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RESEARCH ARTICLE

ASSESSMENT OF GENETIC DIVERGENCE IN *EUCALYPTUS TERETICORNIS*, SM USING PHYSIOLOGICAL PARAMETERS

***Ajith Kumar, K. G., Sunil Kesavadeth, G., Pratheepkumar, V., Bindumole, V.R. and Aswathy, P. J.**

Department of Botany, Govt. College for Women, Thiruvananthapuram, Kerala, India 695 014

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ABSTRACT

Eucalyptus tereticornis is a fast-growing, hardwood species commercially planted as a source of paper pulp and timber. The species has been introduced in India to meet the ever increasing demand for paper pulp and the species shows excellent adaptability in the Indian soils. There is large amount of variability exists in the species but only a few efforts have been made to assess the genetic divergence of this species using physiological parameters. The present study was undertaken to assess the genetic divergence, heritability and genotype clustering of thirty eight clones of *Eucalyptus tereticornis*in order to cluster elite clones for future hybridization programmes and to sort out inferior clones which need further genetic improvement. The results showed that significant differences in net photosynthetic rate (Pn), stomatal conductance (gs), internal CO_2 concentration (Ci), transpiration rate (E), intrinsic wue, instantaneous wue, intrinsic carboxylation efficiency and intrinsic mesophyll efficiency. All the selected parameters showed good heritability values. PCA showed that intrinsic carboxylation efficiency contributed maximum to the genetic divergence followed by intrinsic mesophyll efficiency. D^2 analysis revealed seven clusters of which cluster II and III had elite clones while inferior clones in other clusters. The cluster analysis would definitely help the tree breeders for the selection of genetically divergent parents in order to achieve heterosis in hybrids.

INTRODUCTION

Eucalyptus tereticornis is a fast-growing, arborescent hardwood species commercially planted as a source of paper pulp and timber. The species has been introduced to a number of tropical countries including India in the second half of nineteenth and first half of twentieth century to meet the ever increasing demand for paper pulp. The species shows excellent adaptability in the soils of Indian sub-continent and currently one of the important timber species in India. Assessment of genetic divergence lies in the heart of any tree improvement programme and the success of any breeding method depends on the availability of genetic diversity in the base population. Selection of genetically divergent parents is a crucial step in breeding programme to create new genetic stocks having desirable traits. The importance of genetic divergence in the selection of parents and for crop improvement has been described by many authors in both self and cross pollinated crops (Gaur *et al*., 1978; Griffing and Lindsstromm., 1954). In order to benefittransgressive segregation, genetic distance between parents is necessary (Joshy *et al*, 2004) and higher heterosisin progeny can be obtained by crossing of genetic divergent parents (Joshy and Dhawan, 1966). Furthermore, genetic diversity is the most important component of biodiversity and it is the foundation of ecosystem stability and forest sustainability. Monitoring this diversity in the forest tree species is extremely important for ecologically and socially sustainable forestry programme. Morphological and biochemical traits are generally considered in many species for assessing genetic divergence and for the improvement of potential characteristics such as yield, quality, resistance to diseases and pests and adaptation to climatic and edaphic stress. But, very little importance has been given to the physiological traits for assessing genetic divergence. The importance of physiological traits as major criteria for selection of parents for hybridization was reported by Kundu and Tigerstedt (1999). According to them, yield is determined by the interaction of many physiological and biochemical processes that could be manipulated through plant breeding and genetics. They found a correlation between net photosynthetic rate, stomatal conductance, leaf area, stomata density on the productivity in neem. The variation in Pn and stomatal conductance (gs) has been widely reported in both annuals and perennials (Farquhar and Sharky, 1982; Balasimha *et al*., 1991; Cowan and Farquhar, 1977).

Eucalyptus tereticornis is predominantly an outcrossing species with a greater amount of variability within the population. Significant interspecific and intraspecific variations have been observed in many physiological traits in this genus (Comstock and Ehleringer.,1993. The water relations and WUE in *Eucalyptus* spp. has been studied by many physiologists (Chunyang *et al*., 2000; Kallarackal and

Corresponding author: Ajith Kumar, K. G.,
Department of Botany, Govt. College for Women, Thiruvananthapuram, Kerala, India 695 014.

Somen, 1998). Significant variation in WUE was also reported in the clones of Eucalyptus grandis (Roux *et al*., 1996). However, only a few studies have been carried out in tree species in the assessment of genetic divergence based on physiological parameters event though there is ample scope for tree improvement.

There are several statistical tools available for assessing and quantifying the genetic divergence within a population. The use of Mahalanobis D^2 statistics (1936) for estimating the genetic divergence has been emphasized by many workers (Roy and Panwar, 1993; Ramya and Senthilkumar, 2008; Murthy and Arunachalam., 1996). PCA and Cluster analysis are appropriate methods for determining family relationships (Mellingers, 1972) and Euclidean distance can estimate the genetic distance between parents to maximize the transgressivesegregation (Hoque and Rahman, 2006). The present study was carried out at the Institute of Forest Genetics and Tree Breeding, Coimbatore to assess and quantify the genetic divergence in *Eucalyptus tereticornis* for the photosynthetic traits such as photosynthetic rate (Pn), stomatal conductance (gs), internal CO_2 concentration (Ci) and transpiration rate (E), intrinsic WUE, instantaneous WUE, intrinsic carboxylation efficiency and mesophyll efficiency in order to cluster elite clones for further breeding programmes.

MATERIALS AND METHODS

One year old clones of *Eucalyptus tereticornis*raised in the laterite soil of Panampally in Palakkad District of Kerala (India) in randomized block design with a spacing of 1mx1m, were screened for photosynthetic parameters such as net photosynthetic rate (Pn), stomatal conductance (gs), internal CO_2 concentration (Ci) and transpiration rate (E). The clones released by IFGTB, Coimbatore such as Et 12-11, Et 13-3,Et 17-1,Et 4-5,Et 10-6,Et 1-7 and the clones released by ITC Bhadrachalam such as Et 242,Et 132,Et 130,Et 231,Et 027,Et 008,Et 026,Et 016,Et 261,Et 003,Et 052,Et 399,Et 116,Et 001,Et 122,Et 006,Et 351,Et 099,Et 259,Et 148,Et 251,Et 250,Et 286,Et 228,Et 268,Et 290,Et 419,Et 010,Et 007,Et 071,Et 158,Et 128 were assessed for their photosynthetic efficiency and genotype clustering. The study was conducted in the month of September, just after the monsoon rains in which the temperature ranged from 31^0C to 33^0C, the relative humidity ranged from 42% to 50%, the vapour pressure deficit ranged from 2.0 KPa to 2.5KPa, the photosynthetic Active Radiation ranged from 1010µmol $m^{-2}s^{-1}$ to 1090µmol $m^{-2}s^{-1}$.

The plants were well irrigated before data collection and the measurements were taken during the early hours of the day (between 7.00am and 11.00am) using Portable Photosynthesis System (Li-6200; Li corInc, USA). Three ramets were randomly selected per clone as per the randomization procedure shown by Gomez and Gomez (1984) and three observations were taken from the middle portion of three younger leaves of a ramet. The photosynthetic parameters Pn, gs, Ci and E were used for the analysis of water use efficiency such as intrinsic water use efficiency (ratio of Pn to gs), instantaneous water use efficiency (ratio of Pn to E), intrinsic carboxylation efficiency (ratio of Pn to Ci) and intrinsic mesophyll efficiency (ratio of Ci to gs).

Statistical Analysis

The physiological traits of the clones of *Eucalyptus tereticornis* were subjected to one-way variance analysis using SPSS 16.0 (SPSS Inc., Chicago, IL, USA). The analysis of genetic divergence was done using Mahalanobis (1936) D^2 statistics and the genotype clustering was carried out based on the D^2values.

RESULTS AND DISCUSSION

Analysis of variance showed significant differences among the clones of *Eucalyptus tereticornis* for all the physiological traits studied (Pn, gs, E and Ci) and the data are presented in the table (1). Among the traits, the gs(cv=24.46) showed greater amount of variability followed by Pn (cv=22.64), E (cv=17.79) and Ci (cv=14.15). High heritability (H_b) of these physiological traits indicate their genetical control (Feng *et al*., 2006; Fu and Somers, 2009; Mohammadi *et al*., 2010). Principal component analysis (Table 5) showed that intrinsic carboxylation efficiency contributed optimum (18%) towards total genetic divergence followed by intrinsic mesophyll efficiency (15%) and Pn (14.t5%). The least contributor was instantaneous water use efficiency (8%). All the eight physiological variables were taken for D^2 analysis and the thirty eight clones of *Eucalyptus tereticornis* were grouped into seven clusters.

Cluster I

Cluster I had five clones such as Et 003, Et 026, Et 158, Et 259 and 251 comprising of 13.16% of total genotypes (Table 2). Pn ranged from 15.77µmol$m^{-2}s^{-1}$ to 20.74µmol$m^{-2}s^{-1}$(Table 1) with a mean value less than the total mean value (Table 3). The gs varied from 0.1189µmol$m^{-2}s^{-1}$ to 0.1430µmol$m^{-2}s^{-1}$ with a mean value less than the total mean. E varied from 2.53µmol$m^{-2}s^{-1}$ to 3.19µmol$m^{-2}s^{-1}$ with a mean value more than the total mean. The cluster showed better intrinsic wue and instantaneous wue because the mean value was higher than the total mean value.

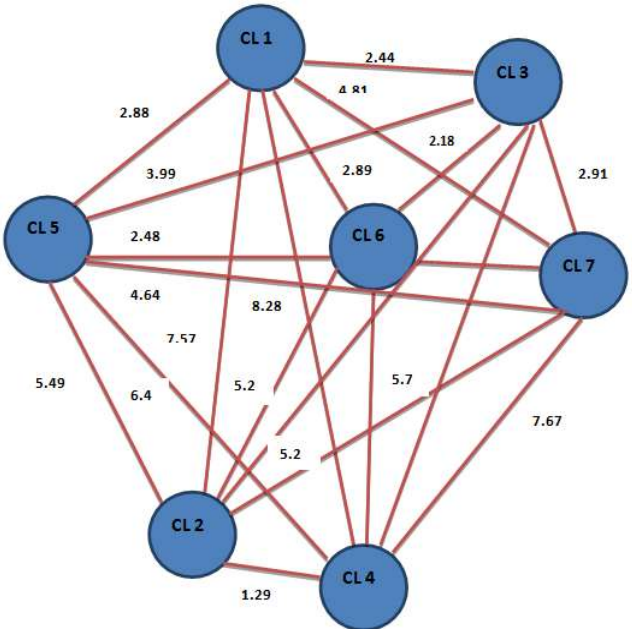

Fig 1. Cluster diagram showing seven clusters and their inter-cluster distances (not exactly to the scale)

Table 1. Thirty Eight Clones of Eucalyptus tereticornis and the physiological parameters Selected for the study

Sl.No	Clones	Pn ($\mu molm^{-2}s^{-1}$)	gs ($\mu molm^{-2}s^{-1}$)	Ci ($\mu moll^{-1}$)	E ($\mu molm^{-2}s^{-1}$)	Pn/gs ($\mu molmol^{-1}$)	Pn/E ($\mu molmmol^{-1}$)	Pn/Ci ($\mu molm^{-2}s^{-1}$)	Ci/gs (μll^{-1} $mol^{-1}m^{-2}s^{-1}$)
1	Et 003	18.54	0.1213	94.92	2.95	152.84	2.95	19.53	0.7825
2	Et 026	20.74	0.1239	91.33	2.53	167.39	2.53	22.71	0.7371
3	Et 158	16.14	0.1233	134.55	3.19	130.9	3.19	11.99	1.0912
4	Et 259	15.77	0.1189	113.6	2.63	132.63	2.63	13.88	0.9554
5	Et 251	18.2	0.143	123.52	2.55	127.27	2.55	14.73	0.8638
6	Et 1-7	29.35	0.36	168.49	2.74	81.53	2.74	17.42	0.4578
7	Et 13-3	24.16	0.1162	66.27	3.09	207.92	3.09	36.45	0.4043
8	Et 027	30.57	0.2604	126.47	2.76	117.4	2.76	24.17	0.4857
9	Et 242	30.85	0.3147	120.7	3.03	98.03	3.03	25.55	0.3835
10	Et 008	32.4	0.2676	133.63	2.76	121.08	2.76	24.24	0.4993
11	Et 261	24.58	0.1815	109.31	3.35	135.43	3.35	22.49	0.6023
12	Et 052	27.73	0.2418	125.11	3.13	114.68	3.13	22.16	0.5174
13	Et 130	41.95	0.3342	115.52	3.73	125.52	3.73	36.31	0.3457
14	Et 351	25.36	0.2281	137.99	2.71	111.13	2.71	18.37	0.6049
15	Et 10-6	26.24	0.2331	131.84	3.13	112.57	3.13	19.9	0.5656
16	Et 099	30.82	0.282	139.94	3.06	109.29	3.06	22.02	0.4962
17	Et 4-5	13.6	0.1234	147.35	2.05	110.21	2.05	9.23	0.3568
18	Et 12-11	35.49	0.4706	175.5	3.28	75.41	3.28	20.22	0.2861
19	Et 286	20.06	0.1875	172.94	1.97	106.99	1.97	11.6	0.9223
20	Et 228	12.92	0.1458	187.1	1.57	88.61	1.57	6.9	1.2833
21	Et 290	17.4	0.1494	165.57	1.71	116.47	1.71	10.51	1.1082
22	Et 268	14.1	0.1624	182.3	1.65	86.82	1.65	7.73	1.1225
23	Et 010	20.44	0.2858	213.61	1.76	71.52	1.76	9.57	0.7474
24	Et 007	15.34	0.1541	183.73	1.56	99.54	1.56	8.35	1.1922
25	Et 016	27.32	0.3384	173.84	2.87	80.73	2.87	15.71	0.9578
26	Et 116	24.04	0.2381	158.68	2.44	100.96	2.44	15.15	0.6664
27	Et 071	21.05	0.3096	206.52	1.54	67.99	1.54	10.19	0.667
28	Et 006	26.16	0.265	157.89	2.52	98.72	2.52	16.57	0.6922
29	Et 148	25.97	0.4137	219.09	2.41	62.77	2.41	11.85	0.5295
30	Et 419	26.55	0.2345	184.19	1.95	113.22	1.95	14.41	0.7855
31	Et 250	21.82	0.2496	172.91	2.07	87.42	2.07	12.62	0.6927
32	Et 128	19.63	0.242	167.52	2.91	81.11	2.91	11.72	0.6922
33	Et 399	30.46	0.3365	167.87	2.7	90.52	2.7	18.14	0.4989
34	Et 132	39.3	0.5287	186.37	2.87	74.33	2.87	21.08	0.3525
35	Et 231	41.09	0.5124	176.62	2.89	80.19	2.89	23.26	0.3448
36	Et 001	32.95	0.4705	190.22	2.39	70.03	2.39	17.32	0.4043
37	Et 122	35.16	0.4142	172.23	2.37	84.89	2.37	20.41	0.4158
38	Et 17-1	34.8	0.6075	225.49	2.31	57.28	2.31	15.43	0.3712
	Average	25.501	0.27078	155.81	2.556053	103.983	2.55605	17.366	0.6548
	Std Dev	8.6027	0.13247	43.574	0.679532	33.9567	0.67953	7.6333	0.28195
	CV (%)	22.64	24.46	14.15	17.79	18.65	14.33	32.56	32.21
	F Value	8.14*	11.32*	12.82*	10.64*	14.22*	9.48*	12.91*	8.99*
	LSD	8.9	0.12	38.48	3.06	28.6	0.54	8.68	0.34
	H_b^2	0.79	0.81	0.72	0.76	-	-	-	-

* values are significant at P<0.05
Pn/gs - Intrinsic water use efficiency
Pn/E - Instantaneous water use efficiency
Pn/Ci - Intrinsic carboxylation efficiency
Ci/gs - Intrinsic mesophyll efficiency

Table 2. Distribution of 38 clones of E. tereticornis into seven clusters by D2 analysis Ci/gs - Intrinsic mesophyll efficiency

Clusters	No. of Genotypes	Genotypes (%)	Genotypes
I	5	13.16	Et 003, Et 026, Et 158, Et 259, Et 251
II	2	5.26	Et 1-7, Et 13-3
III	9	23.68	Et 027, Et 242, Et 008, Et 261, Et 052, Et 351, Et 10-6, Et 099, Et 130
IV	2	5.26	Et 4-5, Et 12-11
V	6	15.79	Et 286, Et 228, Et 290, Et 268, Et 010, Et 007
VI	9	23.68	Et 016, Et 116, Et 071, Et 006, Et 148, Et 419, Et 250, Et 128, Et 399
V	5	13.16	Et 132, Et 231, Et 001, Et 122, Et 17-1

However, the intrinsic carboxylation efficiency was closer to the average and the intrinsic mesophyll efficiency was higher than the average. These two parameters are highly undesirable and need to be improved.

The cluster diagram (Fig.1/Table 4) shows that it is highly divergent from clusters IV (8.28) and II (7.57). However, it is genetically closer to clusters III (2.44), V (2.88) and VI (2.89).

Table 3. The average of traits for each cluster (above number) and the difference between each Cluster with the total mean (below number)

Clusters	Pn ($\mu molm^{-2}s^{-1}$)	gs ($\mu molm^{-2}s^{-1}$)	Ci ($\mu moll^{-1}$)	E ($\mu molm^{-2}s^{-1}$)	Pn/gs ($\mu molmol^{-1}$)	Pn/E ($\mu molmmol^{-1}$)	Pn/Ci ($\mu molm^{-2}s^{-1}$)	Ci/gs (μll^{-1} $mol^{-1}m^{-2}s^{-1}$)
I	17.87	0.126	111.58	2.77	142.2	2.77	16.56	0.886
	-7.63	-0.1447	-44.22	0.22	38.22	0.22	-0.8	0.2313
II	26.75	0.2381	117.38	2.91	144.72	2.91	26.93	0.431
	1.25	-0.0326	-38.42	0.36	40.74	0.36	9.57	-0.2237
III	30.05	0.2603	126.72	3.07	116.12	3.07	23.91	0.5
	4.55	-0.0104	-29.08	0.52	12.14	0.52	6.55	-0.1547
IV	24.54	0.297	161.42	2.66	92.81	2.66	14.72	0.3214
	-0.96	0.0263	5.62	0.11	-11.17	0.11	-2.64	-0.3333
V	16.71	0.1808	184.2	1.7	94.99	1.7	9.11	1.0626
	-8.79	-0.0899	28.4	-0.85	-8.99	-0.85	-8.25	0.4079
VI	24.77	0.2919	178.72	2.37	87.04	2.37	14.04	0.6869
	-0.73	0.0122	22.92	-0.18	-16.94	-0.18	-3.32	0.0322
VII	36.66	0.5066	190.18	2.56	73.34	2.56	19.5	0.3777
	11.16	0.2359	34.38	0.01	-30.64	0.01	2.14	-0.277

Table 4. Average inter-cluster D2 values among seven clusters of E.tereticornis

Clusters	I	II	III	IV	V	VI	VII
I	---						
II	7.568	---					
III	2.437	7.311	---				
IV	8.283	1.288	7.664	---			
V	2.875	5.491	3.995	6.404	---		
VI	2.892	5.292	2.181	5.768	2.478	---	
VII	4.811	5.722	2.906	5.689	4.636	2.295	---

Table 5. Relative contribution (%) of individual trait to the total genetic divergence

Traits	Pn	gs	Ci	E	Pn/gs	Pn/E	Pn/Ci	Ci/gs
Contribution (%)	14.5	10.5	12	10	12	8	18	15

Cluster II

It had two genotypes; Et 1-7 and Et 13-3 representing 5.26% of total genotypes. The Pn ranged from 24.16$\mu molm^{-2}s^{-1}$ to 29.35$\mu molm^{-2}s^{-1}$with a mean value slightly higher than the total mean and gs from 0.1162$\mu molm^{-2}s^{-1}$ to 0.3600$\mu molm^{-2}s^{-1}$ with a mean value almost near to the total mean. E varied from 2.74$\mu molm^{-2}s^{-1}$ to 3.09$\mu molm^{-2}s^{-1}$ with a mean value higher than the total mean. The remarkable characteristic of this cluster is the excellent water use efficiency of the clones. The intrinsic wue, instantaneous wue and intrinsic carboxylation efficiency were far above the total mean and the intrinsic mesophyll efficiency was far below total mean. This cluster can be considered as promising one for further tree breeding programmes. The cluster diagram shows that it is highly divergent from cluster I (7.568) and cluster III (7.311) but very closer to cluster IV (1.288).

Cluster III

Nine clones, Et 027, Et 242, Et 008, Et 261, Et 052, Et 130, Et 351, Et 10-6 and Et 099, comprising 23.68% of total genotypes belonged to this cluster. The Pn ranged from 24.58$\mu molm^{-2}s^{-1}$to 41.95$\mu molm^{-2}s^{-1}$with a mean value higher than the total mean. The gs value varied from 0.1815$\mu molm^{-2}s^{-1}$to 0.3342$\mu molm^{-2}s^{-1}$which is near to the total mean. The E value ranged from 2.71$\mu molm^{-2}s^{-1}$to 3.73$\mu molm^{-2}s^{-1}$and the mean value is higher than the total mean. This cluster also showed better intrinsic wue, instantaneous wue, intrinsic carboxylation efficiency and intrinsic mesophyll efficiency. They are also excellent clones for future tree improvement programmes. The cluster diagram (Fig.1) shows that it is highly divergent from cluster IV (7.664) and cluster II (7.311) but closer to cluster VI (2.181) and cluster I (2.437).

Cluster IV

Only two clones, Et 4-5 and Et 12-11, involved in this cluster comprising 5.26% of total genotypes. The Pn ranged from 13.60$\mu molm^{-2}s^{-1}$to 35.49$\mu molm^{-2}s^{-1}$with a mean value less than the total mean. The gs ranged from 0.1234$\mu molm^{-2}s^{-1}$to 0.4706$\mu molm^{-2}s^{-1}$which is closer to total mean. The E value ranged from 2.05$\mu molm^{-2}s^{-1}$to 3.28$\mu molm^{-2}s^{-1}$with a mean value slightly higher than total mean. This is a cluster of inferior clones with poor water use efficiency because intrinsic wue and intrinsic carboxylation values are far below the total mean. The cluster diagram shows that it is highly divergent from cluster I (8.283) III (7.664) but very closer to cluster II (1.288).

Cluster V

Six clones, Et 286, Et 228, Et 290, Et 268, Et 010 and Et 007, involved in this cluster representing 15.79% of the total genotypes. The Pn ranged from 12.92$\mu molm^{-2}s^{-1}$ to 20.44$\mu molm^{-2}s^{-1}$ with a mean value far below than the total mean. The gs value varied from 0.1458$\mu molm^{-2}s^{-1}$ to 0.2858$\mu molm^{-2}s^{-1}$ which is also below the total mean. The E value ranged from 1.56$\mu molm^{-2}s^{-1}$ to 1.97$\mu molm^{-2}s^{-1}$ and the mean value is lower than the total mean (Table 3). This cluster consists of highly inferior clones in terms of water use

efficiency. The intrinsic wue, instantaneous wue and intrinsic carboxylation efficiency were far below the total mean and the intrinsic mesophyll efficiency was far above total mean. The clones of this cluster need to be improved further. The cluster diagram shows that it is divergent from cluster IV (6.404) but closer to cluster I (2.875).

Cluster VI

This cluster had nine clones, Et 016, Et 116, Et 071, Et 006, Et 148, Et 419, Et 250, Et 128 and Et 399, comprising 23.68% of total genotypes. The Pn ranged from 19.63µmolm^{-2}s^{-1}to 30.46µmolm^{-2}s^{-1} with a mean value less than the total mean. The gs value varied from 0.2345µmolm^{-2}s^{-1}to 0.4137µmolm^{-2}s^{-1} which is near to the total mean. The E value ranged from 1.54µmolm^{-2}s^{-1}to 2.91µmolm^{-2}s^{-1} and the mean value is almost near to the total mean (Table 3). This cluster also consists of highly inferior clones in terms of water use efficiency. The intrinsic wue, instantaneous wue and intrinsic carboxylation efficiency were far below the total mean and the intrinsic mesophyll efficiency was almost near to the total mean. The clones of this cluster need to be improved further. The cluster diagram shows that it is divergent from cluster IV (5.768) and cluster II (5.292) but closer to cluster III (2.181) and cluster VI (2.295).

Cluster VII

Five clones, Et 132, Et 231, Et 001, Et 122 and Et 17-1, included in this cluster comprising of 13.16% of total genotypes. Pn ranged from 32.95µmolm^{-2}s^{-1} to 41.09µmolm^{-2}s^{-1} with a mean value higher than the total mean. The gs varied from 0.4142µmolm^{-2}s^{-1} to 0.6075µmolm^{-2}s^{-1} with a mean value higher than the total mean. E varied from 2.31µmolm^{-2}s^{-1} to 2.89µmolm^{-2}s^{-1} with a mean value equal to the total mean. The intrinsic wueis far below the total mean and the instantaneous wueis equal to the total mean value. However, the intrinsic carboxylation efficiency and intrinsic mesophyll efficiency wereslightly better in these clones. These clones need to be improved further for photosynthetic efficiency. The cluster diagram shows that it is divergent from clusters II (5.722) and IV (5.689). However, it is genetically closer to the cluster VI (2.295).

Conclusion

Determination of genetic diversity of a species is the most important process in a successful tree breeding programme as it helps the breeders to select the right parents for hybridization. Selection of parents from genetically divergent clusters would provide an opportunity for bringing gene constellations of diverse nature resulting in superior hybrid derivatives. The importance of physiological parameters in assessing genetic diversity has been described by many physiologists (Kundu and Tigerstedt, 1999). The present study shows that the selected physiological parameters such as Pn, gs, Ci and E are highly heritable and show variation among the clones of *Eucalyptus tereticornis.* PCA shows that the intrinsic carboxylation efficiency contributed much to the total genetic divergence followed by intrinsic mesophyll efficiency. D^2 analysis categorized thirty eight clones into seven clusters. Cluster II with two genotypes such as Et 1-7 and Et 13-3 are excellent in terms of their water use efficiency. Cluster III containing nine clones, Et 027, Et 242, Et 008, Et 261, Et 052, Et 130, Et 351, Et 10-6 and Et 099 are also highly promising clones in terms of better intrinsic wue, instantaneous wau, intrinsic carboxylation efficiency and intrinsic mesophyll efficiency. These two clusters are highly divergent clones with a genetic distance of 7.311 (D^2 value). According to Rahim et al., (2010) optimum heterosis is obtained in the hybrids of parents having maximum genetic distance. These clones could be considered as the right choices for breeding programmes aimed at improving the photosynthetic efficiency. The clones belonging to other clusters are inferior in terms of wue and hybridization with the promising clones would definitely improve the photosynthetic efficiency in such clones.

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