

Original Research Article

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Clonal Evaluation of Eucalyptus Genetic Resources for Pulping Quality

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A B S T R A C T

The tree farming is ecologically as well as economically more viable than traditional agriculture. Investment in tree plantations always remained relatively low in India, inspite of the fact that the existing forests cannot continue to meet our wood requirements. However, realizing the existing problem, the expenditure on afforestation has increased enormously from fifth five year plan onwards but still the results on the land are not encouraging and we have not been able to increase area as well as the forest productivity to the desired level. The misery caused to the entire nation due to unprecedented eco-degradation is enormous and warrants immediate remedial measures. To counteract the impending crisis, use of fast growing tree species managed with intensive cultural operations especially in tree farming have opened up new vistas in wood biomass production. Against this backdrop, the current study was planned to screen and identify superior genetic resources of *Eucalyptus* for higher pulp yield and wood volume. Twenty seven clones in three *Eucalyptus* species viz., *Eucalyptus camaldulensis*, *Eucalyptus tereticornis* and *E. urophylla* were subjected for pulp quality analysis. The clone EC 48 has been characterized for wood quality towards its amenability for paper and biomass based power generation industries and the results are very encouraging. The clone expressed the Pulp yield of 48%, Kappa number 19.3 and Lignin content of 23.20% which expressed superiority over the local seed sources. Similarly, this clone expressed acceptable strength properties viz., Burst index ($5.0 \text{ K Pa m}^2 \text{ g}^{-1}$), Tear ($8.20 \text{ m Nm}^2 \text{ g}^{-1}$) and tensile index (80.0 Nm g^{-1}) which are again proved superior. The wood characterization for energy properties indicated that the clone EC MTP 48 had higher Calorific value of 4314 kcal/kg, Fuel value index of 142.58 and Heating value of 30.27 MJkg^{-1} and extend scope for its amenability towards biomass based energy utility. For biomass based energy utility, the clone can be harvested at the rotation age of 3 years and hence extend greater scope for High Density Short Rotation (HDSR) Energy Plantations. The productivity studies revealed that three clones viz., EC MTP 48, EC MTP 47 and EC MTP 41 recorded superiority in terms of growth characteristics viz., diameter at breast height, height and volume. The phenotypic and genotypic coefficient of variance estimates were low too high in range and volume recorded the highest PCV and GCV. The heritability values were high for all the traits investigated. Considering the pulp quality and productivity conjointly, the clone EC MTP 48 proved superior and this study recommends the suitability of EC MTP 48 for pulpwood plantation programme.

Keywords

Eucalyptus,
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Introduction

The Indian forests are in a grim situation today with total productivity of only 15 million m^3 of industrial timber and 195 million m^3 of firewood. The requirement of

various woods in India by 2020 AD was projected to 437 million tons of fuel wood and charcoal, 37 million m³ of industrial wood, 33 million m³ sawn timbers, 5.7 million m³ pulp and paper wood and 1.3 million tons of wood based panels (Parveen *et al.*, 2010).

In India, the pulp and paper industry is considered as one of the largest consumers of forest based raw material. The pulpwood is primarily consumed for paper and paperboard production followed by newsprint and rayon making. Application of paper is varied and one cannot think of a life without paper. The paper industry in India comprises of more than 813 mills producing nearly 14.99 million ton of paper, paper board and news print per annum and provides 0.5 million people directly and indirectly employment to 1.5 million people. For the past ten years from 2000 - 2010 paper consumption in India has grown at a compound annual growth rate of 9.93 percent (WWF, 2012). During 2011-2012, the domestic production of paper and paperboard was 11 million tonnes against the consumption of 11.23 million tonnes (mt), a deficit of 0.23 mt. The total production accounts for 1.6 per cent of the world's production. The estimated turnover of the industry was approximately 30,000 to 35,000 crore. The production of paper industry is expected to cross 20 million tons by 2020 and 40 million tons by 2030 with an annual growth rate of 7 - 8 per cent (CRISIL, 2012). Per capita consumption of paper has increased from 5 kg to 13.2 kg per annum between 2003 and 2015 against the world average of 40 kg to 57 kg (MCI, 2015). An increase in consumption by one kilogram of per capita paper would lead to an increase in demand of one million tons.

There are limited options to meet the ever-growing wood demand either by increasing the total forest covers or increasing

productivity of man-made forests substantially. The former happens to be an unachievable target and therefore, the reforestation to be carried out only with genetically improved planting material, which could easily be done either by developing artificial hybrids or clones with substantially higher productivity.

The genus *Eucalyptus* belongs to the family Myrtaceae and comprises about 700 species (Eldridge *et al.*, 1993). In fact, it is one of the most valuable tree species, which is widely planted across the world due to its wide adaptability, faster growth and short rotation. Eucalypts many wood based industries particularly for pulp, paper, furniture, cellulose and poles as scaffoldings. It finds suitability as a feedstock for the production of cellulosic bio-fuels and production of energy from charcoal, which reduces emission of greenhouse gases (Table 5).

In fact, it sequesters about 10-14 tons of carbon ha per yr from planting to harvesting in fast growing tropical plantations. Furthermore, eucalypts have a positive net carbon balance when computing production of CO₂ used for energy from charcoal or as pulp and paper. Eucalypts remove CO₂ from the atmosphere at a rate of about 1.8 tone for every tone of dry wood and also generate O₂ at a rate of 1.3 tone for every tone of dry wood (Myburg *et al.*, 2006).

Millions of seedlings of *Eucalyptus* are being planted in India every year but the productivity has not been consummating with the expected yield basically due to poor quality of planting stock. On the other hand, significant improvement in yields has been achieved in many countries through application of breeding and genetic tools coupled with clonal forestry. Hence, there is a need to identify and screen superior short rotation clone for pulpwood, which has the

potential for high pulp recovery coupled with high productivity.

Materials and Methods

Eucalyptus tree improvement programme was initiated during 2000 by introducing 135 seed lots from CSIRO Australia and the first generation evaluation was completed during 2005. The first generation evaluation identified 20 potential seed lots (Table 1) and from these base populations 20 plus trees (Clones) have been screened and characterized for pulp and energy quality coupled with their evaluation through clonal means. The clonal evaluation trial was established at Forest College and Research Institute, Mettupalayam using first generation screened 20 clones of three Eucalyptus species viz., *Eucalyptus camaldulensis*, *E. tereticornis* and *E. urophylla* and for comparison 7 local clones and 1 seed sources have been used. From each species, a billet of each 1 m length and 50-60 cm girth were collected, debarked and chipped separately and screened. The screened chips were used for pulping experiments. Some chips were converted into dust for proximate chemical analysis. Based on the initial screening study in the laboratory, the wood samples were subjected to analysis of physical and chemical properties. The pulping experiments were also carried out to find out its suitability for papermaking.

The physical characteristics such as bulk density, basic density and moisture content of wood chips are estimated. For the chemical properties analysis, the billets of individual tree species were chipped in pilot chipper; air-dried and converted into wood meal. The wood dust passing through 40 mesh but retained over 60 mesh was subjected to analysis for moisture, ash, hot water soluble, one per cent NaOH soluble, AB extractive, acid insoluble lignin, pentosans,

hollocellulose as per TAPPI methods (TAPPI, 1980). The strength properties such as pulping, identification of kappa number, pulp brightness, paper sheet preparation, paper strength measurement, tensile strength, tearing strength, bursting strength measurement, black liquor analysis were analyzed as per standard method (TAPPI, 1980).

Twenty seven Eucalyptus clones were multiplied at the clonal complex using a coppice shoot cuttings obtained from selected clones. The existing seed source of Eucalyptus hybrid was raised through seeds and used for comparison. The clones and seed source were established in the field in a randomized block design with three replications. In each replication nine ramets/seedlings were used for the experiments. The data on height, diameter and volume index were periodically measured and analysed and the analysis of variance, ANOVA table along with

Associated t test were conducted following the methods of Panse and Sukhatme (1978).

Pulp Wood characterization of eucalyptus clones

Physical properties of wood chips

The results of the study indicated that the moisture contents of wood sample of all the clones were found to be ranged between 9.76 (EC MTP 47) and 10.90 (EU MTP 8). The bulk density (284 kg m⁻³) and basic density (542 kg m⁻³) were found highest in clone EC MTP 48 and lowest in clone EC MTP 41 (Table 2). It showed that increased density to be strongly linked to favourable strength, stiffness, hardness and working properties of sawn timbers, as well as pulp yield and paper making quality. The wood density of Eucalyptus pulp wood is possibly one of the most influential factors controlling the

strength and several other physical characteristics of the paper sheet. It is relatively simple and inexpensive property to determine, even in unsophisticated environments. The bulk density exhibited wide variation and the maximum density was recorded by the clone EC MTP 48. This variation among tested clones and seed source may be due to the differences between early and late wood, which could have created variation between and within trees. Similarly significant difference was observed among *Eucalyptus* species in basic density, which ranged between 446 kg m⁻³ (EC MTP 41) and 542 kg m⁻³ (EC MTP 48). The wood density properties are of major importance for the production of quality pulp and paper. The amount of wood needed to produce one tone of air dried pulp is calculated from the density and pulp yield (Storebraten, 1990). Persson (1975) found that differences in diameter growth have major impact on basic density of wood. Basic density is again highly correlated with late wood content (Bergstedt and Olsen, 2000). Similarly, the variability exhibited in most physical properties studied among different *Eucalyptus* clones in the current study also attests the results of earlier findings. But it is important to understand the exact relationship between wood density and other fibre characteristics of the test clones that have an effect on pulp and paper quality.

Chemical properties of wood chips

The proximate chemical analyses give an idea of potentiality of raw material for paper making. The chemical analysis in terms of ash content ranged between 0.32 (EC MTP 48) and 0.71 (EU MTP 1) (Table 3). The chemical investigation carried out in wood pulp of *Acacia mangium* recorded high ash content (Saepuloh, 1999). However, all the selected clones in the current study exhibited lower ash content, which thus lend a scope for utilization as improved pulp wood. The

alcohol-benzene solubilities of wood constitute the waxes, fats and resinous matter. In the current study, the extractives were in the range between 1.1 (EU MTP 1, EU MTP 2 and ET MTP 29) and 1.4 (ET MTP 14, EC MTP 47 and EC MTP 48) and potential differences were recorded among the selected clones. Similar variation in alcohol benzene extractives were observed among various clones of *Eucalyptus tereticornis*, wherein the extractives ranged between 1.06 and 1.35 (Rao *et al.*, 1999). Among the chemical properties, holocellulose is very important because it is a measure of total carbohydrate content of the wood (Tappi, 2001). The holocellulose constituting cellulose and hemicellulose is the major portion of fibrous raw material. The holocellulose content in the study ranged between 71.6 (S.O) and 75.2 (EC MTP 48) and other *Eucalyptus* species recorded in between these. The result indicated the superiority of EC MTP 48 over the existing seed source and other clones. The content of pentosans ranged between 13.0 per cent (EC MTP 47) and 18.5 per cent (S.O) and acid soluble lignin was found to be in the range of 23.0 per cent (EC MTP 47) to 25.7 per cent (S.O). The overall chemical analysis revealed that the clone EC MTP 48 is most superior among twenty seven clones, which could be preferred for commercial deployment for pulpwood plantation establishment.

Strength properties of wood chips

The strength properties of paper are directly associated with cellulose and inter fibre bonding. The clone EC MTP 48 recorded high holocellulose and low lignin content due to increased pulp yield and is good for interfibre bonding and pulp strength. Similar variations among tree species for various strength properties were also recorded in *Eucalyptus tereticornis* and *Eucalyptus grandis* (Patil *et al.*, 1997). Within the

species, the strength properties varied due to age but in the current study variation occurred among clones of same age which indicated the variation might be due to genetic differences. In the current study, satisfactory levels of strength properties was achieved even in five years of growth, which indicated that the clones tested in the current study could be harvested even in five years as against seven years of current practice by the state forest department.

The comparison of pulping results for yield and strength properties of clones of all the species revealed that EC MTP 48 is most

superior compared to Control (S.O). Among the three species under test, *Eucalyptus camaldulensis* recorded higher strength properties compared to other two species. The strength properties viz., tensile index, tear index, burst index and specific coefficient were recorded superior values in EC MTP 48, EC MTP 47 and EC MTP 41. This might be due to superior fibre characteristic of these genotypes. This besides, the chemical requirement to achieve 20 kappa number in this species is only 17 per cent with normal chemical requirement and good bleaching response might also contributed for improved strength properties.

Table.1 Biometric attributes of *Eucalyptus* seed source evaluation trial at 48 MAP

Species	Seed lot	12 MAP			24 MAP			48 MAP		
		Height (cm)	DBH (cm)	Volume (cm ³)	Height (cm)	DBH (cm)	Volume (cm ³)	Height (cm)	DBH (cm)	Volume (cm ³)
<i>Eucalyptus urophylla</i>										
EU MTP 1	17567/23	132.40	1.16	139.85	230.40	2.50	1130.40	504.40	4.35	7492.44
EU MTP 2	17567/20	107.80	1.07	96.88	215.60	3.45	2014.45	409.20	4.49	6475.87
EU MTP 5	17567/10	142.40	0.91	92.57	261.40	2.90	1725.72	519.80	4.59	8596.69
EU MTP 8	17567/4	93.80	1.01	75.11	183.00	2.07	615.55	433.00	3.29	3679.17
EU MTP 9	17567/19	102.80	0.91	66.83	205.80	2.36	899.79	382.00	3.12	2919.06
<i>Eucalyptus tereticornis</i>										
ET MTP 13	13399/JD954	135.39	1.18	147.99	392.60	2.23	1532.60	619.20	2.85	3948.12
ET MTP 14	16647	106.00	0.93	71.97	208.80	1.32	285.59	458.20	1.98	1410.12
ET MTP 24	13398JD930	110.00	0.66	37.61	262.80	1.78	653.64	488.40	2.44	2282.58
ET MTP 29	19960/K1320	148.00	1.03	123.26	333.60	2.25	1325.75	650.60	2.66	3613.66
ET MTP 31	19960/K1323	142.60	1.07	128.16	263.00	2.26	1054.49	558.40	2.74	3290.91
<i>Eucalyptus camaldulensis</i>										
EC MTP 41	18275/1387	119.40	0.60	33.74	360.80	1.39	547.23	436.60	2.35	1892.73
EC MTP 44	16551/JD1596	167.60	0.81	86.32	239.20	1.00	187.77	301.20	1.47	510.93
EC MTP 45	19965/24	131.80	0.49	24.84	245.80	0.71	97.27	341.00	1.22	398.42
EC MTP 47	16551/JD1595	135.60	1.12	133.53	281.40	1.39	426.80	325.80	1.33	452.40
EC MTP 48	16551/JD1597	163.00	0.88	99.09	424.60	2.93	2861.44	472.20	3.15	3678.04
EC MTP 50	19566/DL1843	129.60	1.07	116.48	325.40	1.19	361.73	258.80	1.51	463.22
EC MTP 53	19615/5090	188.00	1.48	323.26	333.80	1.87	916.30	384.00	2.43	1779.97
EC MTP 56	19566/DL1840	126.80	0.60	35.83	335.00	1.26	417.50	419.40	1.99	1303.78
EC MTP 57	19566/DL1841	141.00	0.63	43.93	316.80	1.30	420.28	454.40	2.10	1573.07
EC MTP 58	19615/5091	135.20	1.20	152.83	248.00	1.27	313.99	311.80	1.70	707.37

Table.2 Physical characteristics of different *Eucalyptus* clones

S. No.	Clones	Moisture content (%)	Bulk density (OD basis) (kg m ⁻³)	Basic density (OD basis) (kg m ⁻³)	Chips classification (%)				
					+ 45 mm	+ 8 mm (over thick)	+7 mm (accept)	+ 3 mm (pin chips)	-3 mm (dust)
1	EU MTP 1	10.49	260	499	Nil	6.1	80.1	13.2	0.6
2	EU MTP 2	10.76	270	510	Nil	5.9	78.5	14.8	0.8
3	EU MTP 5	10.02	224	461	Nil	7.1	81.2	11.3	0.4
4	EU MTP 8	10.90	230	455	Nil	5.7	80.4	13.5	0.4
5	EU MTP 9	10.10	235	473	Nil	6.4	75.3	17.6	0.7
6	ET MTP 13	11.20	230	455	Nil	5.5	76.8	17.2	0.5
7	ET MTP 14	10.61	249	469	Nil	6.2	77.8	15.4	0.6
8	ET MTP 24	10.34	210	477	Nil	8.3	79.6	11.8	0.3
9	ET MTP 29	10.47	236	452	Nil	5.2	80.9	13.5	0.4
10	ET MTP 31	10.91	238	484	Nil	4.6	81.5	13.4	0.5
11	EC MTP 41	10.22	234	446	Nil	6.5	82.6	10.1	0.8
12	EC MTP 44	9.93	224	480	Nil	5.1	78.6	15.7	0.6
13	EC MTP 45	10.12	246	460	Nil	4.9	79.2	15.2	0.7
14	EC MTP 47	9.76	270	510	Nil	4.4	82.8	12.4	0.4
15	EC MTP 48	9.98	284	542	Nil	6.5	81.8	11.3	0.4
16	EC MTP 50	10.97	245	540	Nil	7.2	79.9	12.1	0.8
17	EC MTP 53	10.49	240	540	Nil	5.8	81.5	12.3	0.4
18	EC MTP 56	10.61	212	468	Nil	5.1	82.7	11.6	0.6
19	EC MTP 57	9.73	210	484	Nil	6.7	72.6	20.2	0.5
20	EC MTP 58	10.64	214	456	Nil	4.6	72.6	22.3	0.5
21	FC RI 3	10.53	238	475	Nil	6.8	78.9	13.5	0.8
22	FC RI 53	10.09	217	470	Nil	9.7	76.8	12.9	0.6
23	FC RI 56	10.88	242	455	Nil	8.9	78.4	11.9	0.8
24	FCRI 103	10.03	210	454	Nil	5.8	82.7	11.0	0.5
25	C 106	11.78	240	484	Nil	8.6	79.0	12.1	0.3
26	C 413	10.82	220	510	Nil	9.4	71.1	19.0	0.5
27	C 283	9.89	206	425	Nil	6.7	75.3	17.5	0.5
28	S.O (Control)	10.29	220	455	Nil	8.3	78.6	12.8	0.3

Table.3 Proximate chemical composition of different *Eucalyptus* clones

Sl. No.	Clones	Ash content (%)	Solubility in		Alcohol benzene extractive (%)	Acid insoluble lignin (%)	Pentosans (ash corrected) (%)	Holocellulose (%)
			Hot water (%)	1 % NaOH (%)				
1	EU MTP 1	0.54	3.0	12.9	1.1	24.3	13.4	73.1
2	EU MTP 2	0.45	2.9	12.2	1.1	24.9	13.7	73.1
3	EU MTP 5	0.63	3.3	11.9	1.8	26.0	15.8	68.5
4	EU MTP 8	0.53	2.8	12.5	1.2	24.6	13.2	73.3
5	EU MTP 9	0.50	3.9	12.2	2.7	25.5	15.2	69.8
6	ET MTP 13	0.68	3.5	13.1	2.0	27.8	16.5	68.9
7	ET MTP 14	0.43	2.8	12.8	1.4	24.2	13.8	73.7
8	ET MTP 24	0.55	3.5	14.7	1.8	26.7	14.1	71.4
9	ET MTP 29	0.34	2.7	14.3	1.1	24.3	13.9	73.4
10	ET MTP 31	0.36	3.2	13.9	2.0	25.3	15.1	70.3
11	EC MTP 41	0.43	2.9	13.5	1.2	24.5	13.3	74.6
12	EC MTP 44	0.71	4.1	13.7	1.3	25.4	16.7	71.1
13	EC MTP 45	0.63	3.5	13.6	2.7	27.1	14.8	69.7
14	EC MTP 47	0.46	3.4	12.2	1.4	23.0	13.0	74.8
15	EC MTP 48	0.32	2.7	12.9	1.4	23.2	14.4	75.2
16	EC MTP 50	0.53	3.7	13.8	1.3	24.4	14.8	73.2
17	EC MTP 53	0.48	2.7	12.7	1.3	24.3	14.6	73.2
18	EC MTP 56	0.37	3.3	13.1	1.6	27.6	16.8	72.9
19	EC MTP 57	0.37	3.6	14.2	1.5	26.7	16.2	73.7
20	EC MTP 58	0.48	3.4	12.8	2.4	26.8	15.8	72.3
21	FC RI 3	0.36	3.2	12.5	1.6	27.7	15.2	71.1
22	FC RI 53	0.36	3.6	13.7	2.2	27.8	17.2	70.6
23	FC RI 56	0.63	3.7	14.7	2.1	26.4	17.5	72.8
24	FCRI 103	0.34	3.8	12.2	1.9	26.9	17.2	72.8
25	C 106	0.35	3.4	13.2	1.8	27.3	17.4	72.4
26	C 413	0.31	3.8	12.3	1.6	27.7	14.1	73.3
27	C 283	0.46	3.9	14.5	2.2	27.2	14.2	72.9
28	S.O (Control)	0.38	3.6	14.0	1.2	25.7	18.5	71.6

Table.4 Comparison of different *Eucalyptus* clones with respect yield and strength

Species	Chemical charge for 20 kappa	Unbleached pulp yield (%)	Strength properties at 300 ml CSF		
			Tear index (m Nm ² g ⁻¹)	Tensile index (Nm g ⁻¹)	Burst index (K Pa m ² g ⁻¹)
EU MTP 1	17	45.06	7.5	74.0	4.3
EU MTP 2	17	46.84	7.7	61.0	3.4
EU MTP 8	17	44.65	7.5	70.0	4.1
ET MTP 14	17	44.28	7.6	77.0	4.6
ET MTP 29	17	46.51	7.7	67.0	4.3
EC MTP 41	17	47.35	8.0	78.0	4.7
EC MTP 47	17	47.38	8.0	78.0	4.4
EC MTP 48	17	48.38	8.2	80.0	5.0
EC MTP 50	17	47.02	7.9	71.0	4.1
EC MTP 53	17	46.91	7.8	78.0	4.2
S.O (Control)	17	44.00	7.8	72.0	4.5

Table.5 Energy properties of EC MTP 48

S.No	Properties	Eucalyptus	<i>Prosopis juliflora</i>
1.	Calorific value (kcal/kg)	4314	4860
2.	Moisture content (%)	7.67	6.67
3.	Volatile matter (%)	69.25	68.17
4.	Ash content (%)	2.48	2.83
5.	Fixed carbon (%)	20.60	22.50
6.	Ash Fusion Temperature (%)	1267	1370
7.	Ash Deformation Temperature (%)	1143	1220
8.	Fuel value index	142.58	207.59
9.	Heating Value (MJkg ⁻¹)	30.27	30.56

Table.6 EC MTP 48 growth parameters at different growth periods

Clones	12 MAP		24 MAP		36 MAP		48 MAP		60 MAP			
	Height (m)	DBH (cm)	Height (m)	DBH (cm)	Height (m)	DBH (cm)	Height (m)	DBH (cm)	Height (m)	DBH (cm)	Volume (m ³)	Volume (ton/ha)
EU MTP 1	1.87	1.18**	4.25	3.16	6.43	6.50	9.14	9.37	9.44	10.38	0.0800	80.00
EU MTP 2	1.96	1.27**	5.48	3.21	8.46	7.85	10.33	10.33	11.46	11.43	0.1169	116.94
EU MTP 5	1.77	0.97	4.49	3.01	6.50	6.84	7.80	9.53	9.13	11.10	0.0864	86.42
EU MTP 8	1.79	0.86	4.27	2.51	5.93	5.57	7.97	8.63	9.10	10.00	0.0723	72.33
EU MTP 9	1.80	0.82	4.99	3.85*	7.37	8.92**	8.70	9.98	9.73	10.83	0.0868	86.80
ET MTP 13	1.73	0.81	4.70	4.07**	7.67	7.30	9.43	9.20	10.57	10.52	0.0893	89.31
ET MTP 14	1.87	0.95	5.73	5.37**	9.20**	8.14	9.31	9.88	10.39	10.71	0.0899	89.88
ET MTP 24	1.73	0.83	5.10	3.67	8.59	6.90	11.60**	9.17	12.56	10.50	0.1059	105.95
ET MTP 29	1.80	0.91	6.50**	4.03**	10.37	7.44	11.65**	10.29	12.73**	11.21	0.1210	121.00
ET MTP 31	1.73	0.73	4.10	3.86*	6.30	6.23	9.01	8.71	10.29	9.70	0.0747	74.74
EC MTP 41	2.03*	1.36**	5.23	3.51	8.13	7.11	10.60	9.77	11.68	12.01	0.1297	129.72
EC MTP 44	1.67	1.07**	5.33	2.38	10.37**	5.61	13.57**	8.39	14.60**	9.43	0.0996	99.58
EC MTP 45	1.70	0.94	4.63	4.18**	7.93	9.16**	9.67	11.08	10.61	12.06	0.1164	116.43
EC MTP 47	2.07**	1.19**	4.97	4.55**	9.77**	9.08**	12.05**	10.72	13.22**	11.84	0.1426	142.62
EC MTP 48	2.43**	1.34**	7.53**	4.12**	11.43**	8.57**	14.97**	11.59	15.69**	12.67*	0.1920**	192.03
EC MTP 50	1.93	0.94	6.43**	4.19**	9.87**	8.70**	12.84**	10.40	13.79**	11.25	0.1341	134.08
EC MTP 53	1.80	0.96	6.70**	5.07**	9.17**	8.53**	11.43*	10.31	12.14	11.57	0.1229	122.95
EC MTP 56	1.77	0.77	4.83	3.61	9.27**	8.95**	12.57**	11.13	13.50**	12.18	0.1523*	152.34
EC MTP 57	1.73	0.81	4.50	3.84*	5.97	8.63**	8.57	11.20	9.60	12.63*	0.1168	116.81
EC MTP 58	1.70	0.90	4.05	2.92	6.02	8.80**	8.67	10.81	9.73	11.68	0.0999	99.90
FCRI 3	1.73	0.93	6.31**	2.80	9.34**	8.23	12.29**	10.59	13.33**	11.44	0.1359	135.92
FCRI 53	1.67	0.96	5.05	3.03	8.55	8.67**	11.30	11.17	12.40*	12.32	0.1461*	146.13
FCRI 56	1.87	0.91	5.42	3.13	9.48**	7.79	12.83**	10.53	13.73**	11.64	0.1420	142.04
FCRI 103	1.83	0.81	6.37**	3.04	9.40**	8.65**	11.84**	10.53	12.83**	11.67	0.1330	133.00
C 106	1.77	0.80	6.68**	2.94	9.31**	6.17	12.38**	9.47	13.43**	10.38	0.1087	108.76
C 413	1.73	0.83	5.41	3.19	9.80**	8.68**	12.18**	11.42	13.36**	12.33	0.1540	153.99
C 283	1.83	0.90	5.17	3.25	9.70**	8.27*	13.38**	10.32	14.64**	11.27	0.1420	142.00
S.O (Control)	1.57	0.71	4.01	2.58	6.64	6.05	8.69	8.81	9.72	10.08	0.0745	74.55
Mean	1.82	0.94	5.29	3.54	8.46	7.72	10.88	10.12	11.91	11.24	0.1166	116.65
SEd	0.08	0.02	0.24	0.14	0.24	0.27	0.23	0.87	0.25	0.68	0.0138	
CD (0.05)	0.17	0.04	0.48	0.29	0.48	0.54	0.47	1.75	0.50	1.36	0.0276	
CD (0.01)	0.22	0.06	0.65	0.38	0.63	0.73	0.63	2.33	0.67	1.82	0.1534	

Among the strength properties, tearing strength depends upon fibre length, width etc. Hence, the maximum tearing strength, burst index and tear index in EC MTP 48, EC MTP 47 and EC MTP 41 must be due to superior fibre characteristics. Strength properties are best obtained with EC MTP 48, EC MTP 47 and EC MTP 41, which might be due to higher freeness and optimized kappa number (<20) recorded by the clones. The wood and wood properties are very important not only for production of paper but also the properties of paper (Storebraten, 1990). The pulp and paper property are highly dependent on fibre morphology and sheet forming processes. Wood with different properties give different pulp and paper qualities (Kibblewhite, 1989). However, in the current study, only dominated trees were selected which expressed wide variability. This indicated the genetic differences among clones of different *Eucalyptus* species.

Considering all physical, chemical and strength properties, all the trees subjected for analysis were found suitable as a source of pulpwood. However, considering the pulp yield and kappa number coupled with strength properties (Table 4), the superiority of the EC MTP 48, EC MTP 47 and EC MTP 41 as a source of pulpwood was evident and hence the above three clones are recommended for clonal deployment towards establishment of industrial wood pulpwood plantations.

However, the variation in physical, chemical and strength properties observed among the clones of three *Eucalyptus* species suggest that further improvement could be made via selection, breeding and further clonal deployment of outstanding individuals.

Productivity studies

Genetically improved and fast growing clonal planting stock has revolutionized productivity

and profitability of plantation of many species amenable to vegetative propagation (Lal, 2005). Clonal planting stock is true to type uniform and with all the superior desirable properties of the elite mother tree (Parthiban *et al.*, 2004). It is absolutely necessary to ensure a wide genetic base of clones to safeguard against possible epidemics and to provide continuous superior genetic resources to meet the demands of wood based industries. The existing genetic superiority of elite trees should be evaluated through comparative trial in order to screen site specific clones with superior wood traits. Genetic improvement of the planting stock through clonal evaluation can play a very significant role in improving productivity, yields, quality of produce and profitability. Against this backdrop, clonal evaluation trial was carried out using twenty seven clones and one seed source as control. The clones differed significantly under field conditions during 12, 24, 36, 48 and 60 MAP for various growth parameters such as plant height, diameter at breast height and volume (Table 6).

The clonal evaluation trial indicated that one clone viz., EC MTP 48 expressed superiority in all four characters investigated followed by EC MTP 47 and EC MTP 41. Similarly, in *Eucalyptus tereticornis* four clones viz., ET12, ET9, ET1 and ET6 expressed superiority out of sixteen clones tested (Sasikumar, 2003). Similar results were also reported in the clonal evaluation trials of *Eucalyptus grandis* (Lambeth *et al.*, 1994). Their study involving sixteen clones and seedling checks indicated that the clones had better yield, straightness and all other growth parameters compared to check lots of seed origin and also significant differences between clones. Vegetative propagation is excellent approach for development of clonal forestry programme (Vivekanandhan *et al.*, 1997) and it helps to exploit non additive

characteristics (Zobel and Ikemori, 1983). Similar genetic gain by exploiting clonal forestry approaches was also done in the hybrids clones of *Eucalyptus grandis* and *Eucalyptus urophylla*. The hybrid vigour was exploited through clonal forestry (Chopra, 2004), which thus lend support to the current investigation. The superiority of few clones in the current study might be due to the genetic that inherited from the selected mother trees. Hence, the three clones viz., EC MTP 48, EC MTP 47 and EC MTP 41, which expressed early superiority could be incorporated in the industrial wood plantation programme.

Considering the wood quality traits coupled with growth attributes the current study recommends clone viz., EC MTP 48 for incorporation in the ongoing plantation programme and also in the future breeding programme.

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