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REVIEW ARTICLE

SCREENING THE JUVENILE CLONES OF *EUCALYPTUS TERETICORNIS* SM FOR WATER USE EFFICIENCY

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ABSTRACT

Eucalyptus tereticornis Sm is an exotic fast growing arborescent species, commercially planted as a source of paper pulp and timber. One of the objectives of clonal forestry programme is to obtain better return for a given investment and this can be achieved only by planting with suitable clones. Several clones of *Eucalyptus tereticornis* have been raised by ITC Bhadrachalam and IFGTB, Coimbatore but a clonal comparison for physiological traits have not been carried out. The major objective of the present work was to screen the juvenile clones of *Eucalyptus tereticornis* for the photosynthetic traits such as photosynthetic rate (Pn), stomatal conductance (gs), internal CO_2 concentration (Ci) and rate of transpiration (E). The clones were also assessed for photosynthetic ratios such as intrinsic WUE, instantaneous WUE, intrinsic carboxylation efficiency and mesophyll efficiency in order to identify elite clones of *Eucalyptus tereticornis* for clonal forestry programmes and also for planting drier areas so as to reclaim the waste lands. The results showed a significant variability for the physiological parameters such as Pn, gs, E and Ci and the derived ratios such as intrinsic WUE, instantaneous WUE, intrinsic carboxylation efficiency and intrinsic mesophyll efficiency in the clones of *Eucalytus tereticornis*. Clones were categorized based on their photosynthetic efficiency and some clones such as Et 130, Et 242, Et 008 and Et 027 were identified as superior clones as they had efficient stomatal regulatory capacity combined with better carboxylation efficiency and are ideal planting stock especially for drier areas. The superior clones which are identified based on photosynthetic efficiency could be considered as choice materials for further tree breeding programmes.

INTRODUCTION

Eucalyptus tereticornis Sm is an exotic fast growing arborescent species, commercially planted as a source of paper pulp and timber. It is commonly known as forest red gum or mysore gum, occurs naturally in latitudinal range extending from 6^0 to 38^0S and an altitudinal range from sea level to 1,000m in Austarlia and 800m in Papua New Guinea. It has been introduced to many tropical countries including India to meet the ever increasing demand for paper pulp. Today, eucalypts constitute the majority of world's exotic hardwood forest and one of the world's main sources of biomass. The estimated eucalypts plantations in the world is around 13 million ha and India is the largest planter of eucalypts in the tropics, having 48,00,000 ha under various species of *Eucalyptus*, followed by Brazil with an area of 36, 17, 000 ha (Davidson, 1998). However, the yield per hectare is much less in India. The main aim of industrial forest management is to obtain highest net value for a given investment. This goal is obtainable by adopting clonal forestry programmes and many countries successfully raised clonal plantations and achieved better yield.

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Aracruz Florestal, a private company in Brazil planted clones of the hybrids of *Eucalyptus grandis* x *Eucalyptus urophylla* and achieved yield of the order of 70-100m^3 ha^{-1} $year^{-1}$. Realizing the potential of clonal forestry in India, Lal *et al.*, (1997) carried out extensive studies to develop fast growing, genetically superior and comparatively disease resistant clones of eucalypts at Bhadrachalam Paperboards Limited, Andhra Pradesh. However, the problem with clonal forestry programme is the proper identification of superior clones having desirable characteristics as planting stock. Therefore, screening the clones for desirable traits to improve the yield is a crucial step in clonal forestry programmes. The growth and productivity of a crop is greatly influenced by agro-meteorological variables and water availability in the soil. Environmental factors like temperature, vapour pressure deficit, soil moisture and light affect the ability of a plant to convert atmospheric CO_2 into dry matter. Environmental variables influence stomatal responses and net photosynthetic rate (Pn) in plants (Raschke, 1975; Farquhar and Sharky, 1982; Schulze, 1986). The impact of meteorological variables on plant gas exchange characteristics have been well studied in perennial crops such as rubber (Samsuddin and Impens, 1979), coffee (Nunes, 1988), cashew (Balasimha, 1991), cocoa (Joly and Hahn, 1989; Balasimha *et al.*, 1992) and *Eucalyptus* (Chunyang *et al.*, 2000; Kallarackal and Somen, 1998).

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) and gs imparts more limitations to Pn during abiotic stress (Farquhar and Sharky, 1982). The water relations and WUE in *Eucalyptus* spp. has been studied by many physiologists (Chunyang *et al*., 2000; Kallarackal and Somen, 1998). Significant interspecific and intraspecific variations have been observed in many physiological traits in this genus. Significant variation in WUE was also reported in the clones of *Eucalyptus grandis* (Roux *et al*., 1996). The present study was carried out at the Institute of Forest Genetics and Tree Breeding, Coimbatore to screen the juvenile clones of *Eucalyptus tereticornis* for the photosynthetic traits such as photosynthetic rate (Pn), stomatal conductance (gs), internal CO_2 concentration (Ci) and rate of transpiration (E). The clones were also assessed for photosynthetic ratios such as intrinsic WUE, instantaneous WUE, intrinsic carboxylation efficiency and mesophyll efficiency in order to identify elite clones of *Eucalyptus tereticornis* for clonal forestry programmes and also for planting drier areas so as to reclaim the waste lands.

MATERIALS AND METHODS

One year old clones of *Eucalyptus tereticornis* raised in the laterite soil of Panampally in Palakkad District of Kerala, in randomized block design with a spacing of 1mx1m, were screened for photosynthetic parameters such as Pn, gs, Ci and 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 404,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.

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 cor Inc, USA). Three ramets were selected randomly per clone as per the randomization procedure shown by Gomez and Gomez (1984) and three observations were taken from three younger leaves of a ramet (fifth leaf from the branch apex).

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 shown in the Table (1). Among the traits, the stomatal conductance (cv=24.46) showed greater variability followed by Pn (cv=22.64), E (cv=17.79) and Ci (cv=14.15). The gs varied from a minimum of 0.1189µmol $m^{-2}s^{-1}$ in Et 259 to an optimum of 0.9344 µmol $m^{-2}s^{-1}$ in Et 12-11. While E ranged from a minimum of 6.16 µmol $m^{-2}s^{-1}$ in Et 158 to an optimum of 17.10 µmol $m^{-2}s^{-1}$ in Et 4-5.

This clearly indicates the differences in the inherent ability of the clones to regulate these processes even though the environmental conditions were non-limiting. Intrinsic WUE, the ratio of Pn to gs, implies the inherent ability of the system to assimilate CO_2, significantly varied from 9.17µmol mol^{-1} in Et 13-3 to 167.39µmol mol^{-1} in Et 026 (Fig 1). Marocco (1997) reported that plants with higher intrinsic WUE are efficient water users and they also have efficient stomatal regulatory mechanism.

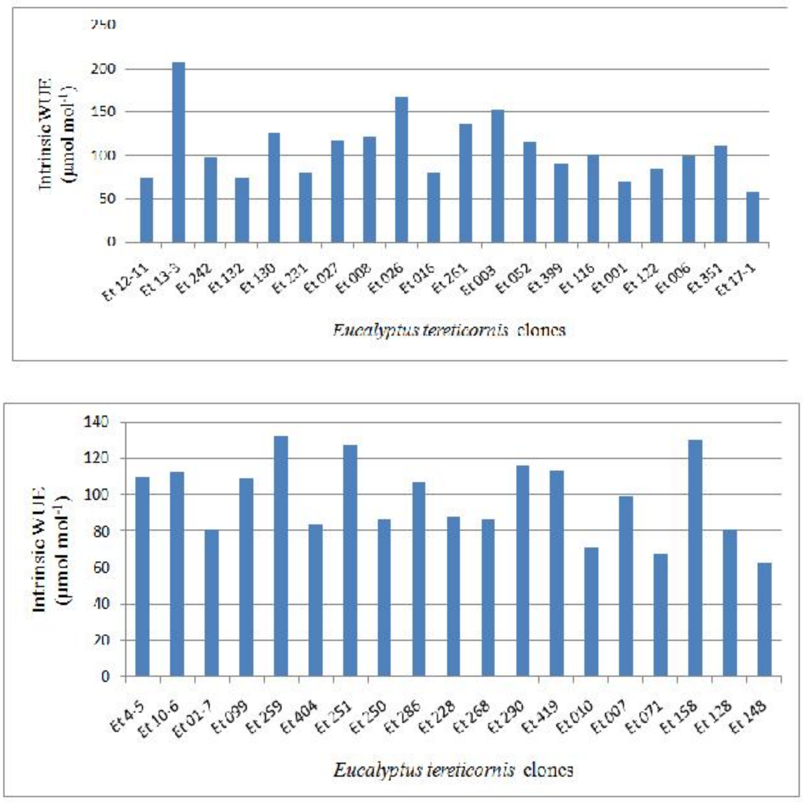
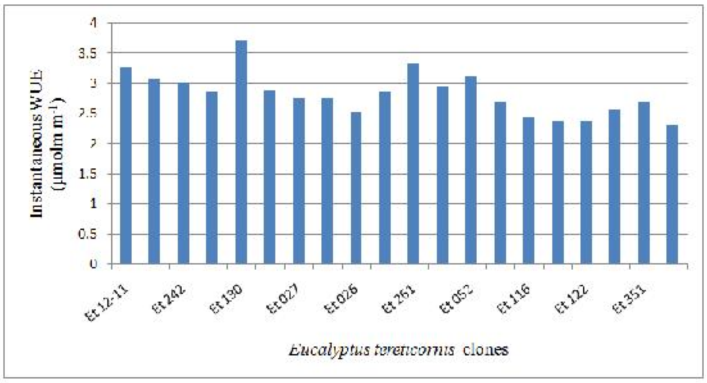


Figure 1. Intrinsic Water use efficiency in the clones of *Eucalyptus tereticornis*

Table 1. Physiological traits and their measurements in the juvenile clones of *Eucalyptus tereticornis* Sm. All the values are averages with ± standard error (n=9)

Sl. No	Clone No	Pn (µmol $m^{-2}s^{-1}$)	Gs (µmol $m^{-2}s^{-1}$)	Ci (µmol l^{-1})	E (µmol $m^{-2}s^{-1}$)
1	Et 12-11	35.49 ± 1.23	0.4706± 0.006	175.50± 7.28	3.28± 0.075
2	Et 13-3	24.16 ± 0.94	0.1162± 0.002	66.27± 3.69	3.09± 0.072
3	Et 242	30.85± 1.05	0.3147± 0.004	120.70± 6.90	3.03± 0.072
4	Et 132	39.30± 1.45	0.5287± 0.006	186.37± 8.23	2.87± 0.068
5	Et 130	41.95± 1.89	0.3342± 0.004	115.52± 5.98	3.73± 0.084
6	Et 231	41.09± 1.78	0.5124± 0.006	176.62± 7.04	2.89± 0.068
7	Et 027	30.57± 1.09	0.2604± 0.001	126.46± 6.58	2.76± 0.067
8	Et 008	32.40± 0.99	0.2676± 0.002	133.63± 6.83	2.76±0.066
9	Et 026	20.74± 0.92	0.1239± 0.002	91.33± 4.94	2.53± 0.062
10	Et 016	27.32± 1.22	0.3384± 0.004	173.84± 8.29	2.87± 0.068
11	Et 261	24.58± 1.32	0.1815± 0.002	109.31± 5.97	3.35± 0.081
12	Et 003	18.54± 0.92	0.1213± 0.002	94.92± 4.29	2.95± 0.069
13	Et 052	27.73± 1.18	0.2418± 0.002	125.11±6.93	3.13± 0.072
14	Et 399	30.46± 1.89	0.3365± 0.004	167.87± 7.01	2.70± 0.066
15	Et 116	24.04± 1.50	0.2381± 0.001	158.68± 8.58	2.44± 0.061
16	Et 001	32.95± 1.19	0.4705± 0.006	190.22± 8.98	2.39± 0.059
17	Et 122	35.16± 2.10	0.4142± 0.006	172.23± 8.02	2.37± 0.060
18	Et 006	26.16± 1.12	0.2650± 0.003	157.89± 6.45	2.52± 0.059
19	Et 351	25.36± 1.30	0.2281± 0.001	137.99± 6.92	2.71± 0.061
20	Et 17-1	34.80± 1.98	0.6075± 0.005	225.49± 9.98	2.31± 0.058
21	Et 4-5	13.60± 0.87	0.1234± 0.002	147.35± 6.23	2.05± 0.053
22	Et 10-6	26.24± 1.12	0.2331± 0.002	131.84± 6.78	3.13± 0.071
23	Et 01-7	29.35± 1.23	0.3600± 0.004	168.49± 7.21	2.74± 0.064
24	Et 099	30.82± 1.67	0.2820± 0.001	139.94± 7.04	3.06± 0.073
25	Et 259	15.77± 0.63	0.1189± 0.001	113.60± 5.56	2.63± 0.064
26	Et 404	26.35± 1.17	0.3135± 0.004	179.29± 7.34	2.48± 0.066
27	Et 251	18.20± 0.82	0.1430± 0.001	123.52± 6.23	2.55± 0.064
28	Et 250	21.82± 1.09	0.2496± 0.002	172.91± 7.22	2.07± 0.052
29	Et 286	20.06± 1.01	0.1875± 0.001	172.94± 6.93	1.97± 0.049
30	Et 228	12.92± 0.68	0.1458± 0.001	187.10± 6.78	1.57± 0.046
31	Et 268	14.10± 0.67	0.1624± 0.001	182.30± 7.43	1.65± 0.048
32	Et 290	17.40± 0.89	0.1494± 0.001	165.57± 7.10	1.71± 0.048
33	Et 419	26.55± 1.23	0.2345± 0.002	184.19± 6.89	1.95± 0.050
34	Et 010	20.44± 1.32	0.2858± 0.002	213.61± 7.98	1.76± 0.049
35	Et 007	15.34± 0.89	0.1541± 0.001	183.73± 6.47	1.56± 0.047
36	Et 071	21.05± 1.06	0.3096± 0.002	206.52± 8.21	1.54± 0.046
37	Et 158	16.14± 0.87	0.1233± 0.001	134.55± 6.98	3.19± 0.075
38	Et 128	19.63± 1.02	0.2420± 0.001	167.52± 7.11	2.91± 0.071
39	Et 148	25.97± 1.29	0.4137± 0.005	219.09± 8.01	2.41± 0.064
	SD	7.70	0.1271	36.61	0.55
	CV	22.64	24.46	14.15	17.79
	LSD	8.90	0.12	38.48	3.06



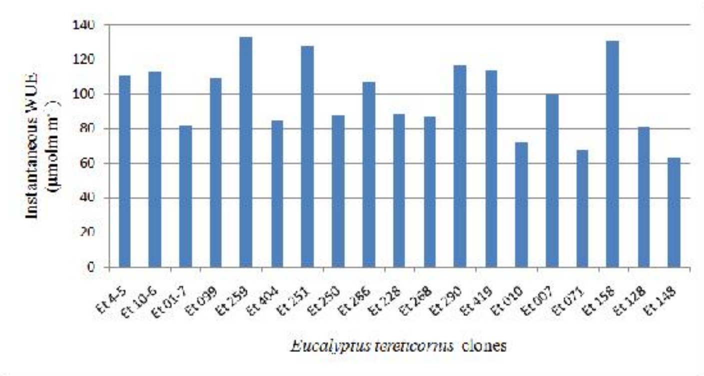


Fig 2. Instantaneous water use efficiency in the clones of *Eucalyptus tereticornis*

Table 2. The water use efficiency, carboxylation efficiency and mesophyll efficiency in the juvenile clones of *Eucalyptus tereticornis* Sm

Sl. No	Clone No	Intrinsic WUE (µmol mol^{-1})	Instantaneous WUE (µmolm m^{-1})	Intrinsic Carboxylation Efficiency (µ$molm^{-2}s^{-1}$nµ$l^{-1}l^{-1}$x10^{-2})	Intrinsic Mesophyll Efficiency (µl l^{-1} $mol^{-1}m^{-2}s^{-1}$)
1	Et 12-11	75.41	3.28	20.22	0.2861
2	Et 13-3	207.92	3.09	36.45	0.4043
3	Et 242	98.03	3.03	25.55	0.3835
4	Et 132	74.33	2.87	21.08	0.3525
5	Et 130	125.52	3.73	36.31	0.3457
6	Et 231	80.19	2.89	23.26	0.3448
7	Et 027	117.40	2.76	24.17	0.4857
8	Et 008	121.08	2.76	24.24	0.4993
9	Et 026	167.39	2.53	22.71	0.7371
10	Et 016	80.73	2.87	15.71	0.9578
11	Et 261	135.43	3.35	22.49	0.6023
12	Et 003	152.84	2.95	19.53	0.7825
13	Et 052	114.68	3.13	22.16	0.5174
14	Et 399	90.52	2.70	18.14	0.4989
15	Et 116	100.96	2.44	15.15	0.6664
16	Et 001	70.03	2.39	17.32	0.4043
17	Et 122	84.89	2.37	20.41	0.4158
18	Et 006	98.72	2.57	16.57	0.6922
19	Et 351	111.13	2.71	18.37	0.6049
20	Et 17-1	57.28	2.31	15.43	0.3712
21	Et 4-5	110.21	2.05	09.23	0.3568
22	Et 10-6	112.57	3.13	19.90	0.5656
23	Et 01-7	81.53	2.74	17.42	0.4578
24	Et 099	109.29	3.06	22.02	0.4962
25	Et 259	132.63	2.63	13.88	0.9554
26	Et 404	84.05	2.48	14.70	0.5719
27	Et 251	127.27	2.55	14.73	0.8638
28	Et 250	87.42	2.07	12.62	0.6927
29	Et 286	106.99	1.97	11.60	0.9223
30	Et 228	88.61	1.57	06.90	1.2833
31	Et 268	86.82	1.65	07.73	1.1225
32	Et 290	116.47	1.71	10.51	1.1082
33	Et 419	113.22	1.95	14.41	0.7855
34	Et 010	71.52	1.76	09.57	0.7474
35	Et 007	99.54	1.56	08.35	1.1922
36	Et 071	67.99	1.54	10.19	0.6670
37	Et 158	130.90	3.19	11.99	1.0912
38	Et 128	81.11	2.91	11.72	0.6922
39	Et 148	62.77	2.41	11.85	0.5295
	SD	30.27	0.55	6.81	0.26
	LSD	28.60	0.54	8.68	0.34

Table 3. Correlation Matrix showing correlation between physiological traits

	Pn	gS	Ci	E	Pn/gS	Pn/E	Pn/Ci	Ci/gS
Pn	1.000							
gS	ns	1.000						
Ci	- 0.374*	0.798*	1.000					
E	ns	0.868*	ns	1.000				
Pn/gS	0.306*	-0.861*	ns	- 0.785*	1.000			
Pn/E	0.720*	- 0.520*	ns	- 0.549*	0.773*	1.000		
Pn/Ci	0.798*	- 0.331*	- 0.764*	Ns	0.689*	0.876*	1.000	
Ci/gS	- 0.503*	- 0.691*	- 0.615*	Ns	ns	ns	0.342*	1.000

* Significant at 5% level for n-2 degrees of freedom. ns- non-significant

Clones with higher intrinsic WUE such as Et 003, Et 130, and Et 261 were identified as elite clones in terms their innate ability to assimilate more CO_2 and hence more dry matter production whereas clones such as Et 010, Et 071, Et 148, Et 17-1 were inferior in terms of their water use efficiency. According to the correlation matrix (Table 3), intrinsic WUE showed a highly significant negative correlation with gs (r=-0.861) indicating that higher stomatal conductance limits water use efficiency. Instantaneous WUE, the ratio of Pn to E, is also a variable trait among the clones, ranged from 0.42µmol $mmol^{-1}$ in Et 13-3 to 3.7342µmol $mmol^{-1}$ in Et 130 (Fig 2). Higher value indicates the efficiency of the system to divert water for photosynthesis rather than transpiration.

Clones such as Et 130, Et 261, Et 052 were identified as efficient water users whereas Et 268, Et 228, Et 007, Et 071 were inferior clones. The correlation matrix (Table 3) showed that instantaneous WUE had a significant negative correlation with gs (r=-o.520). This implies that higher stomatal conductance limits water use efficiency. The significances of intrinsic and instantaneous WUE in improving the crop yield have been suggested by many authors. Cowan and Farquhar (1977) reported that stomata play a major role in both intrinsic and instantaneous water use efficiency (WUE) and in controlling the balance between photosynthetic CO_2 assimilation and transpiration.

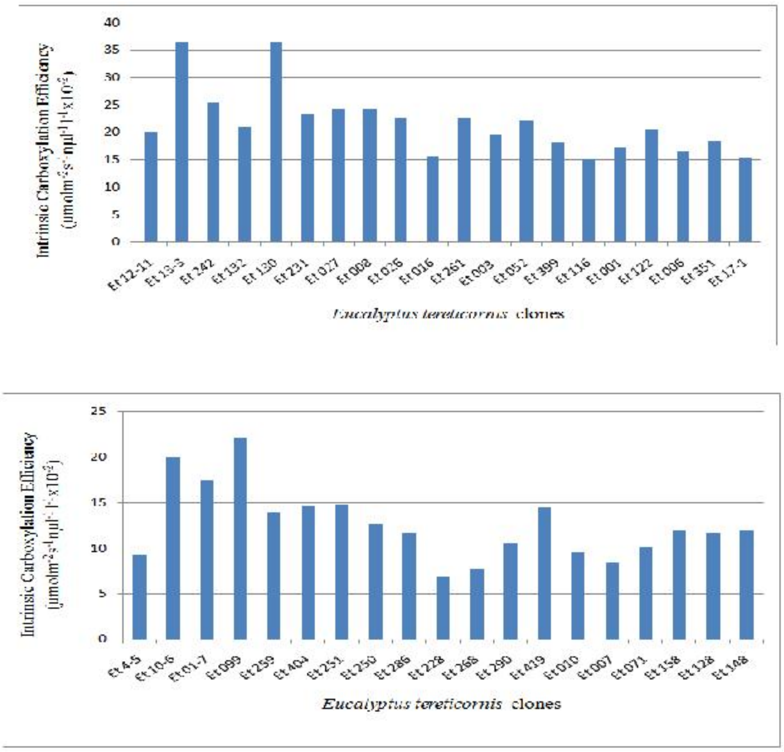


Figure 3. Intrinsic carboxylation efficiency in the clones of *Eucalyptus tereticornis*

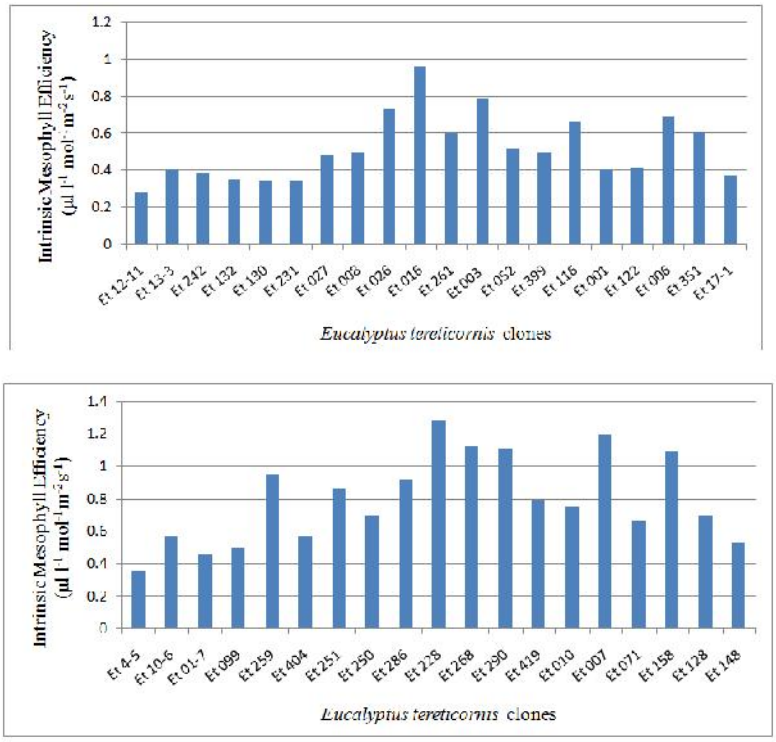


Figure 4. Intrinsic mesophyll efficiency in the clones of *Eucalyptus tereticornis*

The functional significance of stomatal closure in intrinsic and instantaneous WUE has been discussed by Comstock and Ehleringer (1993). The genotypes which can maintain higher WUE, will have an efficient stomatal regulatory capacity (Maroco *et al*., 1997) and increase in WUE may lead to a higher production.

Such a positive correlation between WUE and productivity has been observed by Zhang *et al*., (1993, 1996) in conifers. Intrinsic carboxylation efficiency, the ratio of Pn to Ci, varied from $2.27 \mu molm^{-2}s^{-1}n\mu l^{-1} l^{-1}x10^{-2}$ in Et 13-3 to $36.31 \mu molm^{-2}s^{-1}n\mu l^{-1} l^{-1}x10^{-2}$ in Et 130 (Fig 3). Clone such as Et 13-3, Et 130, Et 242 were found to be elite clones as they had higher value for carboxylation while clones such as Et 228, Et 268, Et 007 were highly inferior in terms of their poor carboxylation efficiency. The correlation matrix showed an inverse relationship between intrinsic carboxylation efficiency and gs (r=-0.331) similarly with Ci (r=-0.764). This clearly indicates that a higher Ci and/ gs limit the carboxylation efficiency in the clones of *Eucalyptus tereticornis* and it has been reported by Sheshshayee (1996). Clones Et 130, Et 242, Et 008 and Et 027 were identified as superior clones as they had efficient stomatal regulatory capacity combined with carboxylation efficiency and are ideal planting stock especially for drier areas. Intrinsic mesophyll efficiency, the ratio of Ci to gs, ranged from 0.2861µl l^{-1} $mol^{-1}m^{-2}s^{-1}$ in Et 12-11 to 1.2833µl l^{-1} $mol^{-1}m^{-2}s^{-1}$ in Et 228 (Fig 4). Correlation matrix (Table 3) showed an inverse relation between intrinsic mesophyll efficiency and Pn (r=-0.503) indicating that higher Ci/gs was accompanied by reduced Pn. According to Sheshshayee (1996), lower Ci indicates better mesophyll efficiency due to rapid uptake of CO_2 from the intercellular spaces for carboxylation in the mesophylls.

This result supports the observation made by him. Clones such as Et 12-11, Et 132, Et 130 and Et 231 were identified as elite clones as they had efficient mechanism for scavenging CO_2 from the intercellular spaces in the mesophylls. The study of WUE is of vital importance in increasing the productivity of crops as the primary concern in cultivating crops is water availability. Water is considered as the second most limiting factor, behind land area, influencing the yield of crops. Planting suitable clones with higher water use efficiency is one way to optimize water use as plants with higher WUE produce more biomass per unit of water consumed than those with low WUE. This is especially important in semi-arid regions where water is scarce. The only novel solution to preserve water in soil is to identify plants with higher WUE.

Conclusion

From the results, it is concluded that the clones of *Eucalytus tereticornis* showed significant variability for the physiological parameters such as Pn, gs, E and Ci and the derived ratios such as intrinsic WUE, instantaneous WUE, intrinsic carboxylation efficiency and intrinsic mesophyll efficiency. Clones were categorized based on their photosynthetic efficiency and some clones such as Et 130, Et 242, Et 008 and Et 027 were identified as superior clones as they had efficient stomatal regulatory capacity combined with carboxylation efficiency and are ideal planting stock especially for drier areas. The superior clones which are identified based on photosynthetic efficiency could be used for further tree breeding programmes.

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