PERFORMANCE OF SOME INTERSPECIFIC F_1 PINE HYBRIDS IN ZIMBABWE

David P. Gwaze
Forestry Commission, P. O. Box HG 595, Highlands, Harare, Zimbabwe

Received August 19, 1998; accepted November 1, 1999

ABSTRACT

Performance in height, diameter, volume and stem straightness of some F_1 interspecific hybrids involving *Pinus caribaea* var. *hondurensis, P. elliottii, P. oocarpa, P. tecunumanii* established at two sites in Zimbabwe is reported. At 5 years of age, hybrid vigour (heterosis) in all the traits was exhibited in all the hybrids at both sites, and was more clearly expressed at the low-elevation drier site. The volume production of the hybrid between *P. caribaea* and *P. tecunumanii* was more than four times that of the commonly grown *P. elliottii* and 52% more than the best performing pure species (*P. tecunumanii*) at the wetter site. This hybrid had less stem breakage than pure *P. tecunumanii* and better stem straightness than the parental species. The other hybrids also performed well relative to the pure species. The volume production of the hybrids between *P. caribaea* and *P. oocarpa*, and that between *P. caribaea* and *P. elliottii* were similar, and more than three times that of pure *P. elliottii* at the wetter site. The major limitation to breeding of the parental species of the best hybrid, *P. caribaea* × *P. tecunumanii*, is the poor flowering of the parental species in Zimbabwe. Therefore, hybrid seed of *P. caribaea* × *P. tecunumanii* for commercial planting in Zimbabwe will have to be imported from other countries where flowering conditions for these species are favourable, and breeding programmes of the species exist. In the short term a good strategy would be to identify the best individual *P. caribaea* × *P. tecunumanii* hybrid families, have them reproduced in Queensland, and start clonal tests in Zimbabwe from hedges developed from seed of the superior families.

Keywords: *Pinus tecunumanii, P. caribaea, P. oocarpa, P. elliottii,* hybrids, heterosis

INTRODUCTION

In Zimbabwe, forestry makes a significant contribution to the national economy. Its contribution is largely based on the wood processing industry which is primarily based on plantations of exotic species, particularly pines and eucalypts. These plantations are located mainly in the Eastern Highlands where the rainfall and soils are ideal for fast growth. Land ideal for plantation development is limited, and the increased demand for forest products in Zimbabwe will have to be met from either higher yields on recycled plantations on good sites or from marginal sites. The need to increase production per unit area in order to satisfy future wood requirements has led to the development of options for sustainable improvement of forest plantation productivity including research into performance of hybrids. Species trials established on marginal areas indicated that the current commercial pine species were not sufficiently productive. Therefore, alternative genotypes which are highly productive in these marginal areas are being tested, including hybrids. Furthermore, the research work on pine hybrids has been inspired by spectacular results from a number of tropical and subtropical countries.

Artificial interspecific hybrids of pines have been developed, and hybrid vigour in these crosses was reported as early as the 1920's in the United States of America (RIGHTER & DUFFIELD 1951). Currently, there is substantial information indicating that hybrids outperform the pure parental species due to heterosis in many tropical and subtropical regions (BLANCO & LAMBETH 1991, POWELL & NIKLES 1996, VAN DER SIJDE & ROELOFSEN 1986, VENKATESH & SHARMA 1977). For example, in South Africa, a hybrid between *Pinus elliottii* and *P. caribaea* var. *bahamensis* at age 14 years was reported to be 50% more in volume production than that of the pure *P. elliottii* commonly planted in that area (VAN DER SIJDE & ROELOFSEN 1986). The hybrid between *Pinus elliottii* and *P. caribaea* var. *hondurensis* at the same age outperformed pure *Pinus elliottii* by 100%. This demonstrates the potential role that hybrids could play in improving productivity of forest plantations and securing future wood supplies.

The first pine hybrid trials in Zimbabwe were established in the 1970's, and these involved *P. elliottii* and *P. taeda* (BARNES & MULLIN 1978). This hybrid was developed because the two species had complementary traits and were likely to cross easily given that they are closely related. Generally, results from these early tests were not spectacular enough to warrant further development of this hybrid. It was not until the 1990's that there was renewed interest in pine hybrids.

The present paper reports on the performance of the second Zimbabwean series of pine interspecific hybrids involving *P. caribaea* var. *hondurensis*, *P. elliottii*, *P. oocarpa* and *P. tecunumanii* established on two sites in 1993.

MATERIALS AND METHODS

Materials

The controlled pollinated hybrid families were provided by the Queensland Forest Research Institute, Australia, through the Oxford Forestry Institute. The sixty hybrid families involved *P. elliottii*, *P. oocarpa*, *P. caribaea* and *P. tecunumanii* (Table 1). The families originated from an incomplete factorial design of unrelated first and second generation parents. The material are described in detail by DIETERS *et al.* (1997). Controls of the pure species were included in the tests, but they were not the actual parents of the hybrids. The *P. elliottii* control from Zimbabwe was a full sib cross between outstanding parents in growth. Seedlings were raised at John Meikle Research Station and the tests were established at Cashel and John Meikle in 1993. Details of the field tests are given in Table 2.

Field design and assessment

Field design at John Meikle Research Station was an incomplete block design with 6 replicates and 16 blocks. Each family was planted in a row of 5 trees and the spacing between trees was 3 × 3 m. At Cashel the design was a randomised complete block design with 6 replicates. Spacing and plot size were similar to those at John Meikle Research Station. Survival, height, diameter and stem straightness were assessed at 5 years of age by the different teams at the two sites. Survival of each taxon was expressed as a percentage of the planted trees. Stem straightness was assessed using a 7-point absolute visual scale (1 = crooked to 7 = very straight) outlined by BARRETT & MULLIN (1968). Volume was derived using the following equation which was previously used by PSWARAYI *et al.* (1996) to estimate volume of *P. elliottii*:

$$\text{Volume} = 0.45 \times \pi \times (\text{diameter}/2)^2 \times \text{height}.$$

The hybrids involving *P. caribaea* and *P. elliottii* are known to have greater bark thickness than that of *P. elliottii* (NIKLES per. comm.). Therefore, the above

Table 1. Details of the genetic material used.

Taxon	Supplier [1]	Families	
		Type	Number
P. elliottii (PEE1)	Zimbabwe, FRC	Full-sib	1
P. elliottii (PEE2)	Australia, QFRI	OP (orchard)	3
P. caribaea var. *hondurensis* (PCH)	Australia, QFRI	OP (orchard)	5
P. tecunumanii (PTEC)	UK, OFI	OP (wild)	2
P.oocarpa (POOC)	Zimbabwe, FRC	OP (orchard)	5
PCH × PTEC	Australia, QFRI	Full-sib	29
PCH × POOC	Australia, QFRI	Full-sib	26
PEE × PCH	Australia, QFRI	Full-sib	5

[1] FRC = Forest Research Centre; QFRI = Queensland Forest Research Institute; OFI = Oxford Forestry Institute (seed from Honduras and Nicaragua); OP = Open pollinated (half-sibs).

Table 2. Details of hybrid field test sites.

	John Meikle	Cashel
Longitude	32° 51' E	32° 50' E
Latitude	18° 41' S	19° 37' S
Altitude (m)	1300	1525
Mean annual rainfall (mm)	1711	745
Soil parental material	Granite	Shale

equation is likely to slightly inflate the volume estimates of these hybrids.

Statistical analysis

The data were analysed using general linear model (GLM) procedure of Minitab with the model used accounting for the effects of replication and family. The coefficient of variation was calculated as standard deviation divided by the mean. Heterosis was estimated in terms of superiority to mid-parent values.

RESULTS

Survival and growth

Survival percentages were greater than 95% in all taxa.

The taxon least squares means and their standard errors coefficients for height, diameter, volume and straightness at each site at 5 years of age are shown in Tables 3 and 4. All the hybrids outperformed the pure species at both sites, with the hybrid between *P. caribaea* and *P. tecunumanii* being the most productive. *P. elliottii* is known to grow slowly at an early age in Zimbabwe, hence the results reported here which show that *P. elliottii* had the poorest growth are not surprising. *P. elliottii* from Australia (PEE2) outperformed the local *P. elliottii* (PEE1), with an advantage of 33% in volume at John Meikle and 16% in volume at Cashel.

Stem straightness

At John Meikle, the hybrids had better stem straightness than the pure species (Table 3). However, at Cashel *P. elliottii* pure species was as straight as the hybrids, and the other pure species had poorer stem straightness than the hybrids (Table 4).

Phenotypic variation

All traits, particularly volume, showed substantial variation: range for coefficient of variation was 9–63%

Table 3. Least squares means(LSM) and standard errors (SE) for height, diameter, volume and stem straightness at 5 years of age at John Meikle.

Taxon	N^1	Height (m)		Diameter (cm)		Volume ($m^3 \cdot ha^{-1}$)		Straightness (score)	
		LSM	SE	LSM	SE	LSM	SE	LSM	SE
PEE1	30	6.5	0.10	9.7	0.21	24.0	1.36	3.5	0.10
PEE2	89	7.1	0.13	10.9	0.22	35.5	2.15	3.8	0.07
POOC	149	8.7	0.14	13.8	0.24	70.9	2.62	3.5	0.06
PCH	150	8.8	0.12	13.8	0.20	69.9	2.41	3.6	0.05
PTEC	59	9.3	0.21	14.1	0.30	76.7	3.94	3.6	0.09
PCH × PTEC	867	10.0	0.05	16.7	0.07	112.9	1.24	4.0	0.03
PCH × POOC	773	9.5	0.05	15.4	0.09	92.9	1.22	4.1	0.02
PEE × PCH	145	9.3	0.11	15.6	0.19	93.5	2.65	4.3	0.06

[1)] *N* = number of trees.

Table 4. Least squares means(LSM) and standard errors (SE) for height, diameter, volume and stem straightness at 5 years of age at Cashel.

Taxon	*N*	Height (m)		Diameter (cm)		Volume ($m^3 \cdot ha^{-1}$)		Straightness	
		LSM	SE	LSM	SE	LSM	SE	LSM	SE
PEE1	30	5.2	0.14	9.3	0.27	17.7	1.34	3.7	0.15
PEE2	90	5.5	0.13	9.7	0.23	20.5	1.21	3.8	0.11
POOC	148	6.6	0.16	10.5	0.27	28.6	1.57	2.9	0.09
PCH	150	6.0	0.11	10.0	0.18	23.4	1.11	2.9	0.06
PTEC	60	7.2	0.29	9.2	0.43	37.7	2.55	2.7	0.14
PCH × PTEC	867	7.6	0.06	13.0	0.09	51.1	0.76	3.8	0.03
PCH × POOC	807	6.9	0.05	11.4	0.10	36.4	0.76	3.5	0.03
PEE × PCH	147	7.1	0.16	13.0	0.31	47.2	2.05	3.7	0.11

Table 5. Superiority (%) of the hybrids over the local control PEE1 *(P. elliottii)* at 5 years of age.

Site	Taxon	Height (m)	Diameter (cm)	Volume ($m^3 \cdot ha^{-1}$)	Straightness (score)
John Meikle	PCH × PTEC	53	72	359	16
	PCH × POOC	46	58	271	17
	PEE × PCH	42	61	273	22
Cashel	PCH × PTEC	48	39	189	3
	PCH × POOC	33	22	87	–6
	PEE × PCH	37	39	166	1

Table 6. Superiority (%) of the PCH×PTEC (*P. caribaea* × *P. tecunumanii*) hybrid over pure parent species and mid-parent at 5 years of age.

Site	Taxon	Height (m)	Diameter (cm)	Volume ($m^3 \cdot ha^{-1}$)	Straightness (score)
John Meikle	*P. caribaea*	14	21	68	12
	P. tecunumanii	7	19	52	12
	Mid-parent	11	20	60	12
Cashel	*P. caribaea*	28	30	118	31
	P. tecunumanii	6	42	36	41
	Mid-parent	17	36	77	36

Table 7. Superiority (%) of the PCH × POOC (*P. caribaea* × *P. oocarpa*) hybrid over pure parent species and mid-parent at 5 years of age..

Site	Taxon	Height (m)	Diameter (cm)	Volume ($m^3 \cdot ha^{-1}$)	Straightness (score)
John Meikle	*P. caribaea*	9	12	40	13
	P. oocarpa	9	10	34	18
	Mid-parent	9	11	37	16
Cashel	*P. caribaea*	15	15	55	20
	P. oocarpa	4	9	28	20
	Mid-parent	10	12	42	20

Table 8. Superiority (%) of the PEE×PCH (*P. elliottii* × *P. caribaea*) hybrid over pure parent species and mid-parent at 5 years of age.

Site	Taxon	Height (m)	Diameter (cm)	Volume ($m^3 \cdot ha^{-1}$)	Straightness (score)
John Meikle	*P. elliottii*	31	46	181	11
	P. caribaea	6	14	37	18
	Mid-parent	19	30	109	15
Cashel	*P. elliottii*	28	33	130	–2
	P. caribaea	18	30	101	28
	Mid-parent	23	32	116	13

(calculated using results in Tables 3 and 4), indicating potential to improve production through selection. The coeffient of variation in growth traits was slightly less in the local *P. elliottii* (PEE1) than in the other taxa at both sites. This may be attributed to the fact that there was only one family in the local *P. elliottii*. Coefficient of variation in all traits was much higher at Cashel than at John Meikle.

Site comparison

Generally, all the taxa had about 30% more volume production and higher straightness scores at John Meikle than at Cashel. There is little apparent taxon × site interaction for volume. Hybrids *P. caribaea* × *P. tecunumanii* and *P. caribaea* × *P. elliottii* ranked first and second at both sites and *P. elliottii* (PEE1), *P. elliottii* (PEE2) and *P. oocarpa* (POOC) ranked 8th, 7th and 5th at both sites. In contrast, stem straightness showed more interaction with site; this was especially so for *P. elliottii* (PEE1) and *P. caribaea* × *P. oocarpa*.

Comparison between performance of hybrids and pure *P. elliottii*

Growth and straightness of all the hybrids were compared to that of pure *P. elliottii* which is commonly grown at John Meikle (Table 5). All hybrids were superior in growth to the local control by at least 33% in height growth, 22% in diameter and 87% in volume. The margin of superiority was highest in volume where it was as high as 359% in *P. caribaea* × *P. tecunumanii* hybrid at John Meikle. The hybrids were also superior in straightness to the local control at John Meikle, but not at Cashel.

Hybrid vigour

The best hybrid (*P. caribaea* × *P. tecunumanii*) exceeded the pure parental species in all the growth traits and in straightness at both sites (Table 6). The mid parental values were exceeded by 60% and 77% in volume at John Meikle and Cashel, respectively, and by 12% and 36% in straightness at John Meikle and Cashel, respectively. This indicates that heterosis was present in this hybrid at both sites and the heterosis was expressed more at the marginal site, Cashel.

The other hybrids (*P. caribaea* × *P. oocarpa* and *P. elliottii* × *P. caribaea*) also exceeded their respective parental species in all the growth traits and in straightness at both sites, except straightness in relation to *P. elliottii* (Tables 7 and 8), indicating that heterosis was present in both hybrids at both sites. Heterosis was also expressed more at the marginal site.

DISCUSSION

BARNES & MULLIN (1978) found that the hybrid between *P. elliottii* and *P. taeda* outperformed the pure species on sites that were marginal for the pure species, but not on sites optimal for the pure species. Heterosis is clearly dependent upon the environment in which the hybrid is grown, and heterosis is strong in areas which are marginal for the pure species (MARTIN 1989). Therefore, matching of hybrids to sites is going to be critical to successful deployment of hybrids. In this study heterosis was present in all hybrids at both sites and the heterosis was expressed more at the more marginal site, indicating strong dominance effects at this age. Although heterosis was expressed more at the marginal site, volume production of all species and hybrids at the marginal site was more than 30% less than at the wetter site. It is important to note that the hybrids in this study were not compared to their true parents. Therefore, the heterosis reported here may be inflated particularly that of the hybrid between *P. caribaea* and *P. tecunumanii* because one of the pure parental species, *P. tecunumanii*, was from natural stands.

Also, BARNES & MULLIN (1978) found that hybrids have less variation than the pure species. This was not supported in this study, particularly at the harsher site, Cashel. However, the comparison of the variation of the various taxa is likely to be confounded by the small number of families in the pure species.

The growth of the hybrids was very impressive, particularly that between *P. caribaea* and *P. tecunumanii*. This hybrid has also grown rapidly in tropical Australia and Fiji (NIKLES & ROBINSON 1989). At 5 years of age at John Meikle, volume production of this hybrid was more than 4 times that of pure *P. elliottii* the commonly planted species at this altitude and 52% more than pure *P. tecunumanii*, the best performing parental species at the site. Apart from the good growth rate, the hybrid had better stem form than the pure species, and field observations indicated that the hybrid had less stem breakage than pure *P. tecunumanii*. Despite the good growth rate of pure *P. tecunumanii* in early introductions in Zimbabwe, it was evident that this species was unlikely to become a commercial species due, primarily, to high stem breakage even though some phenotypic variation has been observed in field tests. Stem breakage in *P. tecunumanii* is caused by winds of moderate intensity and mainly affects the upper portion of the crown at heavily branched whorls (DVORAK *et al.* 1993). Therefore, the hybrid appears to produce traits in useful combination by combining the good attributes of fast growth from *P. tecunumanii* and resistance to stem breakage from *P. caribaea*. The fast growth rate, better stem form and the resistance to stem breakage of the hybrid appears to indicate that commercial planting of this hybrid may be favourable. However, a major constraint to commercial planting of this hybrid, and to breeding of the pure species, is that *P. caribaea* does not flower at high altitudes in Zimbabwe. There are two options to acquire seed of this hybrid: import seed from Australia or improve flowering of the species by planting at low altitudes. The exceptional growth rate of this hybrid may justify importation of the hybrid seed from Australia. Since this seed is likely to be very expensive, the local industry will need to investigate the potential of propagating the few elite materials which is imported, through vegetative or micro propagation methods. A longer term strategy would be to plant *P. caribaea* on low altitude sites to promote early and profuse flowering. The low altitude areas are generally dry, and therefore any trees grown on these sites will have to be irrigated. A breeding programme at the low altitude areas with trees being irrigated may not be sustainable. Therefore, importing hybrid seed from Australia where a breeding program in the species exists may be more economical.

The other hybrids also performed well relative to the pure species. The volume production of the hybrids between *P. caribaea* and *P. oocarpa*, and that between *P. elliottii* and *P. caribaea* were similar, and more than three times that of pure *P. elliottii* at John Meikle. *P. elliottii* is known to grow slowly at early stages (slow starter) in Zimbabwe. If the species are for pulpwood production (rotation age 10–15 years), then *P. elliottii* should not be selected for planting. However, if the species are for sawn timber (rotation age 25–30 years) it is recommended that growth should be monitored up to at least half rotation age because the relative performance of the hybrids and *P. elliottii* at this early age may not reflect relative performance at harvest age. As observed in *Eucalyptus grandis* hybrids (DENISON & KIETZKA 1993), the hybrids reported here express heterosis early in life but may not maintain it up to rotation age.

All the taxa were more productive at John Meikle than at Cashel due better site conditions (higher rainfall, more fertile soils, higher soil depth) at the former site. The ranking of taxa were stable across sites, particularly for growth traits, indicating absence of genotype by environment interactions. Straightness scores were higher at John Meikle than at Cashel. The differences in straightness between the two sites may be partly attributed to different interpretations of the assessment scale by the different assessment teams. Straightness may also be confounded with tree size.

It should be noted that the hybrids reported in this study were from Australia where the species are grown in different conditions from those in Zimbabwe. Therefore, there is a need to test the potential of locally produced hybrids, particularly that between *P. patula* and *P. tecunumanii*. This hybrid between *P. patula* and *P. tecunumanii* may combine the good attributes of fast growth from *P. tecunumanii*, and frost resistance and resistance to stem breakage from *P. patula*. Also, it is envisaged that the hybrid may be successful at lower altitudes where pure *P. patula* is marginal, and that the hybrid may have the good silvicultural attributes of *P. patula*. Controlled crossing of local pine species in order to develop local hybrids is currently underway, and it is hoped that the material will be included in field tests in two years time.

CONCLUSION

The results highlighted that hybrids, particularly that between *P. caribaea* × *P. tecunumanii*, have the potential to improve early volume production and stem straightness of pine plantations in Zimbabwe. This hybrid also had less stem breakage than the parental species, *P. tecunumanii*. A major constraint to local production and subsequent commercial deployment and genetic improvement of the hybrid between *P. caribaea* × *P. tecunumanii* is the poor flowering of *P. caribaea* locally. It is highly recommended that possibilities of commercial deployment of this hybrid in Zimbabwe should be investigated using imported hybrid seed. The seed should preferably be imported from countries where breeding programmes of the parental species exist so that the gains are not once off but are ensured in advanced generations.

The paper also highlighted that heterosis existed in all the tested pine hybrids and the heterosis was differentially expressed at different sites.

Before the potential of hybrids can be fully realised, there is need to make local hybrids, match these carefully to sites, develop cost effective techniques to propagate these hybrids, and develop tree breeding strategies for sustainable genetic improvement of these hybrids. Hybrids will need screening not only for growth performance, but also for rootability of cuttings and for wood quality. Given the exceptional growth rates and desirable traits of hybrids reported here, and once information on the above research needs becomes available hybrids may play a significant role in the forestry industry in Zimbabwe.

ACKNOWLEDGEMENTS

I thank the Queensland Forestry Research Institute for genetic material. I thank the Zimbabwe Forestry Commission field staff at John Meikle and Cashel for managing and assessing the trials. Thanks are also due to Mr. I. Nyoka, Dr. D. G.

Nikles and Dr. M. Dieters for constructive comments, and Mr. C. Gumbie for statistical assistance.

REFERENCES

BARNES, R. B. & MULLIN, L. J. 1978: Three-year height performance of *Pinus elliottii* Engelm. var. *elliottii* × *P. taeda* L. hybrid families on three sites in Rhodesia. *Silvae Genetica* **27**:217–223.

BARRETT, R. L. & MULLIN, L. J. 1968: A review of introductions of forest trees in Rhodesia. Rhodesia Bulletin of Forestry Research no. 1, 227pp.

BLANCO, J. J. & LAMBETH, C. C 1991: Performance of the *Eucalyptus grandis* × *E. urophylla* hybrid, *E. grandis* seed sources, and improved families in Venezuela. Smurfot Group, Forestry Research Report No. 10. Unp.

DIETERS, M. J., NIKLES, D. G., TOON, P. G. & POMROY, P. 1997: Genetic parameters for F1 hybrids of *Pinus caribaea* var. *hondurensis* with both *Pinus oocarpa* and *Pinus tecunumanii*. *Canadian Journal of Forest Research* **27**:2024–1031.

DENISON, N. P. & KIETZKA, J. E. 1993: The use and importance of hybrid intensive forestry in South Africa. *S. A. For. J.* **165**:55–60.

DVORAK, W. S., LAMBETH, C. C. & BAILIAN, L. 1993: Genetic effects on stem breakage in *Pinus tecunumanii*. *New forests* **7**:237–253.

MARTIN, B. 1989: The benefits of hybridization. How do you breed for them? *In:* Proceedings of a conference on breeding tropical trees: population structure and genetic improvement strategies in clonal and seedling forestry (eds. G. L. Gibson, A. R. Griffin and A. C. Matheson). Pattaya, Thailand, 28 November–3 December, 1988. IUFRO working parties.

NIKLES, D. G. & ROBINSON, M. J. 1989: The development of *Pinus* hybrids for operational use in Queensland.*In:* Proceedings of a conference on breeding tropical trees: population structure and genetic improvement strategies in clonal and seedling forestry (eds. G. L. Gibson, A. R. Griffin and A. C. Matheson). Pattaya, Thailand, 28 November–3 December, 1988. IUFRO working parties.

POWELL, M. B. & NIKLES, D. G. 1996: Performamce of *Pinus elliottii* var. *elliottii* and *P. caribaea var. hondurensis*, and their F_1, F_2 and backcross hybrids across a range of sites in Queensland. Dieters, M. J., Matheson, A. C., Nikles, D. G., Hawood, C. E. and Walker, S. M. (Eds). In proc. "Tree Improvement for sustainable tropical forestry", Queensland, Australia, 27–1 November 1996. IUFRO working party S2.08.01. 382–383pp.

PSWARAYI, I. Z., BARNES, R. D., BIRKS, J. S. & KANOWSKI, P. J. 1996: Genetic parameter estimates for production and quality traits of *Pinus elliottii* Engelm. var. *elliottii* in Zimbabwe. *Silvae Genetica* **45**:216–222.

RIGHTER, F. I. & DUFFIELD, J. W. 1951: Interspecies hybrids in pines: a summary of interspecific crossing in the genus *Pinus* made at the Institute of Forest Genetics. *Journal of Heredity* **2**:75–80.

VAN DER SIJDE, H. A. & ROELOFSEN, J. W. 1986: The potential of pine hybrids in South Africa. *S. A. For. J.* **136**:5 –14.

VENKATESH, C. S. & SHARMA, V. K. 1977: Hybrid vigour in controlled interspecific crosses of *Eucalyptus teriticornis* × *E. camaldulensis*. *Silvae Genetica* **26**:121–124.