Mixing of seed crops from different years is an effective management strategy for enhancing effective population size in Eucalyptus seedling seed orchard crops

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Abstracts:

Seed orchard trees contribute more equally to the seed crop if the seed crops from consecutive years are mixed. Fertility variation among trees and effective population size were estimated for two successive years in four seedling seed orchards (eight-nine year old) of *Eucalyptus camaldulensis* and *E. tereticornis* established in two distinctly different locations, a dry (Pudukkottai in Tamil nadu) and a moist (Panampally in Kerala state), in southern India. Fertility variation estimated as the sibling coefficient (Ψ), was high (Ψ = 5-13) in the orchards and varied between two successive years except in the *E. camaldulensis* orchard (Ψ = 2 & 3) established on the moist site. Mixing of seed crops from two successive years reduced the fertility variation considerably. The relative effective population size increased in all orchards by 31 – 48% and the variance effective population size by 36-55%. Since the relative contribution of trees varies between years the composition of the seed crops vary and gene diversity of the seed mix would be equal to or more than that of the best crop. Diversity of seed from orchards of the same origin at different locations could vary since the fertility of families vary between locations but mixing of seed would affect the performance at either site as the seed from an orchard is best suited to a similar site.

Key words: gene diversity, fertility variation, *E. camaldulensis*, *E. tereticornis*, genetic drift

Introduction:

India is one of the largest planters of eucalypts in the world with around 8 million hectares of planted area (FAO, 2000). Industrial plantations of eucalyptus are now a major resource for production of high quality wood pulp in India. The demand for quality planting stock of eucalyptus has increased several folds in recent years. First generation seedling seed orchards were established with selections from natural provenances, to supply quality seed as per a breeding program for *E. camaldulensis* and *E. tereticornis* in southern India (Doran *et al*., 1996).

Seed orchard crops represent a generation of new recombinants and genetic variation is transmitted from one generation to another. Actually seed orchards are the "link between breeding programs and reforestation through the delivery of consistent, abundant yields of genetically improved seed" (Kang, 2001). Seed orchards are expected to produce vigorous high yielding plantations because they provide offspring from mating between carefully selected superior trees. Modern seed orchard management research is the "science, business and art of managing and conserving genetic resources for continued economic, social and environmental benefit" (Kang, 2001). Genetic gain can be manipulated through orchard management alternatives (e.g. selective seed harvest, genetic thinning), while ensuring that reasonable gene diversity is maintained. The current study pertains to the analysis of diversity and management strategies in first generation unpedigreed orchards of *Eucalyptus* in different locations based on fertility observations made for two consecutive years.

Materials and Methods:

Two unpedigreed seedling seed orchards each of *E. camaldulensis* and *E. tereticornis* located in a moist site, Panampally (Kerala state) and an arid location, Pudukkottai, (Tamil Nadu) in southern India were used for the study. Edaphic and climatic details of the orchard sites are presented in Table 1. The seedling seed orchards were established in 1996 using bulked seed from more than 500 selected trees of eleven and sixteen natural provenances of *E. camaldulensis* and *E. tereticornis* respectively, as a short-term strategy for meeting the immediate seed requirement. The same seed lot bulks were used for establishing the seed orchards at both the locations. After initial establishment at 3 x 1.5 m spacing the stands were subjected to two thinnings by four years of age to achieve a final spacing of about 5 m between trees at the time of the study (Hegde and Varghese, 2002). Growth evaluation and thinning are usually completed in eucalyptus orchards by fourth year, when the orchard is normally ready for operational seed production (Meskimen and Francis, 1990). Fertility of the trees was assessed at eight and nine years of age using the methodology of quantifying the flowers and fruits produced by each tree (Varghese *et al*., 2002).

Since the seed used for establishing the stand originated from a wide base of more than 500 parent trees from wild natural stands, the orchard trees were considered to be unrelated and non-inbred. The Sibling coefficient (ψ), Group coancestry (Θ), Status number (N_s), Relative population size (N_r), Variance effective population size ($N_e^{(v)}$) and Gene Diversity (*GD*) were estimated based on the fecundity estimates made in different stands (Kang and Lindgren, 1999; Lindgren and Mullin, 1998; Lindgren *et al*., 1996). -

Constrained seed collection and mixing of seeds:

Two management strategies were considered, namely constrained seed collection and mixing of seed crops from two consecutive years to reduce the impact of fertility variation on diversity of seed crop. Constrained seed collection (selective harvest) was done by collecting equal number of fruits from each parent genotype (Kang *et al*., 2003; Kang and Lindgren, 1999; Bila, 2000; Varghese *et al*., 2006).

Results:

Mixing of seeds from two consecutive harvests helped to enhance the overall fertility and diversity parameters in the seed crop than that of either harvests. Generally this management strategy resulted in enhanced values of status number, relative population size, variance effective population size and gene diversity in all the four orchards.

The *E. camaldulensis* orchard in the moist site had comparatively lower sibling coefficient and group coancestry than the other orchards since this orchard had greater proportion of flowering trees. Mixing of seeds helped to further reduce the sibling coefficient to 2.21 from the first and second year values of 2.24 and 3.19 (Table 2) thereby enhancing the status number and gene diversity in the orchard. The relative contribution of trees increased from 31% to 45% and the variance in effective population size also increased substantially from 83 to 150 in the orchard. At the same site, the *E. tereticornis* orchard had very low proportion of fertile trees resulting in high sibling coefficient (11&13), high group coancestry (0.3) and low relative population size (0.08). Mixing of two seed crops helped to reduce the sibling coefficient by 44% and relative population size by 57%. The variance effective population size increased from 15 to 24.

At the arid site (Pudukkottai), both species had more or less similar flowering trend with almost twice the proportion of fertile trees in the second year compared to the first year. Since there was almost three times more stocking in both species, in the arid site compared to the moist site, the status number and group coancestry of the orchards were on par with those of the moist site. Mixing of seeds further helped to reduce the sibling coefficient by 36% and enhance the status number by 56% in *E. camaldulensis*. In *E. tereticornis* orchard in the same site, the sibling coefficient was reduced by 50% and status number by 95%. The relative contribution of trees almost doubled and the group coancestry decreased by 50% when successive seed crops were mixed.

When seed crops of two years was mixed the cumulative contribution in *E. camaldulensis* orchards increased (Fig. 1a, b) in both moist (by 19 %) and arid sites (by 12 %). In *E. tereticornis* the cumulative contribution increased by 32 % in the moist site and by 7% increase in arid site when seed crops were mixed (Fig. 1c, d). Constrained seed collection would substantially reduce the sibling coefficient and enhance the status number in all the orchards. The gene diversity and relative population size would also increase in the orchards with this strategy.

Discussion:

Selective harvest and genetic thinning and a combination of both are orchard management options that can be used to increase genetic gain while maintaining genetic diversity in seed orchards (Lindgren and El-Kassaby, 1989; Bondesson and Lindgren, 1993). The practice of selective harvest improves only the genetic contribution of seed parents, while both seed and pollen parents are improved with genetic thinning. When fertility variation is very high in orchards, genetic thinning should be done only after fertility evaluation of the trees. Constrained seed collection is very effective in reducing the fertility variation but is often not very feasible when large quantities of seed are required.

Mixing seed crops from different harvests, is an easy option which does not require much technical inputs for implementation. Seed orchard trees contribute more equally to the seed crop if the seed crops from consecutive years are mixed. This strategy would be very effective in species where the trees show alternate bearing tendency (Varghese *et al*., 2007). Since the relative contribution of trees varies between years the composition of the seed crops vary and gene diversity of the seed mix would be equal to or more than that of the best crop. This strategy will be very beneficial in domesticating a newly introduced exotic species as in the case of *E. tereticornis* in tropical humid regions (Varghese *et al*., 2002). A similar observation was made by Kang *et al.* (2005) in seed orchards of *Pinus thunbergii* where fertility variation for the combined seed crops was lower than that observed for any single year, implying that the genetic diversity of seed crops could increase if seeds collected from different years are pooled. Diversity of seed from orchards of the same origin at different locations could vary since the fertility of families vary between locations as seen in the case of *E. tereticornis* orchards in the current study. Mixing of seed from different orchards would however affect the performance at either site as the seed from an orchard is best suited to a similar site.

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Table 1. Location, edaphic and climatic details of *Eucalyptus camaldulensis* and *E. tereticornis* seedlilng seed orchards

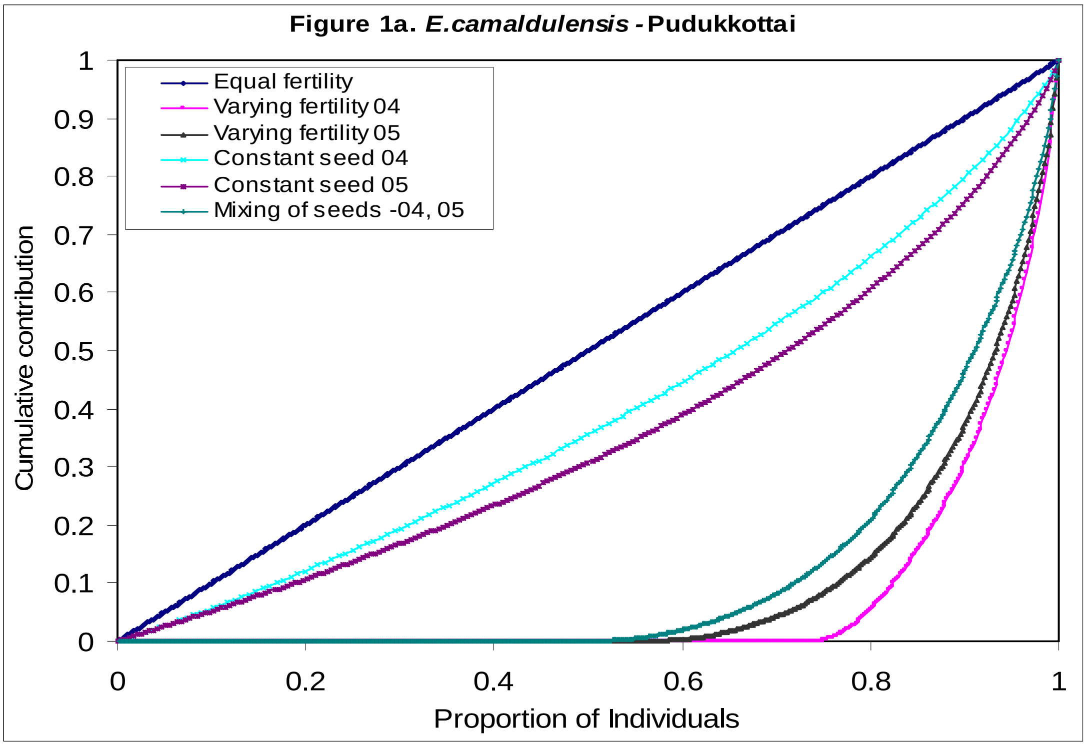
Location	Panampally	Pudukkottai
Latitude	10°52’ N	10°53’ N
Longitude	76°46’ E	78°49’ E
Annual Rainfall (mm)	1400	650
Altitude (m)	400	180
Soil type	Clay loam	Red Sandy Loam
Annual Temp(°C) range	22-39	21-42

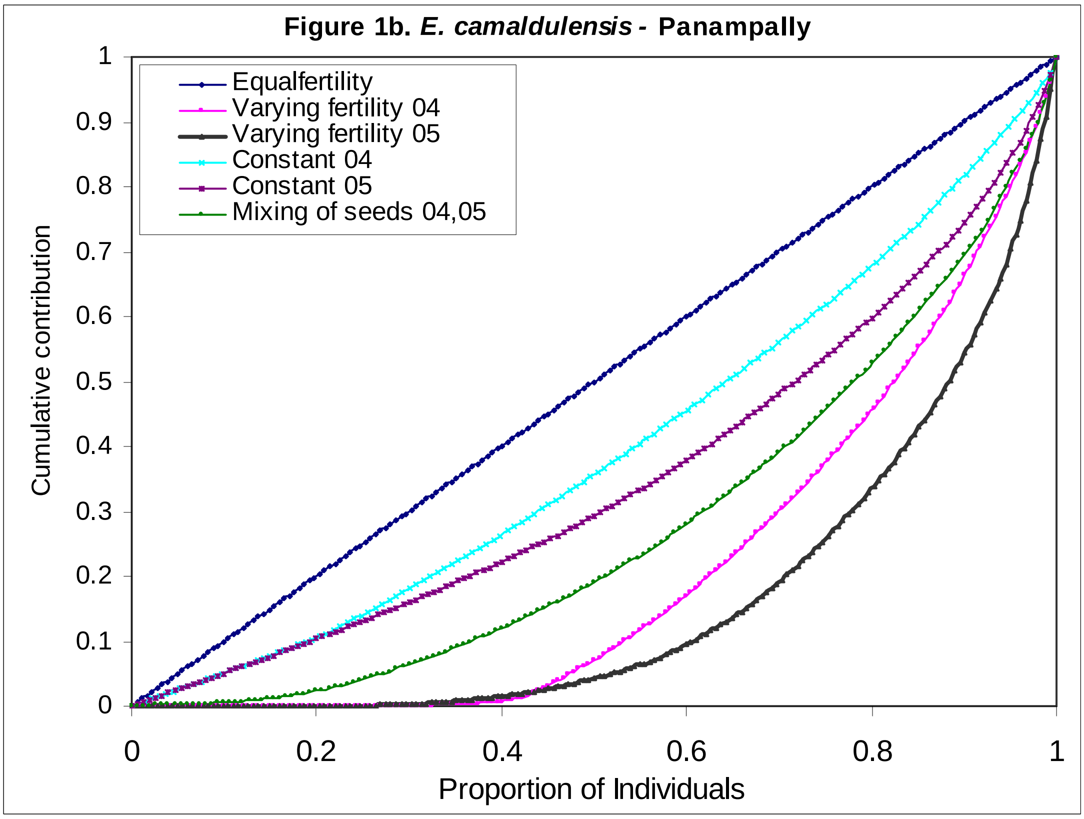
Table 2. Fertility status and the impact of management strategies on fertility variation, effective & variance effective population size and gene diversity in four seedling seed orchards of eucalyptus

Species	*E. camaldulensis*				*E. tereticornis*			
Location	Panampally		Pudukkottai		Panampally		Pudukkottai	
Years	1	2	1	2	1	2	1	2
Varying fertility								
No. of trees (N)	182	182	525	525	192	192	505	505
Fertile trees (%)	73.1	82.4	25.9	44.6	23.4	15.1	28.3	50.5
Average DBH (cm)	15.43	-	12.57	-	14.3	-	12.47	-
Fruits/tree	3939	5114	1195	764	328	227	1674	978
Ψ^1	2.24	3.19	6.72	5.43	13.39	11.70	8.47	5.22
Ns^2	81.08	56.99	78.18	96.59	14.34	16.41	59.6	96.74
Θ^3	0.006	0.009	0.006	0.005	0.035	0.030	0.008	0.005
GD^4	0.994	0.991	0.994	0.995	0.965	0.970	0.992	0.995
Nr^5	0.445	0.313	0.149	0.184	0.075	0.085	0.118	0.192
$Ne^{(v)6}$	146.46	83.02	91.79	117.83	15.420	17.47	67.49	118.94
Constrained seed collection								
Ψ^1	1.59	1.71	4.57	3.04	6.55	7.89	4.77	2.79
Ns^2	114.65	106.54	114.78	172.62	29.33	24.33	105.94	180.98
Θ^3	0.004	0.005	0.004	0.003	0.017	0.021	0.005	0.003
GD^4	0.996	0.995	0.996	0.997	0.983	0.979	0.995	0.997
Nr^5	0.630	0.585	0.219	0.329	0.153	0.127	0.210	0.358
$Ne(v)^6$	309.79	256.95	146.89	257.17	34.62	27.86	134.06	282.07
Mixing of two years seeds								
Ψ^1	2.21		4.27		8.99		4.38	
Ns^2	82.449		122.991		21.348		115.392	
Θ^3	0.006		0.004		0.023		0.004	
GD^4	0.994		0.996		0.977		0.996	
Nr^5	0.453		0.234		0.111		0.228	
$Ne^{(v)6}$	150.735		160.619		24.018		149.568	

1 - Sibling coefficient, 2 - Status number, 3 - Group coancestry, 4 – Gene Diversity, 5 - Relative effective population size, 6 - Variance effective population size

Figure 1. Cumulative fertility contribution (varying, constrained seed collection and mixing of seeds) in seedling seed orchards at different locations (1 a-d)





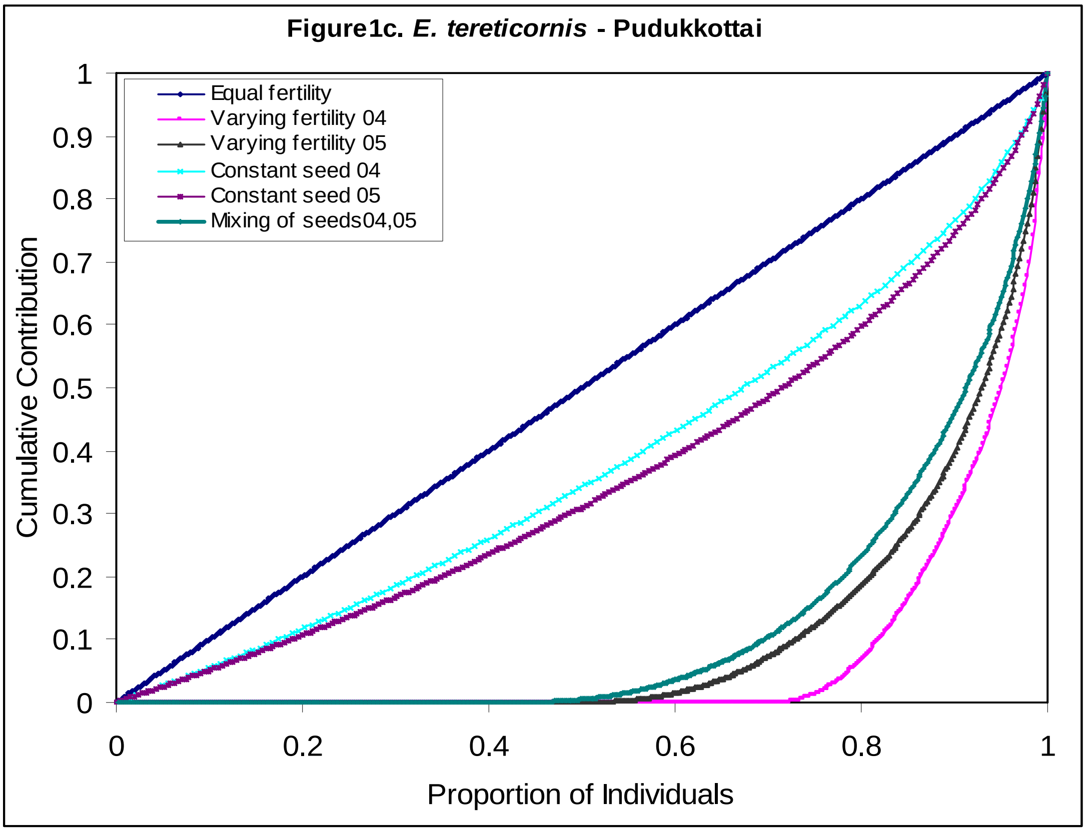


Figure1c. E. tereticornis - Pudukkottai
Equal fertility
Varying fertility 04
Varying fertility 05
Constant seed 04
Constant seed 05
Mixing of seeds04,05
Cumulative Contribution
Proportion of Individuals
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1

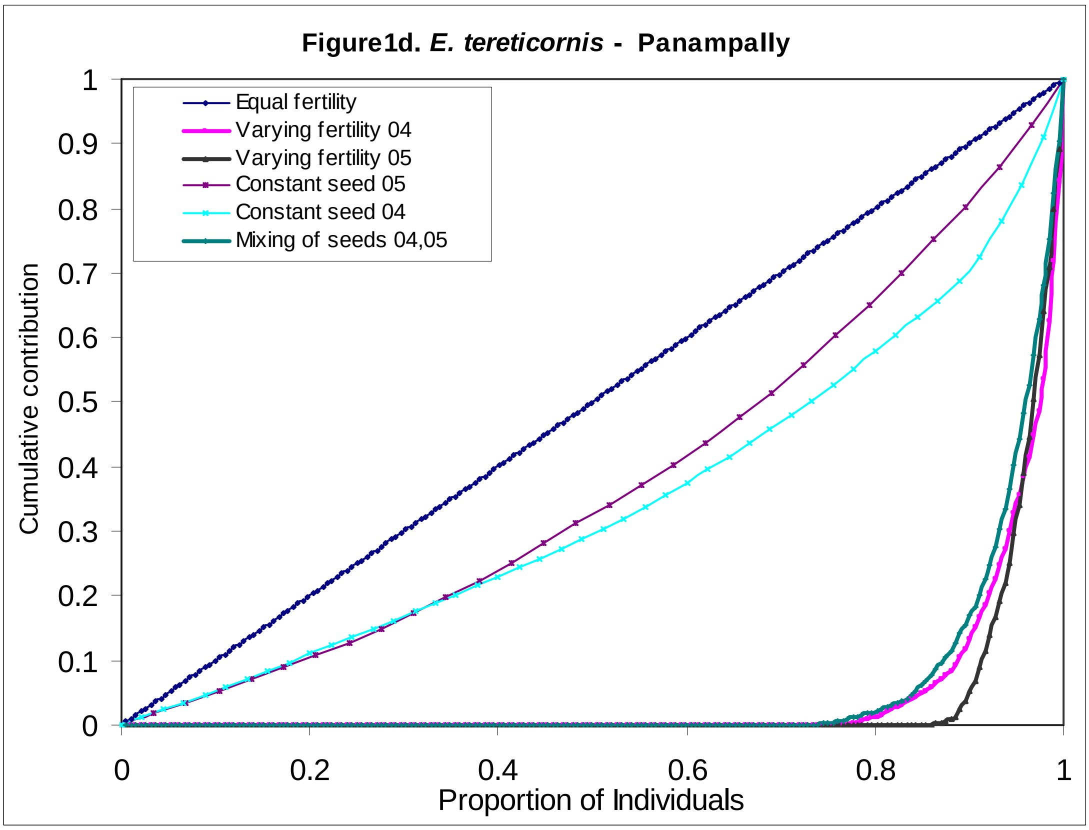


Figure1d. E. tereticornis - Panampally
Equal fertility
Varying fertility 04
Varying fertility 05
Constant seed 05
Constant seed 04
Mixing of seeds 04,05
Cumulative contribution
Proportion of Individuals
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1