Selection of clones of *Eucalyptus camaldulensis* (Dehnh.) based on stability for tree volume

Smitha G Nair¹, Sivakumar Veerasamy²*, A. Vijayaraghavan², G. Suresh², A. Anees² and T. Yuvaraj²

¹College of Forestry, OUAT, Bhubaneswar  
²Institute of Forest Genetics and Tree Breeding, Coimbatore  
*E-Mail: sivav@icfre.org

**Abstract**  
A study on the stability of 21 clones of *Eucalyptus camaldulensis* was carried out in four trials established in the southern part of India viz., Ariyalur and Marakkanam in Tamil Nadu and Karaikal in Puducherry and Tripathi in Andhra Pradesh during 2010. Trials were laid out in Randomised Block Design (RBD) with four replications each with 16 trees. Single tree volume was estimated after measuring tree height, diameter and form factor after seven years of planting. The volume calculated for individual clones present in all four trials were subjected to AMMI stability analysis using CROPSTAT. The average single tree volume of the clones studied varied from 0.035 to 0.11 m³ across locations. The Additive Main Effects and Multiplicative Interaction (AMMI) analysis revealed that the genotypic, environmental and GEI effects were 9.6, 68.6 and 21.8 per cent of the total sum of squares, respectively. Planting site plays a major role when compared to genotype and its interaction with the site. IPCA1 captured 75.43 per cent (p=0.001) followed by IPCA2 that captured 19.29 per cent (p=0.007) of the interaction effects. The AMMI Stability Values (ASV) showed a variation from 0.04 to 1.17. The study identified two clones out of twenty-two to be highly stable across the four locations studied for single tree volume.

**Key words:** *Eucalyptus camaldulensis*, Genotype by Environment Interaction, Single tree volume, AMMI analysis

**INTRODUCTION**  
Tree stem volume is equivalent to the economic value of the trees and hence is widely used by both researchers and forest managers (Arias-Rodil et al., 2017; Westfall et al., 2016). Tree volume is the key aspect of growth and yield prediction systems (Valentine and Gregoire, 2001; Özçelik et al., 2018; Luoma et al., 2019). Forest inventories quantify and assess the volume of the standing crop which in turn is used to estimate yield or productivity (Pereira, 2020; Luoma et al., 2019; Setyaji, 2016). Apart from determining the economic potential of the planting material, accurate and up to date information on growth parameters, volume and yield of the available resources help to identify and select superior genotypes for further plantings and clonal deployments. *Eucalyptus camaldulensis* Dehnh. is an important industrial species, used widely for producing pulp in the country (Ginval, 2014.). There is a wide variation in the yield data available from 12-25 m³/ha/year to 96 m³/ha/year and so is the case with corresponding tree volume (Varghese, 2017; Kulkarni, 2013;). Such differences in yield could be attributed to the genetic potential of the planting material, environmental conditions and silvicultural practices. Droughts dramatically reduce eucalyptus productivity (Almeida et al., 2010; Scoforo et al., 2017; Scoforo et al., 2019). Stands of different origin exhibited varied yield patterns (Amateis and Burkhot, 1987). The productivity in eucalyptus can also be enhanced by altering the water and nutrient levels indicating that the potential growth and
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measured from the photographs of the trees using a Leica Image analyser (QWin 3.1). Volume was calculated using the \( \pi r^2h \times \text{form factor} \). The form factor was estimated for every specific clone taking the billet volume estimated using an image analyser and clone specific form factor was used for volume calculations.

Soil samples collected from all four locations were analysed for the differences in nutrient levels. (Table 2). Average rainfall data for 2017 was collected from the Tamil Nadu government data portal (tn.data.gov.in) and the Ministry of Agriculture and Farmers Welfare (agricoop.nic.in).

Statistical analysis of the data for obtaining clonal stability for volume was performed using CROP STAT 7.2. The AMMI model equation given by Gauch and Zobel (1990) is:

\[
Y_{gen} = \mu + \alpha_g + \beta_e + \sum \gamma_n \delta_n + \rho_n + \epsilon_{gen}
\]

Where \( Y_{gen} \) is the observed yield of \( g \)th genotype in \( e \)th environment for \( r \)th replicate; \( \mu \) is the grand mean; \( \alpha_g \) is the deviation of mean of the \( g \)th genotype from the grand mean \( m \); \( \beta_e \) is the deviation of mean of the \( e \)th environment from the grand mean \( m \); \( \gamma_n \) is the singular value for the \( n \)th interaction principal component axis (IPCA); \( Y_{gen} = \) the genotype eigenvector for \( n \)th (IPCA) axis; \( \delta_n = \) the environment eigenvector values for the \( n \)th IPCA axis; \( \rho_n = \) the residual effects; and \( \epsilon_{gen} = \) the error term.

AMMI STABILITY VALUES (ASV)
ASV is the distance of the coordinate point in a two-dimensional scattergram of IPCA1 scores against IPCA2 scores from zero. The distance from zero is determined by using the theorem of Pythagoras (Purchase et al., 2000). The Genotypic Stability Index (GSI) of the \( n \)th genotype obtained by the simple addition of the rank value based on the mean volume of the genotype (RVOL) across environments and the rank of the genotype based on AMMI stability value (ASV) given by GSI = RVOL + ASV.

AMMI Stability Value (ASV)=
\[
\sqrt{\left[\frac{\text{SSPC1}}{\text{SSPC2}} \times \text{IPCA1 score}\right]^2 + [\text{IPCA2 score}]^2}
\]

RESULTS AND DISCUSSION
The study aimed to identify the most stable clones across the test environments as well as to find out the optimal clones for specific environments. The average single tree volume of the clones studied varied from 0.035 to 0.11 m\(^3\) across locations (Table 3). Clones 9 and 196 outperformed all other clones across locations. It is also worthwhile considering the improved seed lots in planting programmes as the bulk seed lot of the orchard was better than many of the clones. The volume recorded in this study for the bulk seed lot was 0.085 m\(^3\) which was above the mean across sites (0.066 m\(^3\)) and above all other clones except 196 and 9. Griffin (2014) and Kulkarni (2013) also have made a similar observation on Eucalyptus clones. The results also indicate that Tirupati is the best performing site of all with respect to single tree volume although the rainfall is lesser when compared to other sites. Ariyalur and Marakkanam were previously planted with Eucalyptus and Karaikal was previously an agricultural field while Tirupati was virgin soil. The reason for the best performance of the trees in Tirupati could be the virgin soil and fertility level of the deep soil.

The Additive Main Effects and Multiplicative Interaction (AMMI) analysis revealed that the genotypic, environmental and GEI effects were 9.6, 68.6 and 21.8 per cent of the total sum of squares respectively (Table 4). Planting sites played a major role when compared to genotype and its interaction with the site. The suitability of the site factors needs to be studied further for yield improvement. The GxE effect was found to be double the genotypic effect which indicated that the present study was appropriate for closer observations on the adaptability of the clones to different study sites. As reported by Gauch (1992 and 2013) high GE sum of squares or GE sum of squares at least equal to that of genotypic sum of squares makes the AMMI analysis necessary for multi environmental trials.

AMMI 1 biplot (Fig. 1) depicts the principal main effects of genotypes and environment against their respective first multiplicative interactive component (IPCA1). The X axis depicts the genotype and environment main effects for the volume and the y axis depicts the interaction effects. The IPCA1 (Interaction Principal Component Analysis Axis 1) values closer to zero represented high stability and the right side of the x axis represented values higher than the mean. IPCA1 captured 75.43 per cent (p=0.001)
Table 3. Single tree volume (m$^3$) across the studied sites

| Clone | Sites | Clone mean |
|-------|-------|------------|
|       | Ariyalur | Marakkanam | Karaikal | Tirupati |
| 7     | 0.044  | -          | 0.046    | 0.135    | 0.056    |
| 9     | 0.079  | 0.072      | 0.072    | 0.184    | 0.102    |
| 10    | 0.044  | 0.015      | 0.016    | 0.139    | 0.053    |
| 14    | 0.036  | 0.014      | 0.015    | 0.133    | 0.049    |
| 19    | 0.087  | 0.092      | -        | 0.100    | 0.070    |
| 63    | 0.053  | 0.037      | 0.029    | 0.165    | 0.071    |
| 66    | 0.057  | -          | 0.031    | 0.218    | 0.076    |
| 100   | 0.049  | 0.026      | 0.031    | 0.147    | 0.063    |
| 101   | 0.073  | 0.026      | -        | 0.184    | 0.071    |
| 111   | 0.078  | 0.050      | -        | 0.111    | 0.060    |
| 115   | 0.072  | -          | 0.049    | 0.162    | 0.071    |
| 123   | 0.050  | 0.031      | 0.030    | 0.131    | 0.061    |
| 124   | 0.068  | 0.057      | 0.065    | 0.132    | 0.081    |
| 186   | 0.041  | 0.037      | 0.042    | 0.105    | 0.056    |
| 187   | 0.032  | 0.008      | 0.009    | 0.090    | 0.035    |
| 188   | 0.045  | 0.008      | 0.009    | 0.150    | 0.053    |
| 191   | 0.078  | 0.050      | 0.058    | -        | 0.047    |
| 196   | 0.103  | 0.075      | 0.081    | 0.180    | 0.110    |
| 198   | 0.074  | 0.050      | -        | 0.112    | 0.059    |
| 301 (seed lot) | 0.077 | -          | 0.086    | 0.195    | 0.085    |
| 303   | 0.043  | 0.031      | 0.026    | 0.159    | 0.065    |
| 307   | 0.035  | 0.022      | 0.016    | 0.187    | 0.065    |
| Site mean | 0.060 | 0.032      | 0.031    | 0.142    | 0.066    |
| Clone | 0.003  | 0.005      |          |          |          |
| Site  | 0.006  | 0.012      |          |          |          |
| Clone x Site | 0.012 | 0.023      |          |          |          |

Table 4. Analysis of variance for the AMMI model

| SOURCE              | D.F. | S.S.  | M.S.  | F value | F Prob |
|---------------------|------|-------|-------|---------|--------|
| Clone               | 21   | 0.025 | 0.001 |         |        |
| Sites               | 3    | 0.179 | 0.060 |         |        |
| Clone X Sites       | 63   | 0.057 | 0.001 |         |        |
| AMMI component 1    | 23   | 0.043 | 0.002 | 5.39    | 0.001  |
| AMMI component 2    | 21   | 0.011 | 0.001 | 3.207   | 0.007  |
| AMMI component 3    | 19   | 0.003 | 0.000 | ****    | 1.000  |
| TOTAL               | 87   | 0.261 |     |         |        |

followed by IPCA2 that captured 19.29 per cent (p=0.007) of the interaction effects, indicating that the first IPCA contributes maximum to the interaction sum of squares as observed in several other studies (Anandan et al., 2009; Bose et al., 2014; Ajay et al., 2020). AMMI1 biplot reveals that clones 196 with an average volume of 0.11 m$^3$ and clone 9 with an average volume of 0.102 m$^3$ were superior in terms of mean volume as well as stability.

If the genotypes fell almost on the same perpendicular line, they had similar means and those which fell almost on the same horizontal line had similar interaction patterns. Accordingly, clones 19, 303, 115 and 101 were found to have similar means and clones 196, 14, 7, 10, 100, 9, 10 and 303 similar interaction patterns. The ideal genotypes for cultivation are those with higher mean coupled IPCA1 values near unity (Koundinya, 2019). In the present study, clone 196 and clone 9 can be considered stable across sites and recommended for mass plantation. Tirupati was observed to be a favourable site while Marakanam and Karaikal were observed to be poor and sites Ariyalur as an average site. The biplot revealed that clones 198, 111 and 123 showed specific adaptability to Ariyalur, 191 to Marakanam; and 187 to Karaikal.
Fig. 1. Ammi Biplot 1; IPCA1 Vs MEAN

Fig. 2. AMMI BIPLLOT 2; IPCA1 Vs IPCA2
Farthest the distance between the marker and its origin in the biplot 2 (Fig.2) as it is observed for Tirupati and Marakanam in the present study showed that the two are the most discriminating environments. Vector angles more than 90° between any two environments in the biplot 2 indicated that the clonal responses between these environments were negatively correlated (Olivoto et al., 2019) or unstable in their performance (Tena et al., 2019). The performance of clones 307 and 101 was negatively correlated with clones 198 and 111 between Marakanam and Tirupati where vector angles exceeded 90 degrees (Fig.2). The performance of clones 198 and 111 was superior at Marakanam; at the same time 307 and 101 were superior in Tirupati and comparatively their performance in vice versa sites was poor.

Clones 191, 19 and 66 were far away from the centre of the biplot and hence are expected to be site specific clones. Based on their proximity to the environments, clone 191 is adapted to Karaikal, Clone 19 adapted to Marakanam and Clone 66 is adapted to Tirupati. Lesser angles and clustering of the clones in a quadrant corresponding to the environment suggests the similarity in performance of the clones in that particular environment. IPCA2 which projects the environmental vectors and genotypes in the four quadrants of the biplot helped to identify the most adaptable genotype to a specific environment (Sharifi et al., 2017).

Observations shown in the biplot were confirmed by the ASV (AMMI Stability Values as shown in Table 5. ASV showed a variation from 0.04 to 1.17. Clone 191 showed poor volume and stability while clone 196 ranked high for both mean volume as well as its stability. Low ASV values and GSI indicated high clonal stability across environments (Kang 1988; Kang 1991; Farshadfar, 2008; Zaluski et al., 2020). On the contrary, genotypes with low stability values along with low mean are considered undesirable (Gauch and Zobel, 1990; Bose et al., 2014). In the present study, clones 196 and 9 are the most desirable clones with high mean volume and high stability. On the other hand, a seedling origin seed source (301) in spite of the high mean volume, did not exhibit stability as per GSI.

It is concluded that the studied environments influenced the single tree volume and in turn the yield of *E. camaldulensis* plantations. The results also indicated that Tirupati was the best environment with respect to single tree volume for the clones studied. AMMI stability values and GSI could be used for discerning clones 196 and 9 as the most stable clones. Tirupati and Ariyalur were the two environments to which the clones responded differently whereas, the clonal performances were highly similar in the other two environments. The species is heavily dependent upon for paper production by industries in the country. Where there is not adequate production and an avid requirement to improve the quality and quantity of the raw materials, selection of planting material is essential. The presence of GEI in clonal trials results in ambiguous

### Table 5. Mean Volume, AMMI stability Values (ASV) and Genotype Selection Index (GSI) for the Clones

| Variety/Site | Clone Mean Volume (m³) | Mean Vol (Ranking) | IPCA1 | IPCA2 | ASV | Ranking (ASV) | GSI |
|-------------|------------------------|-------------------|--------|--------|-----|----------------|-----|
| 7           | 0.050                  | 17                | -0.025 | -0.096 | 0.130 | 7               | 24  |
| 9           | 0.102                  | 2                 | -0.016 | -0.008 | 0.063 | 3               | 5   |
| 10          | 0.053                  | 18                | -0.026 | 0.004  | 0.103 | 6               | 24  |
| 14          | 0.049                  | 20                | -0.020 | 0.000  | 0.080 | 4               | 24  |
| 19          | 0.070                  | 9                 | 0.146  | 0.163  | 0.591 | 20              | 29  |
| 63          | 0.071                  | 6                 | -0.043 | 0.024  | 0.170 | 9               | 15  |
| 66          | 0.076                  | 5                 | -0.174 | -0.007 | 0.681 | 21              | 27  |
| 100         | 0.063                  | 12                | -0.021 | -0.010 | 0.084 | 5               | 17  |
| 101         | 0.071                  | 8                 | -0.087 | 0.102  | 0.354 | 17              | 25  |
| 111         | 0.090                  | 14                | 0.077  | 0.099  | 0.317 | 16              | 30  |
| 115         | 0.071                  | 7                 | -0.058 | -0.078 | 0.241 | 13              | 20  |
| 123         | 0.061                  | 13                | 0.013  | -0.007 | 0.052 | 2               | 15  |
| 124         | 0.081                  | 4                 | 0.057  | -0.049 | 0.230 | 12              | 16  |
| 186         | 0.056                  | 16                | 0.086  | -0.048 | 0.263 | 14              | 30  |
| 187         | 0.035                  | 22                | 0.051  | -0.023 | 0.200 | 10              | 32  |
| 188         | 0.053                  | 19                | -0.054 | 0.020  | 0.210 | 11              | 30  |
| 191         | 0.047                  | 21                | 0.298  | -0.116 | 1.171 | 22              | 43  |
| 196         | 0.110                  | 1                 | 0.012  | -0.019 | 0.050 | 1               | 2   |
| 198         | 0.059                  | 15                | 0.072  | 0.097  | 0.298 | 15              | 30  |
| 301         | 0.085                  | 3                 | -0.112 | -0.102 | 0.449 | 19              | 22  |
| 303         | 0.065                  | 11                | -0.043 | 0.017  | 0.170 | 8               | 19  |
| 307         | 0.065                  | 10                | -0.113 | 0.039  | 0.442 | 18              | 28  |
phenotypic expressions and misinterpretations about the genetic effect thus making selections challenging. The present study showed that an understanding of GEI in *E. camaldulensis* is essential for high and reliable yield before the clones are deployed. Furthermore, where a sufficient number of tested genotypes are available and where the area to be planted is characterised by varied agrodnic conditions, the grouping of clones and matching them to specific areas would prove to be a more efficient breeding strategy. It would also provide better yield and improved economic returns. More environments and more genotypes could also be explored for identifying site specific clones.

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