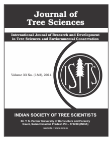
Print : ISSN 0970-7662
Online : ISSN 2455-7129



Journal of Tree Sciences
online available at www.ists.in

Volume 35 No.2 December, 2016

Biomass and Carbon Stock in Forest Plantations: Manipulation Through Spacing

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DOI: 10.5958/2455-7129.2016.00012.1

ABSTRACT

Eucalyptus urophylla ST. Blake is one of the fast growing tree species introduced to India as pulp wood species. Several efforts were made to standardize the silvicultural practices for this species in captive plantations. The present study was conducted on assessment of biomass and carbon stock in different spacing regimes for specific clone EUB 31 of *E. urophylla*under tropical humid conditions of Karnataka. After six years of planting, growth parameters, biomass and carbon stock were evaluated. Spacing had significant effect onbiomass and carbon stock of the trees. Biomass of trees under different spacing regimes varied from 89.6 Mg ha^{-1} to 119.6 Mg ha^{-1}. Significantly higher value for total biomass was found in 2.00 m × 3.00 m and least was with 2.75 m × 3.00 m spacing (89.6 Mg ha^{-1}). Carbon stock for different spacing was ranging from 42.1 Mg ha^{-1} to 56.2 Mg ha^{-1}.Among the different spacing regimes, closer spacing (2.00 m × 3.00 m) was found to have higher carbon stock and mean annual carbon sequestration compared to wider spacing. The carbon sequestered annually had a significant difference among the spacing regimes with values ranging from 7.02 Mg ha^{-1} yr^{-1} (2.75 m × 3.00 m)to 9.37 (m × 3.00 m) Mg ha^{-1} yr^{-1}.Thus, biomass production and carbon sequestration in trees can be manipulated with spacing.

Keywords:
Biomass, Carbon sequestration, carbon stock, Clone, *Eucalyptus urophylla*, Spacing

INTRODUCTION

The general consensus states that the increasing concentration of greenhouse gases have led to changes in the earth's climate and warming of the earth's surface. The major greenhouse gases include carbon dioxide (CO_2), methane, oxides of nitrogen and chlorofluorocarbon (CFCs) compounds. Among these the CO_2 is predominantly responsible for global warming. It is estimated that around 80 per cent of total CO_2 emission comes from coal or biomass based power plants, industries and transportations while remaining comes from deforestation and peat land destruction (IPCC 2007). Emissions of CO_2 from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010 (IPCC 2014). The atmospheric levels of CO_2 had risen from preindustrial levels of 280 ppm to present levels of

387.18 ppm (0.038718 % of dry air) as of October 2010 (ESRL 2010). Hence, there is an urgent need to manage the atmospheric CO_2 through appropriate carbon sequestration technique. Carbon sequestration is a geo-engineering technique for the long-term storage of carbon dioxide or other forms of carbon, for the mitigation of global warming. CO_2 is usually captured from the atmosphere through biological, physical or chemical processes.

Capture and storage of CO_2 from the atmosphere is gaining attraction as means to deal with climate change. Forestry and afforestation in particular, is regarded as an important contributor to the offset of greenhouse gas emissions. Hence, forests play an important role in the global carbon cycle (Kirschbaum, 2001; Masera et al. 2003). Trees are important sinks for atmospheric carbon *i.e.* CO_2, since 50 per cent of their standing biomass is carbon itself (Ravindranath et al. 1997). They absorb CO_2 from atmosphere, and store carbon in wood, leaves, litter, roots and soil by acting as "carbon sinks". Carbon is released back into the atmosphere when forests are cleared or burned. Globally, forests store an estimated 638 Gt of carbon, much more than the quantity currently found in the atmosphere. However, about 5.8 Gt of CO_2 equivalent per year are being released due to deforestation (FAO 2010). More than 80 per cent of all terrestrial aboveground carbon and more than 70 per cent of all soil organic carbon are stored in forest ecosystems (Jandl 2007). Hence, projects that increase the area of plantations have been suggested for inclusion under the Clean Development Mechanism (CDM) as defined in Article 12 of the Kyoto Protocol (Van Vliet et al. 2003).

Establishment of plantations to mitigate increased CO_2 in the atmosphere is one of the key options in reducing global warming. Efforts have been made to calculate the amount of CO_2 that can be sequestered by planting trees with specific silvicultural treatments. Workers have variously concentrated on the amount of carbon stored in the living trees. However, significant uncertainties in the reliability of carbon pool and flux measurements make it difficult to determine the (net) carbon benefits of afforestation or forestry management practices. Hence, the current study is an attempt to assess the effect of spacing on carbon stock of *E. urophylla* clone EUB31under tropical humid conditions of South India and to know

Clonal planting stock is true to type, uniform and with all superior desirable properties of the elite mother tree. Full advantage can be taken of existing natural variation and genetically superiority of individual plus trees through cloning, field testing of the resultant clones and raising in large scale commercial plantation based on tested, most adopted, site specific and genetically superior clones (Lal et al. 2006). This is particularly important to some of the pulp and paper yielding trees like *Acacia,* due to its inherent sensitivity for genotype and environmental interactions, which can be utilized for matching clones to site or silvicultural treatment. A thorough literature survey revealed that little effort has been made towards the quantification of carbon capture by different genotypes particularly clones in plantations.

Spacing of trees in short-rotation plantations affects individual tree growth rates and stand productivity as well as the costs of management practices and utilization. Tree and stand growth rates, and hence carbon sequestration rates, vary by many factors such as: stand type, stand age, site productivity/quality, stand density (spacing), as well as other silvicultural inputs/treatments (Smith et al. 2006). *Eucalyptus urophylla* ST. Blake is also a fast growing eucalyptus species which is used primarily for pulp and boards (Davidson 1998), due of their acceptable wood quality, rapid growth and high volumetric yield. Owing to its use, the species has been cultivated in industrial plantations in India.

MATERIALS AND METHODS

Study site and plant material

Spacing trial plot was established by Mysore Paper Mill (MPM), Bhadravathi located at Ambutheertha, Shivamogga district of Karnataka state, India (14° 17'N Latitude, 74° 25' E Longitude and 730 m altitude). The area enjoys tropical humid conditions with mean annual rainfall of 2000-3000 mm. Ambutheertha research plot was established in the year 2006 with clone EUB31 of *Eucalyptus urophylla* which was identified and released by Mysore Paper Mills Limited, Bhadravathi. .The soil of the experimental site was lateritic with brown colour and it was acidic in nature. Site preparation was done by engaging heavy duty D50 dozers with single shank to clear the stumps, roots, small vegetation and other debris. Ripping had been carried out to loosen the top soil, create congenial conditions for the development of microbial activities and to improve the soil physical properties, with the aid of rippers attached to the machine. The experimental plantation was established in Randomized Complete Block Design (RCBD) with five treatments (Table 1) and five replications. Intercultural operations such as fertilizer application and weeding were carried out. Fertilizers were applied only in the first year of planting (after 15 days of planting). Generally, 17:17:17 (N: P: K) mixture at the rate of 30 g per plant was applied. Spot application method (15 cm away from plants) of fertilizer was practiced in two directions. Same quantity of fertilizer was applied after one month as second application. Three weeding operations were carried out in the first year of planting, followed by two weeding in the second year.

Assessment of growth parameters

All the growth parameters under the considerations in this research were evaluated after six years of field planting. Observation on growth traits like diameter at breast height (cm) and total height (m) was recorded; and in order to estimate the volume of the individual tree, basal area (m^2), total height (m) and form factor (0.33) were multiplied.

Biomass and carbon estimation

Five representative tree shaving average diameter in each replication for a particular spacing treatment were selected and harvested at the ground level. Above ground portion of the felled tree was separated into bole wood, branch wood, bark and foliage. The fresh weight was recorded immediately after felling. A known quantity (one kilogram) of bole wood, branch wood, bark and foliage were collected and transferred to laboratory. The samples collected were dried to constant weight for a time period of 72 hours at 70° C for leaves and 100°C for bole wood, branch wood and bark. Oven dry weight of the samples was obtained using the digital balance. Biomass of a tree was estimated by summing up the dry weights of bole wood, branch wood, barks and leaf weight. Biomass per plot, biomass per hectare was computed. Biomass of a tree was estimated by summing up the dry weights of bole wood, branch wood, barks and leaf weight. Biomass per plot was obtained by multiplying the number of trees survived in the plot and the individual tree biomass and was extrapolated to per hectare basis. Total biomass was calculated summing up above ground biomass and below ground biomass (Biomass per hectare × 0.26, (IPCC 2006)). Carbon stock in each tree was estimated by multiplying the total above ground biomass of individual tree with carbon fraction 0.47 (IPCC 2007). Mean annual carbon sequestration was determined by dividing total carbon stock by stand age.

Statistical analysis

Data obtained on the biomass and carbon stock were analyzed as per the procedure of Williams and Matheson (1994). The data was subjected to one way analysis of variance (ANOVA) on Randomized Complete Block Design (RCBD) using the GENSTAT software (Genstat 5 Release 3.2).

RESULTS AND DISCUSSION

Growth parameters

Spacing regimes with density varying from 1666 to 1111 for the Eucalyptus plantation at different spacing are given in Table 1. Effect of spacing on growth parameters such as diameter at breast height, height and individual tree volume are depicted in Table 2. Existence of significant effect of spacing on diameter growth was evident in the present study. Among the different treatments, 3.00 m × 3.00 m had significantly higher value (17.72 cm) over all the treatments and least diameter growth was observed in treatment 2.00 m

× 3.00 m (16.03 cm) followed by 2.25 m × 3.00 m (16.47 cm), 2.75 m × 3.00 m (16.92 cm) and 2.50 m × 3.00 m (17.72 cm). Higher diameter growth in wider spacing could be ascribed to additional available growing space in wider spacing compared to closely spaced trees. Similar observation on decrease in diameter growth with increased planting density was observed in *Eucalyptus grandis* (Harris 2008).

Mean tree height varied significantly from 16.45 m to 17.96 m under different spacing treatments (Table 2). The maximum tree height was recorded in 2.50 m × 3.00 m (17.96 m), while the minimum was found in 2.25 m × 3.00 m (16.45 m) which was on par with the height of trees under 2.75 m × 3.00 m spacing (16.85 m). Generally, the height growth of trees are least influenced by the spacing and in the present study it was contrary to the general norms. Estimated means of individual tree volume under different spacing treatments varied significantly. The values ranged from 0.12 to 0.15 m^3. Among the different spacing regimes, maximum value for volume was found in 3.00 m × 3.00 m (0.15 m^3), which was differing significantly from all other treatments. Generally, greater diameter growth in wide spacing is a major contributing factor for increased volume production of individual tree it could be due to the fact that increase in spacing increased stem diameter growth which would have influenced the diameter growth. According to Persson et al. (1995) an increase in spacing increased stem diameter and volume growth at the cost of height growth in *Pinus sylvestris.* Similar observation was also reported by Peltola et al. (2009) in *Pinus sylvestris*.

Table 1. Spacing regimes evaluated in *E. urophylla*

Treatments	Spacing	Plot Area (m^2)	No. of trees / plot	Trees ha^{-1}
T^1	*2.00 m × 3.00 m*	240.00	40	1666
T^2	2.25 m × 3.00 m	236.00	35	1481
T^3	2.50 m × 3.00 m	225.00	30	1333
T^4	2.75 m × 3.00 m	247.50	30	1212
T^5	3.00 m × 3.00 m	225.00	25	1111

Table 2. Growth of individual trees under different spacing

Treatments	DBH (cm)	Height (m)	Volume (m^3)
T_1- 2.00 m X 3.00 m	16.03^{a}	16.88^{b}	0.12^{a}
T_2- 2.25 m X 3.00 m	16.47^{ab}	16.45^{a}	0.12^{a}
T_3- 2.50 m X 3.00 m	17.08^{c}	17.96^{d}	0.14^{c}
T_4- 2.75 m X 3.00 m	16.92^{bc}	16.85^{ab}	0.13^{b}
T_5- 3.00 m X 3.00 m	17.72^{d}	17.42^{c}	0.15^{d}
S. Em (±)	0.19	0.16	0.004
CD.(0.05)	0.47	0.40	0.009

Ñ Parenthetical values are arc sine transformed;Figures with similar letters as superscript do not differ significantly; CD- Critical Difference

Biomass production

Effect of spacing on different biomass parameters of an individual tree was apparent in the study. Biomass of an individual tree increased with increased spacing regimes. Bark dry weight for different spacing regimes varied significantly (Table 3). Biomass of different components (bark, branch wood, foliage and pulpwood) of each tree and above-ground biomass varied significantly with spacing. The estimated means of bark dry weight were found to be highest in wider spacing (3.00 m × 3.00 m), which was significantly superior over all the other treatments. Means of branch wood dry weight under different treatments varied significantly with values ranging from 2.78 kg to 5.59 kg (Table 3). Highest value for the branch wood dry weight was observed in 2.50 m × 3.00 m (5.59 kg) and was found to be on par with 3.00 m × 3.00 m (4.86 kg) and significantly superior over other treatments. Leaf dry weight under different treatments varied with spacing, the highest value was recorded in 3.00 m × 3.00 m spacing (1.59 kg) and was significantly higher over few spacing regimes. The pulp wood dry weight under different spacing regimes varied from 44.40 kg to 59.20 kg. The treatment 3.00 m × 3.00 m was found to be superior over all the other treatments and least pulp wood dry weight (44.40 kg) was recorded in 2.00 m × 3.00 m.

Above ground biomass and total biomass per hectare under different spacing treatments varied significantly (Table 3). Above ground biomass produced under treatment 2.00 m × 3.00 m (94.90 Mg ha^{-1}) was found to be significantly superior over the other treatments. Total biomass under different treatments varied from 89.60 Mg ha^{-1} to 119.60 Mg ha^{-1}. Significantly higher value for total biomass was found in 2.00 m × 3.00 m whereas total biomass produced in other spacing treatments did not differ significantly.

Biomass of an individual tree increased with increased spacing which could be associated to the crown width as crown of an individual tree increased with increase in spacing. In wider spacing, trees produce larger crown with more foliage for photosynthesis resulting in more biomass production. The effect of spacing on relative resource capture is amplified as competition for resources could be less in wide spacing which would have resulted in higher biomass production per tree. It is important to understand the influence of spacing and the response of the species in terms of growth and biomass accumulation in different plant parts over time (Bernardo et al. 1998). In the current study above-ground biomass and the biomass of each tree component (bark, branch wood, foliage and pulpwood) varied significantly with spacing (Table 3). Generally, wider spacing resulted in production of higher quantity of bark, branch wood, leaf and pulpwood in individual tree. Biomass allocation of individual trees in different spacing regime revealed that more than 80 per cent of the above ground biomass is allocated towards pulp wood production and less than 10 per cent for bark production (Fig. 1). Allocation of more biomass for bark, foliage and branch wood production would affect the quantity of marketable wood.

Total biomass of the stand (which includes both above ground and below ground biomass) also varied with different spacing. Allocation of photosynthate to different components of the plant systems is an important physiological process; and biomass allocation strategies of plants need to be understood for an effective captive plantation programme. Clear bole wood volume, low branching and narrow crown are attributes used for selecting plus trees. Spacing is also as important as the genetic potential of the genotype to obtain maximum allocation of biomass for bole wood production. Closer spacing led to greater biomass production due to larger number of trees per unit area. The results are in line with the findings of Belanger and Pepper (1978) that spacing has a strong influence on biomass production in sycamore plantations and very close spacing can increase biomass production in short rotation plantation species.

Carbon stock

Mean carbon stock in trees under different spacing was ranging from 42.10 Mg ha^{-1}to 56.20 Mg ha^{-1}(Table 3).The significantly highest carbon stock was observed in 2.00 m × 3.00 m

Table 3. Biomass allocation and carbon stock in trees under different spacing regimes

Treatments	Individual tree					Stand			
	Bark Dry weight (kg)	Branch wood dry weight (kg)	Leaf dry weight (kg)	Pulp wood dry weight (kg)	Total dry weight (kg)	Above ground Biomass (Mg ha^{-1})	Total Biomass (Mg ha^{-1})	Total carbon (Mg ha^{-1})	MACS (Mg ha^{-1})
T_1 -2.00 m X 3.00 m	6.94 ^{ab}	2.87 ^{a}	1.00 ^{a}	44.4 ^{a}	54.3 ^{a}	94.90 ^{c}	119.60 ^{b}	56.20 ^{b}	9.37 ^{b}
T_2- 2.25 m X 3.00 m	6.82 ^{a}	2.78 ^{a}	1.09 ^{a}	44.5 ^{a}	54.1 ^{a}	79.40 ^{b}	100.00 ^{a}	47.00 ^{a}	7.84 ^{a}
T_3- 2.50 m X 3.00 m	8.16 ^{bc}	5.59 ^{c}	1.03 ^{a}	46.1 ^{a}	59.9 ^{a}	76.40 ^{a}	96.30 ^{a}	45.30 ^{a}	7.54 ^{a}
T_4- 2.75 m X 3.00 m	6.99 ^{ab}	3.61 ^{ab}	1.30 ^{ab}	48.8 ^{a}	59.4 ^{a}	71.10 ^{a}	89.60 ^{a}	42.10 ^{a}	7.02 ^{a}
T_5- 3.00 m X 3.00 m	8.82 ^{c}	4.86 ^{bc}	1.59 ^{b}	59.2 ^{b}	72.8 ^{b}	80.90 ^{b}	102.00 ^{a}	47.90 ^{a}	7.99 ^{a}
S.Em(±)	0.44	0.49	0.11	3.14	3.61	4.80	8.56	2.85	0.47
CD.(0.05)	1.33	1.46	0.33	9.41	10.82	6.79	18.25	8.58	1.43

Δ Parenthetical values are arc sine transformed; Figures with similar letters as superscript do not differ significantly; CD- Critical Difference; MACS- Mean Annual Carbon Sequestration.

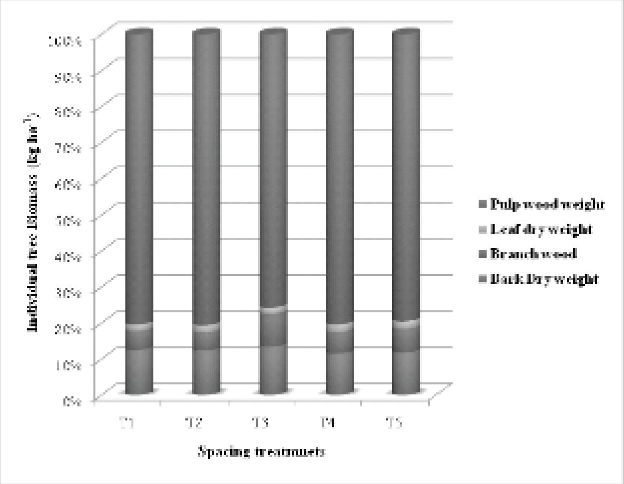

Fig 1. Biomass allocation pattern under different spacing treatments

compared to other spacing treatments. Values of mean annual carbon sequestration (MACS) under different spacing regimes varied significantly with values ranging from 7.02 Mg ha^{-1} yr^{-1} to 9.37 Mg $ha^{-1}yr^{-1}$. The highest value was found in 2.00 m × 3.00 m, which was significantly superior over the other treatments.

Influence of spacing on the carbon stock was very mush evident in the present study and generally, increasing the stand density (closer spacing) of existing forests at stand level and landscape scale could increase the carbon sequestration through trees above ground carbon storage decreased with increasing thinning intensity resulting wider spacing (Keyser 2010). Estimated carbon stock in the present study are found to be lower than the carbon mitigation potential (74.75 Mg ha^{-1}) of degraded forest land in India (Lal and Singh 2003) and above ground carbon stock observed in clonal plantation of *Eucalyptus urophylla* (Amanulla et al. 2009) and according to the report the estimated above-ground carbon stock in six year old clonal trial plantations of *E. urophylla* varied from 118.50 Mg ha^{-1} to 182.53 Mg ha^{-1} with a mean annual carbon sequestration of 19.75 Mg ha^{-1} to 30.42 Mg ha^{-1}. However, the values observed in the present study was much higher than that was reported for *Acacia* hybrid by Vijaykumar et al. (2011) who reported that the carbon stock in the different clonal plantations of *Acacia* hybrid varied considerably from 5.10 Mg ha^{-1} to 20.03 Mg ha^{-1} with a mean annual carbon sequestration of 0.85Mg ha^{-1} yr^{-1} to 3.34 Mg ha^{-1} yr^{-1}.

Thus, among the different spacing regimes, closer spacing (2.00 m × 3.00 m) with more trees was found to have higher carbon stock and mean annual carbon sequestration compared to wider spacing. Nelson et al. (2007) observed CO_2 equivalent accumulation rates for tree planting varied with site index and planting density. It was reported that in ponderosa pine planting density was more important than site index in determining carbon accumulation. Cheng et al. (2013) also concluded that changes in stand structure (stand density) could greatly influence carbon storage.

CONCLUSION

Trees in forests (including plantations), if well-stocked, typically sequester carbon at a maximum rate. Fast growing plantations are important to meet the raw material requirement of the industries. Overall productivity of the plantation is mainly manifested by the genotype, environment and interaction between the genotype and environment in which the planting is done. Maximum production of desirable wood is the prime objective of the captive plantation programmes. Biomass production and carbon sequestration in trees vary with spacing. Generally, wider spacing resulted in more biomass production in individual tress and however, on stand level biomass production, carbon stock and carbon sequestration is more in closer spacing.

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