop'n)	68.9	d	122%	90%	<i>E. camaldulensis</i> x <i>globulus</i> (selects)	104.4	d	236%	100%

Table 3: BLUP means for mean stem volume (dm³ per tree), significance of differences between means (P = 0.05), and stem volume gain relative to the best pure-species (%), for: (a) the two winter maximum rainfall trials (Mona Vale and Tuffnell Park); and, (b) the four trials spanning uniform and summer maximum rainfall areas (Lui Station, Winston Park, Silsoe and Emerald Hills). There is no significant difference between taxa with the same letter.

(a) Southern NSW trials (Winter maximum rainfall)				(b) Central and northern NSW trials (Uniform and summer maximum rainfall)			
Species	Mean stem volume (dm³)	Significance (p ≤ 0.05)	Relative gain (%)	Species	Mean stem volume (dm³)	Significance (p ≤ 0.05)	Relative gain (%)
<i>E. caldocalyx</i>	6.0	a	-46%	<i>A. mearnsii</i>	10.9	a	-37%
<i>E. sideroxylon</i>	8.6	b	-23%	<i>C. variegata</i>	10.3	ab	-40%
<i>E. camaldulensis</i>	10.4	c	-6%	<i>E. argophloia</i>	13.4	b	-2
<i>A. mearnsii</i>	9.9	cd	-11%	<i>E. camaldulensis</i>	15.1	c	-12%
<i>C. maculata</i>	11.2	d	0%	<i>E. sideroxylon</i>	17.1	d	0%
Select hybrids	14.5	e	30%	Select hybrids	21.7	e	27%

Figure 1: Growth curves to 85 months of age for mean stem volume at Mt Scobie. Growth curves for the mean of all clones of both the *E. camaldulensis* x *E. grandis* and *E. camaldulensis* x *E. globulus* hybrid types, plus the mean of commercial clone selections of each hybrid are shown in comparison to the growth curves of their pure-species parents: *E. grandis*, *E. globulus* and *E. camaldulensis*. Stem volume growth of both the hybrid populations trialled and the select commercial sets is significantly greater than that of any of the pure-species parents.

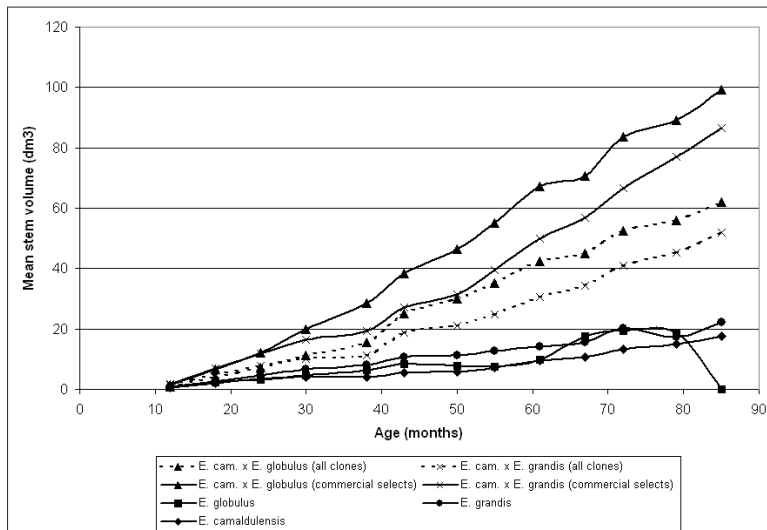


Figure 2: Three and a half year old stand of *E. camaldulensis* x *E. grandis* and *E. camaldulensis* x *E. globulus* hybrids at Mt Scobie in northern Victoria. Note the salt encrustation on the bare scalded area in the foreground. Poorly formed trees on the edge are pure *E. camaldulensis* planted as buffer rows. Mean tree height of the closest replicate is 5.7 m. Predominant height (tallest 50 trees per hectare) of the closest replicate is 8.0 m.