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Evaluation of novel eucalyptus clones for biomass production in clonal testing areas of central Telangana zone

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Abstract
Eucalyptus is among the most widely planted forest species in the world owing to its adaptability to a wide range of climatic and edaphic conditions and the utilization in the paper and pulp industry. The higher productivity the species generates in a short rotation of 6-7 years is the major driver in the utilization of species at the farming as well as commercial level in agroforestry. The clonal trials of Eucalyptus at various sites provides superior clones according to requirement and performance. The present study was conducted to evaluate the performance of novel eucalyptus clones under trial in the six (06) Clonal Testing areas in three divisions of Central Agroclimatic Zone of Telangana State Forest Development Corporation. The growth parameters -GBH, collar girth, height, basal Area, volume, total biomass, carbon stocks and carbon sequestration potential were estimated at the age of 2 years. The clones showed significant differences for the parameters mentioned. In the Central Telangana Zone, the clone 1806 had the maximum height of 6.10 m. The clone 1801 recorded the maximum girth at breast height (17.18 cm) and the basal area (3.93 m^2/ha), volume (12.39 m^3/ha), the greatest above ground biomass of 10.41 ton/ha, and the below ground biomass of 2.71 ton/ha and total biomass13.11 ton/ha. Clone 1801 also recorded the greatest carbon stocks of 6.56 ton/ha and 24.04 ton/ha metrics of carbon sequestration potential. Clone SK 23 had recorded the lowest girth at breast height (14.04 cm), lowest height (4.95 m), basal area (2.64 m^2/ha), above and below ground biomass (5.72 and 1.49 ton/ha) respectively thereby the lowest total biomass of 7.21 ton/ha, SK 23 was also the least performer in terms of carbon stocks and carbon sequestration potential metrics with 3.60ton /ha and 13.22 ton/ha respectively.

Keywords: Eucalyptus, agroforestry, clones, clonal trials, carbon stock

Introduction
Climate change has become an important and sensitive environmental issue that has captured the global attention of many intellectuals during the recent past. The increasing concentration of carbon dioxide in the atmosphere is believed to have contributed significantly to the climate change (IPCC, 2001, 2007). One of the most feared dangers of the new millennium causing the climate change is global warming. The strongest causal factor for global warming is thought to be carbon emissions. As a result, one of today's key problems is rising carbon emissions, which is properly addressed in the Kyoto Protocol (Nair *et al*., 2011) [26]. Among all the available options, the use of perennial woody vegetation is an efficient, cost-effective and environmentally friendly strategy for storing and sequestering the atmospheric carbon was found the most feasible and an immediate solution (Burschel *et al*., 1993; Schlamadinger and Marland, 1996) [27, 28]. United Nations Framework Convention on Climate Change (UNFCCC) in this regard has recognized the importance of plantation forestry as a greenhouse gas mitigation strategy to preserve and enhance terrestrial carbon stocks (Updegraff *et al*., 2004) [29]. The short rotation plantations either as farm forestry or agroforestry systems, are considered handy owing to their ability to relieve pressure on timber extraction from natural forests, and thus contribute to forest conservation. Furthermore, trees play an important role in boosting soil C content and, as a result, improving soil C sequestration. (Prasad *et al*., 2012) [30]. The genus Eucalyptus in this aspect is regarded as one best options among the fast-growing tree species widely planted in the tropics mainly for grown for pulpwood and plywood and are utilised as the multi-purpose tree species especially in the agricultural and forestry industries (L. K. Behera,2016) [2]. Since 1992, additional clonal Eucalyptus plantations have appeared on the horizon, covering almost 2, 50,000 hectares of land representing 8.00%

of all planted forests (ICFRE, 2011). The major Eucalyptus growing countries are Brazil, China and India. Trees like Eucalyptus can be harvested year-round and provide a living inventory of available biomass. Coming to the Indian context, mainly two species *Eucalyptus tereticornis* (red gum) and *Eucalyptus camuldulensis* (blue gum) have been planted extensively, owing to its fast growth, suitability to all types of soils, adoptability to varying climatic conditions and tolerance to water logging, salinity and sodicity (Singh *et al*., 2014) [18] and for their economic, ecological values and high survival traits (Joshi *et al*., 2013). Eucalyptus can grow up to the soil pH of 11.0, 9.2 and 8.8 in sandy soil, clay and loamy soils respectively (Gupta *et al*., 1990) [31]. Eucalyptus is also being planted in farmlands because of its short rotation period and good economic benefits. In India, the total planted area is currently over 8 million hectares, with the majority of these plantations being seed-based (Aregowda *et al*., 2010) [32]. The productivity of *Eucalyptus* varies from country to country with changing climatic, edaphic and topographic conditions. In Congo, Brazil and Papua New Guinea, clonal plantations of *Eucalyptus* have produced 80-90 m^3/ha/year (Ugalde and Perez, 2001) [33] whereas in Indian conditions, the productivity ranged from 6 to 10 m3/ ha/ yr in seed route plantations (Lal, 1993) [34] to 20 to 23 m3/ ha/ yr in rainfed conditions and 50 m^3/ ha/ yr in clonal based managed farm plantations (Lal, 2001; Kulkarni, 2002) [35, 11], sometimes, it reached to 100 t/ha in pulp wood plantation (Kulkarni, 2002) [11]. Therefore, the present investigation was under-taken with the aim of assessing the growth of 21 Eucalyptus clones in Clonal Testing Areas of Telangana State Forest Development Corporation.

Material and Methods

The present study was conducted during 2021-22. The state of Telangana comes under subtropical climate. The summer usually begins in the mid-March reaching its peak by the month of May-June and severe winter during Dec-Jan. The average annual rainfall ranges from 905 mm in the state with majority of showers being seen in the monsoon in confluence with the south west monsoon. The winter showers are generally mild. Separate experimental designs were laid out in Randomized Block Design at six different sites (Table 1) with 21 Eucalyptus clones (Table 2) planted in common in all the clonal testing areas with a spacing of 3×2 m. Three replications per clone with 100 ramets per box for each clone are planted in the year 2020-2021. The girth at breast height was recorded at a height 1.37 m from ground level by the measuring tape. The conventional pole method was followed for measuring height for which a wooden pole of 1.5 mts height was used.

Estimation of biomass

The basal area, volume, above Ground biomass, below ground biomass, total biomass and carbon stock were worked out on single tree basis and converted to per hectare (ha) basis by the non- destructive method.

Biomass was estimated as follows

- Girth at breast height (GBH): This was measured at 1.37 m height from the base of the tree using measuring tape.
- Diameter at breast height (DBH) was calculated as follows DBH = GBH/3.14
- Basal area (BA) of the tree was calculated using the formula given by Chaturvedi and Khanna BA = $\pi d^2/4$, where d is the diameter
- Volume: To calculate volume of the tree, basal area was multiplied by height of the tree.
- Volume (m^3) = Basal area (m^2) × height (m) x Form factor
- Aboveground biomass: To estimate this, volume was multiplied by the specific gravity of wood of the tree.
- Aboveground biomass (kg) = Volume (m^3) × specific gravity of the wood.
- Specific gravity of the wood was calculated by the following formula $= \frac{\text{Oven dry weight of wood sample}}{\text{Green volume of wood sample}}$
- Belowground biomass: This was estimated by multiplying the aboveground biomass with 0.24 (IPCC, 2 006)
- Belowground biomass (kg) = Aboveground biomass × 0.24
- Total Biomass is the summation of aboveground biomass and belowground biomass. Total Biomass (t ha^{-1}) = Aboveground Biomass + Below ground biomass

Estimation of carbon stock in trees

- Biomass was converted into carbon by multiplying it with carbon fraction (0.47) of dry matter. The calculation of carbon from biomass uses the following formula:
- Carbon stock (t ha^{-1}) = Total tree biomass * 0.47 (IPCC, 2006)
- Carbon sequestration potential was calculated by multiplying carbon stocks with molecular weight of CO_2 *i.e.,* 3.667 (IPCC, 2006).
- The collected data was statistically analysed using SPSS software package and the grand means were worked out across the six CTA's.

Table 1: Location particulars of the Clonal Testing Areas

Sl.No	Name of the CTA	Division	Area (Ha.)	Latitude	Longitude
1.	Kesappagudem	Sathupalli	4 ha	17.3222	81.12611
2.	Jagannadhapuram	Sathupalli	4 ha	17.251948	80.81639
3.	Pentlam	Paloncha	4 ha	17.34229	80.81933
4.	Mulkalapally	Paloncha	4 ha	17.48622	80.8578
5.	Pogallapally	Kothagudem	4 ha	17.56239	80.85127
6.	Srirampur	Kothagudem	4 ha	17.32635	80.87827

Table 2: Details of Eucalyptus Clones planted in clonal testing areas

Sl.no	Clone no	Particulars
1	283	*E. uro grandis* from South Africa
2	316	*Eucalyptus tereticornis*
3	405	*Eucalyptus tereticornis*
4	1801	*Eucalyptus tereticornis*
5	1802	*Eucalyptus tereticornis*
6	1803	*Eucalyptus tereticornis*
7	1804	*Eucalyptus tereticornis*
8	1805	*Eucalyptus uro grandis*
9	1806	*Eucalyptus tereticornis*
10	EC X ED	*Eucalyptus camaldulensis* x *Eucalyptus deglupta* Clone K 7 From Laos
11	EC 4	*Eucalyptus camaldulensis*
12	2135	Clone 7 x Clone 4
13	SK 8	*E. camaldulensis x E. pellita*
14	SK 11	Triploid E. camaldulensis x *E. uro grandis*
15	SK 13	EC 53 X EC 19
16	SK 14	EC 71 X EC 1
17	SK 16	EC19 X EC111
18	SK 18	TRIPLOID E. camaldulensis X Uro grandis
19	SK 21	*E. camaldulensis x E. pellita*
20	SK 23	IFGTB *E. camaldulensis* X Clone 7
21	SK 62	*Eucalyptus camaldulensis* hybrid

Results and Discussion

In Central Telangana Zone, the highest girth at breast height for the clones ranged in between 14.04 and 17.18 cms (Table 3). The highest GBH was recorded in the clone 1801 with 17.18 cms followed by clones 1803 (17.13 cms) and1806 (16.94 cms). The lowest GBH among the tested clones in Central Telangana Zone was recorded in the clone SK 23 with 14.04 cms followed by the clones 1805 and 2135 with 14.42 cms and 14.57 cms respectively. The present results were in congruence with maximum GBH was noted from clone 526 (9.04 cm) which was followed by 2136 (8.84 cm), P-50 (8.53 cm) P-14 (8.33 cm), P- 32 (8.04 cm), 2023 (7.88 cm) and P-13 (7.81 cm) respectively and P-13 (3.73 m) over control and other treatments (Srivastav *et al.*, 2018) [24].Kumar *et al*., (2010) [12] also observed similar results and concluded that Clone 17 attained maximum DBH over other genotypes for second and third year followed by clones 14 and 11. The height of the 21 novel eucalyptus clones ranged in between 4.95 m and 6.14 m (Table 3). The maximum height was recorded in the clone 1802 with a recorded height of 6.14 m followed by clone 1806 (6.10 m) and 1802 (6.06 m). The clone SK 23 with 4.95 m height recorded the lowest height followed by clones 1805 (5.18 m) and 2135 (5.26 m). Similar results were observed by Saravanan (2021) [16], who concluded that the clone C-188 registered the maximum height growth of 9.39 m followed by the clones C-19 (8.9 mt) and C-63 (8.7 m) whereas the least height of 5 m was recorded in the clone C-115 followed by a height of 5.7 m in check clone1 and B2253 recorded the maximum height (23.6 m) and clone P405 recorded the lowest height among the 20 tested clones(Behera *et al.*,2016) [2]. This is because Eucalypts hybrids grow as well as or better than their parents, and large changes in growth across hybrid clones can be linked to both genetic and environmental variables and management, especially the weeding frequency and the protection of the seedlings from pests and diseases, drought and seedling handling during planting period (Wamalwa *et al.*,2007) [37].

The means for basal area of the tested clones showed that that the basal area in the zone ranged in between 2.64 m^2 /ha and 3.93 m^2 /ha (Table 3). The highest basal area was recorded in the clone 1801 with 3.93 m^2 /ha followed by clones1806 (3.92 m^2 /ha) and 1803 (3.91 m^2 /ha). The lowest basal area was recorded in the clone SK 23 with 2.64 m^2 /ha. Clones 1805 (2.79 m^2/ha) and 2135 (2.94 m^2 /ha). The results obtained in the present investigation were in conformity with Pima *et al*., (2016) [38] who observed that basal area of Eucalyptus clones differed significant (p<0.05) between clones within a site. The best clone had recorded a value of 28.18 m^2 ha^{-1} for GU 608 compared to 17.20 m^2 ha^{-1} for GC 514. GT 529, GC 940 and GC 514 showed significantly higher basal area values of 12.66, 12.70 and 12.77 m^2 ha^{-1} respectively& Karthik and Pragasan (2014) [39] whose observed value was 9.42 m^2/ha of basal area for eucalyptus plantation.

Table 3: Grand Means of GBH, Height and Basal Area of various clones in CTA's

Clone	GBH (cm)	Height(m)	Basal Area(m^2/ha)
283	15.82	5.64	3.52
316	16.10	5.81	3.61
405	15.53	5.57	3.23
1801	17.18	6.06	3.93
1802	16.88	6.14	3.82
1803	17.13	5.93	3.91
1804	15.06	5.47	3.04
1805	14.42	5.18	2.79
1806	16.94	6.10	3.92
EC X ED	16.66	5.73	3.75
EC4	15.90	5.91	3.37

2135	14.57	5.26	2.94
SK8	16.38	5.79	3.58
SK11	15.84	5.68	3.35
SK 13	16.61	5.92	3.68
SK 14	16.12	5.64	3.47
SK 16	15.65	5.48	3.27
SK 18	15.93	5.45	3.44
SK21	15.82	5.37	3.34
SK23	14.04	4.95	2.64
SK62	16.14	5.72	3.46
C.D.	1.66	0.65	0.62
SE(m)	0.59	0.23	0.22

Volume

The mean volume of the 21 tested clones in this zone ranged in between 6.81 and 12.39 m^3/ha (Table 4). The highest volume of 12.39 m^3/ha was recorded in the clone 1801, followed by clones 1806 (12.27 m^3/ha) and 1802 (12.20 m^3/ha) respectively. The lowest volume was recorded in the clone SK 23 with a volume of 6.81 m^3/ha followed by the clones 1805 and 2135 with 7.54 m^3/ha and 8.44 m^3/ha respectively. Behera *et al*., (2016) [2] also reported that the volume of standing trees ranged between 0.12 m^3 and 0.28 m^3 during the evaluation of 20 Eucalyptus clones at the age of five and a half years. Clones P2045 and B2245 had the largest volume of 0.28 m^3, followed by P413 with 0.27 m^3 and P526 with 0.24 m^3 volume.

Total Biomass

The above ground biomass of the 21 clones in the zone ranged in between 5.72 ton/ha and 10.41 ton/ha (Table 4). The clone 1801 with a recorded AGB of 10.41 ton/ha was the highest followed by the clones 1806 (10.30ton/ha) and clone 1802 (10.25ton/ha). The least performance in terms of above ground biomass was observed in the clone SK 23 with AGB of 5.72ton/ha followed by clones 1805 and 2135 with 6.34 ton/ha and 7.09 ton/ha respectively. The below ground biomass of the clones ranged in between 1.49ton/ha and 2.71ton/ha. The highest BGB in this zone was observed in the clone 1801 with a recorded value of 2.71ton/ha followed by the clones 1806 and 1802 with 2.68 ton/ha and 2.66 ton/ha of BGB respectively. The lowest below ground biomass was recorded in the clone SK 23 with a BGB of 1.49 ton/ha followed by the clones 1805 with 1.65ton/ha and 2135 with 1.84 ton/ha. Similarly, total biomass per hectare ranged in between 7.21 ton/ha and 13.11ton/ha. The highest total biomass was recorded in the clone 1801 with 13.11ton/ha followed by the clones 1806 and 1802 with 12.98ton/ha and 12.91ton/ha respectively. The lowest total biomass was recorded in the clone SK 23 with a biomass of 7.21ton/ha in total, followed by the clones 1805 and 2135 with 7.98 and 8.93 ton/ha of total biomass respectively. The results were in close conformity with Saravanan (2021) [16] who reported the greatest AGB of 10.52 kg tree in C-188. followed by C-10, C-14, C-19, C-123, and C-186.The lowest below ground biomass (BGB) was observed in the clone C-124 with a below ground biomass (BGB) of 1.26 kg tree followed by C-100 and check clone 7 and C-188 recorded the highest BGB of 2.44 kg tree with the mean of 1.51 kg tree.

Table 4: Grand Means of Volume, AGB, BGB, TB, Carbon stocks and sequestration

Clone	Volume (m^3/ha)	AGB (t/ha)	BGB (t/ha)	Total Biomass (t/ha)	Carbon Stocks (t/ha)	Carbon Sequestration Potential (t/ha)
283	10.18	8.55	2.22	10.77	5.39	19.75
316	10.85	9.11	2.37	11.48	5.74	21.05
405	9.36	7.86	2.04	9.90	4.95	18.16
1801	12.39	10.41	2.71	13.11	6.56	24.04
1802	12.20	10.25	2.66	12.91	6.45	22.61
1803	11.90	10.00	2.60	12.60	6.30	23.10
1804	8.73	7.33	1.91	9.24	4.62	16.94
1805	7.54	6.34	1.65	7.98	3.99	14.63
1806	12.27	10.30	2.68	12.98	6.49	23.80
EC X ED	11.38	9.56	2.49	12.05	6.03	22.09
EC4	10.21	8.58	2.23	10.81	5.41	19.82
2135	8.44	7.09	1.84	8.93	4.47	16.37
SK8	10.73	9.01	2.34	11.35	5.68	20.81
SK11	9.85	8.27	2.15	10.42	5.21	19.12
SK 13	11.24	9.44	2.46	11.89	5.95	22.76
SK 14	10.07	8.46	2.20	10.66	5.33	19.54
SK 16	9.21	7.74	2.01	9.75	4.88	17.88
SK 18	9.92	8.33	2.17	10.50	5.25	19.25
SK21	9.28	7.79	2.03	9.82	4.91	18.01
SK23	6.81	5.72	1.49	7.21	3.60	13.22
SK62	10.12	8.50	2.21	10.71	5.35	19.64
C.D (5%)	2.60	2.18	0.57	2.75	1.37	4.27
SE(m)	0.93	0.78	0.20	0.98	0.49	1.08

*AGB=Above Ground Biomass, BGB=Below Ground Biomass, TB=Total Biomass

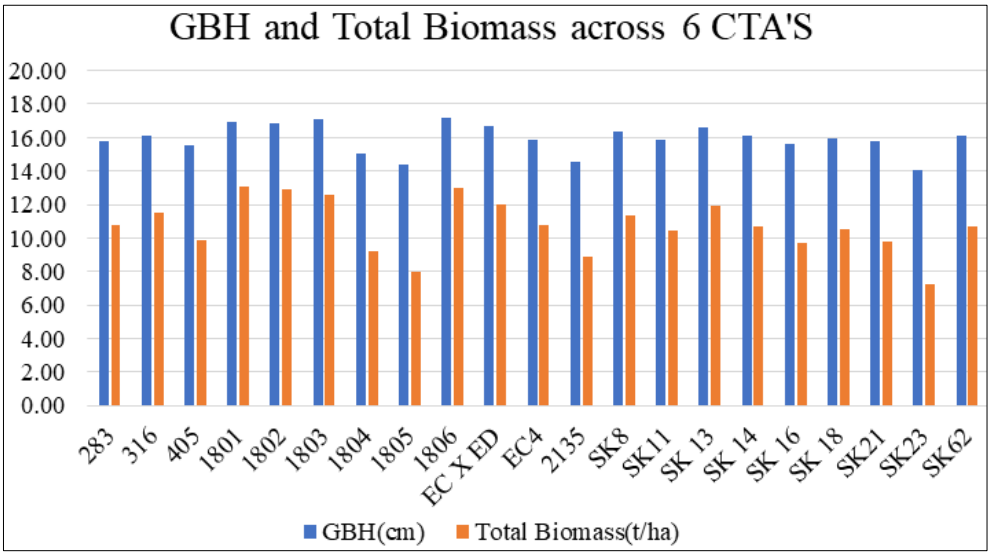

Fig 1: GBH and Total biomass of various clones in Clonal Testing areas.

Carbon stocks and Carbon sequestration

The carbon stocks in the zone ranged in between 3.60 ton/ha and 6.56ton/ha. The clone 1801 with 6.56 ton/ha recorded carbon stocks outperformed the other clones followed by the clones 1806 with 6.49 ton/h and 1802 with 6.45ton/ha. The lowest total biomass was recorded in the clone SK 23 with 3.60 ton/ha in total, followed by 1805 and 2135 with 3.99ton/ha and 4.47ton/ha respectively. The carbon sequestration potential ranged in between 13.22ton/ha and 24.04 ton/ha. The clone 1801 with 24.04 ton/ha recorded carbon sequestration potential followed by clones 1806 with 23.80 ton/ha and 1802 with 23.10ton/ha were the top performers and the lowest carbon sequestration potential was recorded in the clone SK 23 with 13.22ton/ha in total followed by clones 1805 and 2135 with 14.63 ton/ha and 16.37ton/ha respectively. The carbon stocks and the carbon sequestration potential results are supported by Madhusudanan *et al.*, (2011) [36], who concluded that *E. tereticornis* fixes 114.36 Mg ha^{-1} of carbon and 4.20 ton/ha and total C storage of 9.36 ton/ha reported by Chauhan *et al*., 2009 [1]. Behera *et al*., (2016) [2] stated that short rotation plants like Eucalyptus, in addition to carbon storage, provide biomass for energy and help to lower greenhouse gas emissions due to their quick growth rate and flexibility to a variety of conditions.

Summary and Conclusion

Based on the observed values for total biomass, clones 1801 and SK 23 proved to be the top and the least performing clones. However, these were early growth findings at the age of 2 years with low juvenile mature correlations predicted, and growth monitoring has to be continued in this trial series to validate evaluation of potential clones across the regions and the present data may not suffice to rank the clones. The evaluation of the performance of Eucalypt clones will aid in the selection of potential clones for the given location, allowing planting stock of desirable clones to be raised for further cultivation in the field. The increase of Eucalyptus plantings in agroforestry will aid in lessening forest pressure and expanding trees outside of forests fetching good economic returns in the short span of time.

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