PERFORMANCE OF INTERSPECIFIC F_1 EUCALYPT HYBRIDS IN ZIMBABWE

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ABSTRACT

Survival, growth and stem straightness were assessed at 7 years of age for F_1 hybrids of *E. grandis* with *E. saligna*, *E. pellita* and *E. urophylla* established at a high rainfall area, and the same traits were assessed at 6 years for F_1 hybrids of *E. grandis* with both *E. camaldulensis* and *E. tereticornis* established at two low rainfall sites in Zimbabwe. Survival was moderate to high in all taxa. Both *E. grandis* × *E. saligna* and *E. grandis* × *E. urophylla* hybrids from controlled crosses outperformed the local control in growth and straightness with the former outperforming the local control by 41 %, and the latter by 16 % in volume. The natural hybrid *E. grandis* × *E. pellita* had similar growth to the local control, and the natural hybrid between *E. grandis* and *E. saligna* was outperformed by the control. The most productive hybrid at the low rainfall sites, *E. grandis* × *E. camaldulensis*, outperformed the control by as much as 68 % in volume. The other dry-zone hybrid, *E. grandis* × *E. tereticornis*, outperformed the control by 25 % in volume. Heterosis was exhibited in all the hybrids and was expressed differentially at different sites, in different traits and in crosses involving different species. The fast growth rate of the hybrids in this study suggests that, with confirmation via further tests in more appropriate field designs with broadly-based controls, commercial planting of eucalypt hybrids both in high and low rainfall areas may be favourable in Zimbabwe. For the best eucalypt hybrids, *E. grandis* × *E. saligna* and *E. grandis* × *E. camaldulensis*, the best clones could be selected and coppiced, and then clonal tests from the coppices could be started. Given that all the controlled crosses reported in this study were from South Africa, there is a need to test the potential of locally produced hybrids.

Key words: *Eucalyptus camaldulensis*, *E. grandis*, *E. pellita*, *E. saligna*, *E. tereticornis*, *E. urophylla*, hybrids, heterosis.

INTRODUCTION

Eucalyptus grandis is the most important exotic hardwood in Zimbabwe, comprising 90 % of the hardwood plantations. It is fast growing and well known for its excellent form. It is extensively used for poles, mining timber, pulp and furniture. *E. grandis* is also a major timber species in many tropical and subtropical parts of the world, especially Brazil and South Africa. Its success as an exotic species has been due primarily to its fast growth rates and wide adaptability. However, in Zimbabwe, *E. grandis* is limited to high-rainfall, moderate-altitude areas due to its poor resistance to drought, frost and diseases. Its wood is prone to splitting and warping and has relatively low density. To overcome the above limitations through complementarity *E. grandis* hybrids have been tested in Brazil, Congo and South Africa, and they are being tested in Zimbabwe.

Hybrid vigour has been widely reported by several researchers in eucalypts (BLANCO & LAMBETH 1991, MARTIN 1989, PARAMATHMA *et al.* 1997, VENKATESH & SHARMA 1977, VIGNERON *et al.* 2000), and in pines (GWAZE 1999, POWELL & NIKLES 1996, VAN DER SIJDE & ROELOFSEN 1986). For example, the hybrid *E. grandis* × *E. tereticornis* produced 35 m^3/ha/year in Congo while *E. grandis* was not adapted to the local field conditions and *E. tereticornis*, the then commonly planted species, produced only 12 m^3/ha/year at six years of age (CHAPERON 1984). The hybrid exhibits the vigour of *E. grandis* and the adaptability of *E. tereticornis*. Also, the hybrid *E. grandis* × *E. urophylla* had 81 % more volume per hectare than *E. grandis* at three years of age in Colombia (BLANCO & LAMBETH 1991).

The hybrids *E. grandis* with *E. urophylla, E. tereticornis* and *E. camaldulensis* are now managed profitability in large-scale plantations around the world. According to NIKLES (1992), the greatest successes with interspecific hybrids operationally have been with eucalypts in Brazil, China, Congo and South Africa. These successes with eucalypt hybrids have had a large influence in the development of hybrids in other countries and in other genera. The eucalypt and the pine hybrid programmes in Zimbabwe were influenced by spectacular results from South Africa (e.g. VAN DER SIJDE & ROELOFSEN 1986).

The present paper reports on the performance of F_1 eucalypt interspecific hybrids planted on three sites in

Zimbabwe. The hybrids involved *E. grandis*, with *E. camaldulensis*, *E. saligna*, *E. pellita*, *E. tereticornis* and *E. urophylla*.

MATERIALS AND METHODS

Materials

In 1990 seeds of the hybrids between *E. grandis* with *E. camaldulensis, E. saligna, E. tereticornis* and *E. urophylla* were obtained from Hans Merensky Holdings (Tables 1), South Africa. Hybrid parents of *E. grandis, E. saligna* were intensively-selected clones in seed orchards, while those of *E. camaldulensis, E. tereticornis* and *E. urophylla* were selections in provenance trials. In all the hybrids, *E. grandis* trees were used as the female parents. A natural hybrid between *E. grandis* and *E. pellita* was obtained from Australia, and the natural hybrid between *E. grandis* and *E. saligna* was obtained from Australia and Zimbabwe. Controls of pure species were included in tests, but they were not the actual parents of the hybrids. These control pure species were from Australia and Zimbabwe, and were at various stages of improvement (Table 1). Pure species of *E. pellita* was obtained from a natural stand in Australia, *E. saligna* and *E. camaldulensis* from provenances trials and *E. grandis* from a seed orchard in Zimbabwe (Table 1). These controls were narrowly based, being represented by only a few families.

Field Design and Assessment

In 1991 three hybrid trials were established at John Meikle Research Station for the wet-zone hybrids, and at Mtao and Norton for the dry-zone hybrids (Table 2). Field design was a randomized complete block design with 30 replicates. Families were planted in single tree plots at a spacing of 2.7 × 2.7 m. Survival, height, diameter and straightness were assessed at 7 years for the wet-zone hybrids and 6 years for the dry-zone hybrids. Stem straightness was assessed using a 7-point absolute scale (1 = crooked to 7 = very straight) outlined by BARRETT & MULLIN (1968). Volume (m^3) was derived using the following *Eucalyptus grandis* volume equation by BREDENKAMP (1982):

$$\log(\text{Volume}) = -4.2328 + 1.7154 \log(\text{DBH}-2) + 1.1070 \log(\text{HT})$$

where DBH is diameter at breast height in centimetres and HT is height are in metres.

Statistical Analysis

The data from each individual site were analysed using general linear model (GLM) procedure of SAS[a] (1985) assuming the random effects of replication, fixed effects of taxon and random effects of their first order interaction. For pooled analysis of the dry-zone hybrids the fixed

Table 1. Details of the genetic material used.

Taxon	Supplier[1]	Families	
		Type[2]	Number
Taxa planted at the wet zone trial at John Meikles Research Station			
E. grandis (EGR)	Zimbabwe, FRC	OP (orchard)	1
E. saligna (ESA)	Zimbabwe, FRC	OP (provenance trial)	1
E. pellita (EPA)	Australia, ATSC	OP (wild)	1
EGR × ESA	Australia, ATSC , Zimbabwe, FRC	OP (natural hybrid)	4
EGR × ESA	South Africa, Hans Merensky Holdings	Full-sib	10
EGR × EUR[3]	South Africa, HansMerensky Holdings	Full-sib	4
EGR × EPE	Australia,ATSC	OP (natural hybrid)	1
Taxa planted at the dry zone trials at Mtao and Norton			
E. camaldulensis (ECA)	Zimbabwe, FRC	OP(provenance trial)	2
E. grandis (EGR)	Zimbabwe, FRC	OP(orchard)	3
E. tereticornis (ETE)	Zimbabwe, FRC	OP(provenance trial)	1
EGR × ECA	South Africa, Hans Merensky Holdings	Full-sib	8
EGR × ETE	South Africa, Hans Merensky Holdings	Full-sib	8

[1)] FRC = Forest Research Centre; ATSC = Australian Tree Seed Centre; [2)] OP = open pollinated; [3)] EUR = *E. urophylla*.

Table 2. Details of eucalypt hybrid field sites.

Site	John Meikle Research Station	Mtao	Norton
Longitude	32° 51′ E	30° 38′ E	30° 44′ E
Latitude	18° 41′ S	19° 22′ S	17° 53′ S
Altitude (m)	1300	1477	1400
Mean annual rainfall (mm)	1711	755	1000
Soil parental material	granite	granite	granite

Table 3. Taxon least squares means ∓standard errors for height, diameter, volume and straightness at 7 years of age in the wet zone trial.

Taxon	Survival (%)	Height (m)	Diameter (cm)	Volume ($dm^3.tree^{-1}$)	Straightness (score)
EGR	83	24.9 ± 1.01^{ab}	16.5 ± 0.95^{b}	253.1 ± 34.0^{bc}	4.5 ± 0.23^{ab}
ESA	67	24.4 ± 0.94^{ab}	15.6 ± 0.88^{b}	245.3 ± 31.6^{bc}	4.0 ± 0.21^{b}
EPE	67	13.3 ± 0.94^{d}	9.6 ± 0.88^{c}	55.0 ± 31.5^{d}	2.7 ± 0.21^{c}
EGR×ESA[1]	88	21.8 ± 0.44^{c}	15.5 ± 0.40^{b}	212.5 ± 14.6^{c}	4.0 ± 0.10^{b}
EGR×ESA	87	26.8 ± 0.32^{a}	19.1 ± 0.30^{a}	379.9 ± 10.9^{a}	4.8 ± 0.07^{a}
EGR×EUR	66	25.1 ± 0.60^{a}	17.5 ± 0.56^{ab}	307.3 ± 20.1^{bc}	4.9 ± 0.13^{a}
EGR×EPE[1]	94	22.7 ± 1.17^{bc}	15.3 ± 1.10^{b}	258.0 ± 39.4^{bc}	4.2 ± 0.26^{b}

[1)] Natural hybrid; [a, b, c, d] means within a column with different superscripts differ at ($p < 0.05$).

Table 4. Taxon least squares means ∓ standard errors for height, diameter, volume and straihtness at 6 years of age at Mtao.

Taxon	Survival (%)	Height (m)	Diameter (cm)	Volume ($dm^3.tree^{-1}$)	Straightness (score)
ECA	100	9.8 ± 0.16^{a}	8.4 ± 0.21^{b}	28.8 ± 1.69^{b}	3.0 ± 0.05^{c}
EGR	89	9.7 ± 0.18^{a}	8.7 ± 0.24^{b}	30.6 ± 1.87^{b}	3.5 ± 0.05^{a}
ETE	96	8.5 ± 0.37^{b}	7.2 ± 0.49^{c}	19.8 ± 3.90^{c}	3.0 ± 0.11^{c}
EGR × ECE	84	9.7 ± 0.14^{a}	9.6 ± 0.20^{a}	39.6 ± 1.55^{a}	3.2 ± 0.04^{bc}
EGR × ETE	93	9.0 ± 0.12^{b}	8.7 ± 0.17^{b}	32.3 ± 1.31^{b}	3.3 ± 0.04^{b}

[a, b, c, d] means within a column with different superscripts differ at ($p < 0.05$)

Table 5. Taxon least squares means ∓ standard errors for height, diameter, volume and straightness at 6 years of age at Norton.

Taxon	Survival (%)	Height (m)	Diameter (cm)	Volume ($dm^3.tree^{-1}$)	Straightness (score)
ECA	89	10.8 ± 0.26^{a}	8.3 ± 0.33^{bc}	33.5 ± 3.32^{b}	2.9 ± 0.07^{b}
EGR	84	9.2 ± 0.31^{c}	7.8 ± 0.40^{c}	30.0 ± 39.6^{b}	2.9 ± 0.08^{b}
ETE	92	10.6 ± 0.40^{a}	8.6 ± 0.53^{bc}	34.6 ± 5.25^{b}	3.3 ± 0.11^{a}
EGR × ECA	69	10.4 ± 0.17^{a}	9.9 ± 0.23^{a}	51.6 ± 2.28^{a}	3.2 ± 0.05^{a}
EGR × ETE	80	9.7 ± 0.16^{bc}	9.0 ± 0.21^{b}	39.3 ± 2.13^{b}	3.3 ± 0.04^{a}

[a, b, c, d] means within a column with different superscripts differ at ($p < 0.05$)

effects were the taxons and the random effects were site, replication, interactions between site and taxon and between replication and taxon. Heterosis was estimated in terms of superiority to mid-parent values. Superiority of the hybrid to the each of the parental species was also determined.

RESULTS

Individual site analysis

Survival

Survival percentages (Tables 3, 4 and 5) were high for all the pure species and their hybrids at Mtao and Norton except for the hybrid between *E. grandis* and *E. camaldulensis* at Norton (69 %). Survival was greater at Mtao than at Norton for all taxa probably due to greater soil depth at the former site. Despite the high rainfall at John Meikle Research Station, survival percentages were low for *E. saligna, E. pellita* and the hybrid between *E. grandis* and *E. urophylla* (66–67 %), probably due to the fact that 1992 was a particularly dry year. The *E. grandis* × *E. camaldulensis* hybrid had the lowest survival at both Mtao and Norton (Tables 4 and 5).

Growth

The taxa differed significantly in growth traits at all the - sites ($p < 0.001$), and the interaction between taxon and replication was not significant in all the growth traits, except for height at Mtao ($p < 0.05$) (Table 6).

All the hybrids planted at John Meikle Research station, except the natural ones, outperformed the pure species (Table 3), though these differences were not always statistically significant. The most productive hybrid was *E. grandis* × *E. saligna*, which outperformed the *E. grandis* control (preferred species for the site) by 7 % in height (not statistically significant at $p < 0.05$), 16 % in diameter and 41 % in volume (both statistically significant at $p < 0.05$). The second most productive taxon, *E. grandis* × *E. urophylla*, outperformed the local control by 1 % in height, 6 % in diameter and 16 % in volume, though none of these differences were significant at $p < 0.05$. The natural hybrid *E. grandis* × *E. pellita* had similar growth to the local control and the natural hybrid between *E. grandis* and *E. saligna* was outperformed by the control.

The most productive hybrid in the dry-zone, *E. grandis* × *E. camaldulensis*, outperformed all the pure species in diameter and volume at both sites (significant at $p < 0.05$) but not in height (Tables 4 and 5). At Mtao it outperformed the local control (*E. grandis*) by 32 % in volume and at Norton it surpassed the local control (*E. camaldulensis*) by 68 % in volume. *E. grandis* × *E. tereticornis* outperformed the local control by 12 % in volume at Mtao and by 25 % at Norton, but the differences were not statistically significant at $p < 0.05$.

As expected, the hybrids used in the wet-zone grew much faster than those used in the dry-zone due to the higher rainfall at John Meikle Research Station than the other two sites. The best hybrid at John Meikle Research station had about seven times more volume than the best hybrid at the drier sites (Tables 3–5).

There was large variation both among families and within families in the hybrids planted in the wet zone. For example, families within *E. grandis* × *E. saligna* hybrid ranged from 250–469 dm^3 in volume per tree and the top three families of this hybrid surpassed the best control by 75 %. Variation within the hybrids planted in the dry zone was also large with volume ranging from 28.1 to 65.6 dm^3 for families within *E. grandis* × *E. camaldulensis* hybrid. The top three families within this hybrid surpassed the best control by 100 %.

Straightness

The taxa differed significantly in straightness at all sites ($p < 0.001$), and the interaction between taxon and replication did not differ significantly at all sites, except at Norton ($p < 0.001$) (Table 6).

The best hybrids in the wet-zone in terms of growth (*E. grandis* × *E. saligna, E. grandis* × *E. urophylla*) also had better stem straightness than the pure species, but their stem straightness did not differ significantly from that of *E. grandis* (Table 4). The hybrids planted at Mtao had inferior stem straightness to the control (*E. grandis*), while at Norton both *E. grandis* × *E. camaldulensis* and *E. grandis* × *E. tereticornis* hybrids had better stem straightness than the local control (*E. camaldulensis*) (Tables 4 and 5).

Pooled analysis

The taxa were significantly different in all traits ($p < 0.001$) on data pooled across two sites (Table 7). Both hybrids grown in the dry zone performed better in volume growth ($p < 0.05$) and straightness compared to the pure species ($p < 0.05$, except *E. grandis*) (Table 8). The best performing taxon in volume growth across both Mtao and Norton sites, *E. grandis* × *E. camaldulensis*, had 56 % more volume per tree than the best pure species (Table 8).

On average all taxa had significantly better height and volume growth ($p < 0.001$) at Norton than at Mtao (Tables 4, 5, and 7). This may be attributed to higher rainfall at the former site (Table 2). However, *E. grandis* grew better at Mtao than Norton. Taking into account the rainfall at Mtao and the fact that *E. grandis* is drought sensitive, *E. grandis* is not expected to grow well at this site. However, due to the deep soils found at Mtao, *E. grandis* is grown commercially at this site. The deep soils explain why *E. grandis* performed better at Mtao than at Norton despite the former site having lower rainfall.

Table 6. Significance levels of the treatment effects for growth and straightness.

Site	Variable	Treatment		
		Replication	Taxon	Replication × taxon
John Miekle Research Station	Height	**	***	ns
	Diameter	*	***	ns
	Volume	ns	***	ns
	Straightness	ns	***	ns
Mtao	Height	**	***	*
	Diameter	ns	***	ns
	Volume	ns	***	ns
	Straightness	***	***	ns
Norton	Height	*	***	ns
	Diameter	ns	***	ns
	Volume	ns	***	ns
	Straightness	***	***	***

ns =not significant; * = significant at 5 % level; ** = significant at 1 % level; *** = significant at 0.1 % level

Table 7. Significance levels of the treatment effects for growth and straightness for pooled analyses of dry-zone hybrids at Mtao and Norton.

Treatment	Variable			
	Height	Diameter	Volume	Straightness
Site	***	ns	***	ns
Rep (Site)	***	ns	ns	***
Taxon	***	***	***	***
Site × Taxon	***	*	ns	***
Taxon × Rep (Site)	**	**	ns	**

ns, *, **, *** = not significant, significant at 5, 1 and 0.1 % levels, respectively.

Table 8. Taxon least squares means∓ standard errors for height, diameter, volume and straightness at 6 years of age for pooled analysis of data Mtao and Norton.

Taxon	Height (m)	Diameter (cm)	Volume ($dm^3.tree^{-1}$)	Straightness (score)
ECA	10.3 ± 0.15^{a}	8.4 ± 0.19^{bc}	$31. \pm 1.78^{bc}$	3.0 ± 0.04^{b}
EGR	9.5 ± 0.17^{bc}	8.3 ± 0.22^{bc}	30.3 ± 2.06^{bc}	3.2 ± 0.05^{a}
ETE	9.5 ± 0.28^{bc}	7.9 ± 0.34^{c}	27.2 ± 3.39^{c}	3.1 ± 0.08^{ab}
EGR × ECA	10.0 ± 0.12^{ab}	9.8 ± 0.15^{a}	45.6 ± 1.40^{a}	3.2 ± 0.03^{a}
EGR × ETE	9.4 ± 0.10^{c}	8.9 ± 0.13^{b}	35.8 ± 1.24^{b}	3.3 ± 0.03^{a}

^{a,b,c,d} means within a column with different superscripts differ at ($p < 0.05$)

As indicated by the significance levels of the site × taxon effect (Table 7), genotype × environment interaction was present in all the traits, except volume. Genotype × environment interactions were due mainly to change in ranks of the taxa across sites. For example, *E. grandis* was ranked second in height and first in straightness at Mtao, but last for both traits at Norton (Tables 4 and 5).

Hybrid vigour

Hybrid vigour for *E. grandis* × *E. urophylla* could not be estimated since no pure *E. urophylla* was planted. However, the hybrid *E. grandis* × *E. urophylla* performed better than *E. grandis* by 16 % in volume (Table 3) but not significantly so at $p < 0.05$. Given that *E. grandis* is likely to be the better parent at this site, heterosis may be inferred in this hybrid.

Heterosis, defined as superiority to mid-parent value, was observed in the other hybrids grown in the wet-zone (Table 9), but it was not statistically significant for diameter and straightness in *E. grandis* × *E. pellita* hybrid. Although heterosis in *E. grandis* × *E. pellita* was observed in volume, this hybrid was not superior to the best parental species.

Heterosis in hybrids grown in the dry-zone ranged from 10–23 % in diameter, 3–63 % in volume and 2–10 % in stem straightness (Table 9). Heterosis was statistically significant for diameter and volume, except diameter at Mtao and volume at Norton in *E. grandis* × *E. tereticornis* hybrid. Heterosis was not statistically significant from zero for height at both sites and in both hybrids. Negative heterosis was found in height growth in *E. grandis* × *E. tereticornis* hybrid at Mtao and Norton, whether the sites are analysed individually or pooled together.

Heterosis for height was expressed more strongly by the hybrids grown in the wet-zone than those grown in the dry-zone. It was expressed more strongly in volume, and less in straightness and height in all hybrids at all sites.

Table 9. Superiority (%) of the hybrids over pure species and mid–parent at 7 years of age at John Meikle Research Station, and at 6 years at Mtao and Norton.

Site	Hybrid	Pure species	Height	Diameter	Volume	Straightness
John Meikle Research Station	EGR×ESA	*E. grandis*	7	16	50	4
		E. saligna	10	22	55	20
		Mid-parent	9**	19***	53***	12***
	EGR×EPE	*E. grandis*	–9	–7	2	–9
		E. pellita	71	59	369	56
		Mid-parent	19**	20^{ns}	67*	8^{ns}
Mtao	EGR×ECA	*E. grandis*	0	10	29	–9
		E. camaldulensis	–1	14	38	7
		Mid-parent	-1^{ns}	12**	34***	-1^{ns}
	EGR×ETE	*E. grandis*	–7	0	31	–6
		E. tereticornis	6	21	14	10
		Mid-parent	-1^{ns}	11^{ns}	23*	2^{ns}
Norton	EGR×ECA	*E. grandis*	13	27	72	10
		E. camaldulensis	–4	19	54	10
		Mid-parent	5^{ns}	23***	63***	10**
	EGR×ETE	*E. grandis*	5	15	10	14
		E. tereticornis	–8	8	–4	0
		Mid-parent	-2^{ns}	12*	3^{ns}	7**
Mtao & Norton combined	EGR×ECA	*E. grandis*	5	18	50	0
		E. camaldulensis	–3	17	47	7
		Mid-parent	1^{ns}	18***	49***	4^{ns}
	EGR×ETE	*E. grandis*	–1	7	18	3
		E. tereticornis	–1	13	32	6
		Mid-parent	-1^{ns}	10**	25**	5^{ns}

ns, *,**,*** = Not significant, Significant at 5,1 and 0.1 % levels, respectively.

DISCUSSION AND CONCLUSION

In this study few hybrid families were available in some cases, and even fewer unrelated control families, and also average individual tree diameters and volumes would have been affected by differences in space available to individual trees (due to imperfect survival) and by differential competition in the single-tree plots. Notwithstanding, the results from this study suggest that heterosis was expressed but differentially at different sites, in different traits and in crosses involving different species. The criterion of heterosis reported in this study was not true heterosis since the hybrids were not compared to their true parents. However, the measurement of heterosis reported here for *E. grandis* × *E. camaldulensis* and *E. grandis* × *E. tereticornis* may be close to the true heterosis because the pure parental species were at the same stage of selection as the parents used to produce the hybrids. Both the *E. grandis* used in hybrids and that used as controls were from second-generation seed orchards, and the other species were from the best performing provenances. For the natural hybrid *E. grandis* × *E. pellita*, the heterosis reported in this study may be less than the true heterosis since one of the pure parental species, *E. grandis*, was from a seed orchard. In order to adequately quantify hybrid vigour, future hybrid tests in Zimbabwe should ensure proper parental representation. It should be noted that in eucalypts even where the proper parental species are available hybrid vigour might be biased upwards if the parents are from open pollinated seed. Eucalypts are self-fertile, and therefore seed from open pollination may have reduction in performance due to inbreeding effects. However, hybrids are from control pollination, and will not be affected by inbreeding effects.

For the hybrids grown in the wet-zone, the *E. grandis* × *E. saligna* hybrid grew best, outperformed the local control by 41 % in volume. Such an improvement in productivity, if repeatable operationally, should increase profitability of eucalypt plantations in Zimbabwe. However, such increase in productivity should be treated with caution due to the imperfect survival and other imperfections of the design highlighted above. It is suggested additional trials, with better design and breath of material be undertaken, and that wood studies be carried out on this hybrid to determine if it has superior wood qualities to pure *E. grandis*. *E. grandis* has lower wood density than *E. saligna* (BARNES 1998). One of the reasons for testing *E. grandis* × *E. saligna* hybrid was that the hybrid may combine the fast growth of *E. grandis* with the good wood qualities of *E. saligna*. Hence, the perceived attributes of the hybrid were faster growth, less splitting and higher wood density than *E. grandis*. For hybrids involving *E. grandis*, the indications are that the density is either intermediate between the parental species (DENISON & KIETZKA 1993), or higher than that of *E. grandis* (VAN WYK *et al.* 1989). From this study *E. grandis* × *E. saligna* had faster growth than *E. grandis* but the assertion on wood qualities needs to be tested as well.

Although superiority of *E. grandis* × *E. urophylla* to *E. grandis* in growth was observed in this study, commercial planting of this hybrid may only be justified after determining its disease resistance and wood quality attributes since its growth was inferior to that of *E. grandis* × *E. saligna*. The results in this study suggest that *E. grandis* × *E. urophylla* hybrid warrants little or no further attention, but consideration should be given to the fact that the hybrid was tested only at one site and using few families and its growth is exceptional in Brazil, Congo and South Africa. Therefore, it may be premature to dismiss this hybrid without testing it over a broad range of environments. Further tests should be carried out, particularly at lower altitudes, to determine if there is a hybrid habitat for *E. grandis* × *E. urophylla*. Although *E. grandis* × *E. pellita* does not appear to have as much potential to increase productivity as the other two hybrids grown in the wet-zone, it should also be tested over a broader range of environments using several families of control-crossed hybrids and adequate controls in appropriate design.

The present study points to the benefits of parental selection in order to increase productivity in hybrids. Natural hybrids were outperformed by the pure species while hybrids of selected parents were not, indicating the benefits of selecting within the pure species prior to crossing. Furthermore, the natural hybrids may have included inbred, advanced generation hybrids and/or backcrosses. Assuming additive gene effects predominate for traits of interest in the hybrid population, genetic improvement of the hybrids could be achieved by making recurrent selections in the parental species populations prior to hybridization. This will ensure that gain in the hybrid population is not 'once off', but is cumulative. Given the observed variation within the best hybrids, potential also exists to improve productivity in plantations by testing many hybrid families and selecting the best families or individuals within families and cloning. Other complex breeding strategies might be required if non-additive gene effects for traits being selected predominate in the hybrid population.

For the hybrids grown in the dry-zone, the hybrid *E. grandis* × *E. camaldulensis* outperformed the control by as much as 68 %, while *E. grandis* × *E. tereticornis* outperformed the control by 25 %, though the former had consistently lower survival. Apart from the improvement in growth, the hybrids grown in the dry-zone may have other features that may make them more attractive for planting. The hybrids *E. grandis* × *E. tereticornis* and *E. grandis* × *E. camaldulensis* were selected for testing in Zimbabwe because *E. tereticornis* and *E. camaldulensis* are more drought tolerant, have higher wood density, less splitting and less warping, but have poorer growth and poorer stem straightness compared to *E. grandis*. These hybrids may have the potential to make the marginal areas more productive by combining the fast growth trait of *E. grandis* and the drought resistance and better wood quality traits of *E. tereticornis* and *E. camaldulensis*. Apart from the high growth rate, the most promising hybrid grown in the dry-zone, *E. grandis* × *E. camaldulensis*, had better stem straightness than *E. camaldulensis* at Mtao but not at Norton. It is recommended that wood studies be carried out to determine if the most promising dry-zone hybrid, *E. grandis* × *E. camaldulensis*, has superior wood qualities to *E. grandis*.

Although there is a need to test these hybrids over a broader range of environments using several families of control-crossed hybrids, the fast growth rate of the hybrids suggests that, if confirmed in further tests with better designs, commercial planting of eucalypt hybrids both in high and low rainfall areas may be favorable in Zimbabwe. In the best hybrids, *E. grandis* × *E. saligna* and *E. grandis* × *E. camaldulensis*, the best individual trees would be selected, and these trees could be felled. The coppice from felled trees could be planted in a clonal multiplication area, which would provide cuttings for commercial planting. At the same time large number of clones from the best families should be screened to identify superior clones, which are adaptable to selected sites.

The hybrids reported in this study were developed in South Africa where conditions differ from those in Zimbabwe. Hence, it is important to test the potential of locally produced hybrids. Controlled pollination of hybrids between *E. grandis* and *E. camaldulensis* were started at Mtao in 1998, and will be extended to other crosses depending on pollen availability and success of pilot pollinations at Mtao. The most successful eucalypt hybrids in the world have *E. grandis* as one of its parents, and show hybrid vigour under conditions similar to Zimbabwe and hence the Zimbabwe Forestry Commission should also concentrate on the *E. grandis* hybrids.

Knowledge of genetic parameters is critical for the development of an effective hybrid-breeding programme. The Zimbabwe Forestry Commission should ensure that the new hybrids being developed locally would come from mating designs that allow for the efficient estimation of genetic parameters so as to make informed future decisions on the most effective breeding strategy.

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