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Effect of spacing on growth and yield of *Eucalyptus camaldulensis* in Eastern Ghat high land zone of Odisha

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Abstract
The study was conducted during the period 2017–2021 under On-farm Trial as mandatory activity of KVK, Koraput. The main objective of the on farm trial was to investigate the effect of different spacing levels on the growth and utilizable biomass production in *Eucalyptus camaldulensis* plantation grown in the Eastern Ghat High Land Zone of Odisha, India. Establishing the optimum plant density in forest trees is a major challenge under the present land constraint situation. Therefore, present trial was carried out to address the issue by planting trees at different spacing *viz*., 3m × 3m, 3m × 2m, 3m × 1.5m, and 3m × 1m. Results exhibited significant effect of spacing on the growth and yield of the trees. Among the different spacing regimes, the wider spacing of 3m × 3m significantly gave better tree height, diameter at breast height, utilizable biomass and maximum mean volume per tree, where as the maximum total volume per hectare was observed in 3m × 1m spacing and minimum was observed in 3m × 3m spacing at different growth period. Maximum total utilizable biomass (73.025 kg tree^{-1}) was obtained from the wider spacing of 3m × 3m and maximum total biomass (106.198 ton ha^{-1}) was obtained from the closer spacing of 3m × 1.5m. In general, the maximum tree height, DBH, tree volume and utilizable biomass production per tree were recorded in wider spacing and the minimum in closer spacing. Similarly the total wood biomass and volume production per hectare was observed in closer spacing, due to the more number of trees presentas compared to wider spaced regimes.

Keywords: Biomass, eucalyptus, growth, spacing, tree density

1. Introduction
Shrinking productivity of natural forests has highlighted the importance of plantations in meeting the global demand for wood and wood products, which could triple by 2050 (Hakamada *et al.*, 2017) [7]. Among tree species used in forest plantations, *Eucalyptus* constitutes a large share of the world economy in relation to pulpwood, plywood and solid wood production (Dhakad *et al*., 2018) [5]. *Eucalyptus* was introduced in India in later part of the 18th century. Presently, it is estimated to be grown in over 3 million ha, about 80% of which is under agro/farm forestry. India has about 10% of the world's *Eucalyptus* plantation. Every year around 150,000 ha of *Eucalyptus* plantation is grown in India, creating employment in rural areas (Juhari, 2017) [9].

To protect natural resources and the environment for the sustainable development, plantation has become the major source of timber supply for timber industry such as solid wood, plywood, pulp and paper. A good plantation species should produce not only high timber yield, but also the desired properties of wood for highly valued end products. Accelerating tree growth rate or shortening the rotation could potentially affect wood quality (Alterac *et al*., 2005) [1]. Several pulp and paper mills, forest departments and forest development corporations have substantial areas of plantations either directly under their control or in farmer's land from which wood is purchased. Eucalyptus are the major raw material of the pulp and paper industries in India, so it is imperative that planting stock of high genetic quality be used to increase the yield from plantation mainly for Eucalyptus.

Eucalyptus camaldulensis is renowned globally for its fast growth, high levels of drought tolerance and adaptability to diverse climatic conditions and soils, which make it popular among eucalyptus tree growers (Bindumadhava *et al*., 2011) [3]. Clonal propagation is an extensively used strategy to gain economic potential of eucalyptus species by multiplying desirable types, which strategically improve the productivity (Zobel, 1993) [19].

Production of genetically improved clonal plantation stocks of Eucalyptus can improve the quality of produces such as wood for paper and pulp, leaves for oil extraction and other

medicinal value (Lal, 2001) [12]. It is found that farmers are easily adopt and grow the Eucalyptus species due to its fast growing nature and wide demand by the pulp and paper industries as well as pole for building construction. The productivity of Eucalyptus varies from country to country with changing climatic, edaphic and geographic conditions (Gahlot *et al*., 2021) [6]

In India, the rapid increase in population and use of paper as environment friendly packaging material, has led to a rapid increase in paper consumption. Increasing demand for fuel, timber and other usufruct is causing heavy pressure on the limited forest resources in India. This has gradually led to degradation and shrinkage of forests both in quality and extent. The Indian pulp and paper industry is the 15th largest industry in the world and is, thus, an important industrial sector in terms of socio-economic development as it provides employment to nearly 1.5 M people (Suri, 2007) [17]. In India, the current total consumption of paper and paper board, including newsprint, is around 11.15 Mt of which 10.11 Mt is produced in India and 1.04 Mt is imported annually (Kulkarni, 2013) [11]. High growth in the printing industry, heavy government investment on education and the growing demand for paper as an alternative for plastic as packaging material will contribute towards the further increase in demand in the years to come.

Tree stand density is a very important tool of silvicultural treatment and offer a means to affect the growing conditions of trees and thus, also the stem wood production. With the worldwide move towards intensive silviculture and shorter rotations, the quality of wood and end products fromthis changing resource has become a concern for the forest products industry (Knudson *et al*., 2006) [10].

In this connection, On farm trials were carried out in farmers field by KrishiVigyan Kendra (KVK), Koraput by introducing fast growing trees species with potential resources for short rotation pulp production in Eastern Ghat High Land Zone of Koraput.

2. Materials Methods

Seedling of *Eucalyptus camaldulensis* were collected from JK paper mills Pvt. Ltd, Jayakapur. The seedling were planted in the farmers field in the three bock of Koraput district viz. Pottangi, semiliguda, Nandapur during the period from 2017 to 2021 under On Farm Trial as mandatory activity of KVK, Koraput. The district lies between 18° 13′ to 19° 10′ north latitude and between 82° 5′ to 83° 23′ east longitude. The climate condition of the district is warm and humid. Average annual rainfall is 1567 mm. The soil type of the study area is red lateritic soil.

Te seedlings were planted in the farmer's field using a randomized block design with seven blocks. Each block had four experimental plots (Four different spacing). The spacing between the seedling was 3m x 3m, 3m x 2m, 3m x1.5m and 3m x 1m. The growth parameters viz. Tree height and DBH were recorded on the entire tree at 12, 24 and 36 months after planting and the biomass was estimated excluding trees on borders to avoid the edge effect. Trees were felled and separated into foliage, branches and stem. The volume of standing trees were estimated as well as total tree utilizable biomass (total wood, stem wood and branches wood) was measured. The observed data were statically analyzed as per the procedure and design given by Panse and Sukhatme (1985) [14].

3. Results and Discussion

The analysis of data revealed that at all the stages; the diameter at breast height (DBH) varied significantly an all for spacing regimes. The maximum DBH (0.064, 0.089 and 0.113 m) was observed in 3m x 3m and minimum DBH (0.043, 0.071 and 0.09 m) in 3m x 1m spacing (Table 1). This show that diameter varies with the planting density, which is against the observation of Srivastav *et al*., 2020 [15] for different species of Eucalyptus, who reported that planting density had no significant effect on diameter at breast height of the eucalyptus at early period of rotation and mean diameter decreases as planting density increased in Eucalyptus. Tree growth is function of age, spacing and site quality (Nissen *et al*., 2001) [13].

Table 1: Effect of plant spacing on the growth parameters and tree volume for *Eucalyptus camaldulensis* at different growth period.

Tree Parameters	MAP	Tree spacing (m)				SE (m)±	CD at 5%	CV
		3 x 3	3 x 2	3 x 1.5	3 x 1			
DBH (m)	12	0.064	0.055	0.045	0.043	0.00073	0.0021	3.717
	24	0.089	0.082	0.076	0.071	0.00042	0.0012	1.403
	36	0.113	0.102	0.093	0.090	0.00052	0.0015	1.401
Height (m)	12	7	6.442	5.971	5.5	0.0446	0.1327	1.897
	24	11.488	11.781	10.457	9.568	0.0429	0.1276	1.05
	36	15.577	15.611	14.454	13.395	0.0235	0.0700	0.422
Mean Tree Volume (cft)	12	0.570	0.429	0.285	0.243	0.0016	0.0048	1.136
	24	2.041	1.717	1.29	1.133	0.0091	0.0272	1.572
	36	6.107	3.571	2.652	2.433	0.2129	0.6326	15.262
Total volume (m^3 ha^{-1})	12	17.934	16.924	17.781	19.88	0.0228	0.0680	0.334
	24	63.281	79.11	80.732	81.17	0.0545	0.1621	0.189
	36	147.352	168.635	166.448	171.245	0.1023	0.3040	0.165

The tree height varied significantly in all four spacing regimes. The maximum height (7 m) was observed in 3m x 3m spacing at 12 MAP, where as 24, 36 MAP, maximum height (11.781 m, 15.611 m respectively) was observed on 3m x 2m spacing and minimum height (5.5 m, 9.568 m and 13.395 m respectively) was observed in 3m x 1m spacing (Table 1). This can be explained that increasing in the height of trees with increasing in the distance between trees i.e. change in density is simply a result of exploiting same available below ground resources particularly water and nutrient by less number of trees (Aref *et al*., 1999) [2].

The statistical comparison showed that the total volume per tree was significantly influenced by spacing and increased with wider spacing (Table 1). At 12, 24 and 36 MAP, maximum volume (0.570, 2.041 and 6.107cft $tree^{-1}$ respectively) was observed in 3m x 3m and minimum (0.243,

1.133 and 2.433cft tree^{-1}) recorded in 3m x 1 m spacing. The total volume per hectare revealed that, the higher production was in closer spacing and lower in wider spacing i.e. maximum volume per hectare (19.88, 81.17 and 171.245 m^3 ha^{-1}respectively) in 3m x 1m spacing where as minimum volume per hectare (16.924 m3 ha-1) in 3m x 2 m spacing at 12 MAP and (63.281 and 147.352 m^3 ha^{-1}) in 3m x 3 m spacing at 24 and 36 MAP respectively. It clearly showed that the number of trees per hectare plays an important role in total volume production. Chen *et al*., 2011 [4] in *Eucalyptus urophylla* x *Eucalyptus grandis* revealed that, the average individual tree volume increased as initial stocking decreases. Srivastava (1999) [16] investigated the growth of *Terminalia arjuna* under varied plant spacing and reported that the mean stand basal area and volume increased with increase in plant density.

Table 2: Effect of plant spacing on the mean total utilizable biomass production and biomass allocation for *Eucalyptus camaldulensis.*

Tree Spacing (m)	Utilizable Biomass (kg tree^{-1})			Utilizable Biomass (ton ha^{-1})		
	Main stem wood	Branches wood	Total wood biomass	Main stem wood	Branches wood	Total wood biomass
3 x 3	67.282	5.742	73.025	74.597	6.287	80.884
3 x 2	50.437	4.771	55.208	84.445	8.158	92.602
3 x 1.5	45.182	3.471	48.654	99.067	7.131	106.198
3 x 1	40.177	2.585	42.762	99.134	6.612	105.747
SE (m)±	0.1075	0.0773	0.1364	0.0161	0.0267	0.0273
CD at 5%	0.3194	0.2298	0.4052	0.0479	0.0793	0.0813
CV	0.56	4.941	0.657	0.047	1.002	0.075

The results reported that the maximum total wood, stem wood and branch wood yield per tree at harvest (36 MAP) was observed in wider spacing (3m x 3 m) with a value of 73.025, 67.282 and 5.742 kg per tree, respectively and the minimum in closer spacing (3m x 1m) with a value of 42.762, 40.177 and 2.585 kg per tree respectively (Table 2). A study was conducted by Hegazy *et al*., 2008 [8] in *Concocarpus erectus* revealed that biomass of an individual tree increased with increased spacing regimes.

While total wood and Branch wood per hectare was observed maximum (106.198 and 8.158 ton ha^{-1}) in 3m x 1.5 m and 3m x 2 m spacing respectively, where as stem wood yield (99.134 ton ha^{-1}) was in 3m x 1 m spacing and minimum in low density stand of 3m x 3 m spacing with a value of 80.884, 6.287 and 74.597 ton ha^{-1} respectively (Table 2). A study was conducted by Vidhya, 2012 [18] in *Casuarina hybrid* clone revealed that wider spaced trees produced more stem wood compare to closer spaced trees where as closer spaced trees produced more wood per hectare than wider spaced trees.

4. Conclusion

The result of on-farm-trial apparently indicates that spacing is the primary silviculture practice for improving the growth of the plantation, directly responsible for higher yield and helps fulfilling the requirement of raw materials for fuel wood and paper and pulp industries. In general, the maximum tree height, DBH, tree volume and utilizable biomass production per tree were recorded in wider spacing and the minimum in closer spacing. Similarly the total wood biomass and volume production per hectare was observed in closer spacing, due to the more number of trees present.

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