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Assessing the carbon sequestration potential of eucalyptus plantations of different ages

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Abstract
The carbon content in above ground biomass components *viz.*, stem, branch and leaf and below ground biomass *viz.*, root of eucalyptus trees of 1 to 5 year old plantations was estimated. The data revealed that the per cent carbon content of stem, branch, leaf and root increased with an increase of age of plantations. Analogous to this, the total biomass carbon content also increased due to the age of trees. The studies on soil organic carbon showed that the soil organic carbon per cent of eucalyptus plantations increased over the ages. Among the two distances (from the tree base), significantly higher per cent soil organic carbon was recorded at closer distance (0.50 m) than at wider distance (1.0 m) at all the five ages of plantations. The surface layer recorded higher organic carbon when compared to sub surface layer at all the ages of plantation. The total soil organic carbon content also followed the same trend as that of soil organic carbon and significant difference was observed due to age, distance and soil depth. The calculated and estimated total carbon (i.e. soil organic carbon and calculated total biomass carbon) was found to be increased due to ages of the plantations.

Keywords: Eucalyptus, tree biomass carbon, soil organic carbon, total carbon

Introduction
The investment in forestry sector to store carbon in the trees and forests is one of the viable options for offsetting the gases released by fossil fuel burning and mitigating the potential effect of global warming. Perennial vegetation, notably forests have an important role to play in regional, national and international greenhouse gas balances. Afforestation and Reforestation (A/R) as an effective way to reduce atmospheric carbon by building up terrestrial carbon stocks and to produce Certified Emission Reductions (CERs) in the second commitment period of the Kyoto Protocol (2013–2020). The carbon sequestration by tree plantations and the existing forest area is estimated to sequester 15-20% GHG emissions in India.

Plantation is being considered as a mitigation option to reduce the atmospheric CO_2 and mitigate climate change. Soil organic carbon, being the largest terrestrial carbon pool plays a very significant role in global terrestrial ecosystem carbon balance. Estimated that by 2050, plantations in tropical countries have the potential to capture as much as 16.4 Gt C whereas agroforestry has the potential to capture 6.3 Gt C. Differences in per cent carbon among different tree species and among the tree components within a single tree indicated the need to estimate biomass and carbon content for each species and each tree component. Most published studies on this subject, however, have focused on total aboveground biomass and carbon, whereas discrimination among the different parts of the tree and stocking densities by age is rarely done. The proportion of carbon stored in plantation varies widely depending on site quality, age of the plantation and prevailing climatic conditions. Unlike in the developed countries, the developing countries like India do not have carbon inventories and data bank to monitor and enhance carbon sequestration potential of different plantations. In India, attempts were made to assess carbon sequestration at macro level, mostly with the available data (Ravindranath *et al.*, 1997) [25]. No attempt has been made so far to assess the biomass and soil carbon sequestration at micro level. Therefore, the current study is designed to estimate the carbon stock available in Eucalyptus plantations of different ages.

Materials and Methods
Eucalyptus hybrid clonal plantations established by Tamil Nadu Newsprint and Papers Limited, Kakithapuram (11^{o} 3' N latitude and 77^{o} 59' E longitude) was taken for this study.

The laboratory studies were conducted at Forest Soils and Forest Microbiology laboratories of Forest College and Research Institute, Mettupalayam. The present study was undertaken in 1 to 5 year old Eucalyptus plantations. Two different soil depths *viz*., 0-15 cm and 15-30 cm and two distances from the tree *viz*., 0.5 m and 1.0 m were choosen. The tree samples of various components *viz*., stem, branches, leaves and roots were collected from selected Eucalyptus plantations of different ages, then samples were air dried and oven dried. Oven dried biomass samples were powdered in Willey Mill and carbon content in above ground components of plantations was determined by using Ash content method.

The carbon estimation in biomass was carried out in two methods. First method was the methodology described by Myers (1990) who adopted carbon fractions as the fifty per cent of biomass. Second method was the assessment of carbon content (%) in different components of tree biomass. The total biomass carbon was calculated by using the following formulae.

1. AGB carbon (t C ha^{-1}) = Components of above ground biomass (t ha^{-1}) × Carbon content (%)
2. BGB carbon (t C ha^{-1}) = Components of below ground biomass (t ha^{-1}) × Carbon content (%)
3. Total biomass carbon stock (t C ha^{-1}) = AGB carbon + BGB carbon

For estimating soil carbon, the soil samples were collected from surface (0-15 cm depth) and sub-surface (15-30 cm dpeth) layer separately, dried and powdered using wooden mallet and sieved through 2 mm sieve. The soil organic carbon content was estimated in 0.5 g sieved soil samples as per Walkley and Black's Wet Oxidation Method (Walkley and Black, 1934) [30]. Bulk density was determined by Cylinder method. The bulk density (Mg m^{-3}) was used for the estimation of soil organic carbon density (Mg ha^{-1}) and soil organic carbon stock. Bulk density was determined using following formula *viz.*, Bulk density = Weight of soil / Volume of soil (Mg m^{-3}). Soil organic carbon (t/ha) was determined using following formula given by Joas Carlos *et al*., (2001). Soil organic carbon (t/ha) = Soil Organic Carbon (%) × Depth (cm) × Bulk Density (Mg m^{-3}). Soil organic carbon (t/ha) was also determined using following formula given by IPCC (1996) *viz.*, Soil Organic Carbon (t/ha) = Soil Mass × Soil Organic Carbon (%).

Results and Discussion

Carbon Content in Above Ground Biomass

The results reported that there was a significant difference in the carbon content (C) in above ground biomass between the ages of plantations. The per cent carbon content in stem wood diverged from 40.20 per cent in 1 yr old to 48.97 per cent in 5 yr old plantations and the total stem wood carbon ranged from 4.24 t C ha^{-1} in 1 yr old plantation to 37.97 t C ha^{-1} in 5 yr old plantation. The data depicted that the carbon content of stem wood increased with an increase of age (Table 1and 2).

In the present study, stem wood sequestered 50 per cent carbon to the above ground biomass carbon, since it contributes more biomass production. The result of present study was in accordance with the result of Ravi (2012) [24] who revealed that carbon concentration of stem wood was 45.79 per cent in *Casuarina equisetifolia*. The per cent carbon content in branch wood ranged from 33.48 per cent to 47.48 per cent between 1 and 5 yr old plantations. The total branch wood carbon content was 4.24 t C ha^{-1} in 1 yr old trees to 37.97 t C ha^{-1} in 5 yr old trees. The per cent carbon content of leaf ranged from 37.65 per cent in 1 yr old trees to 43.44 per cent in 5 yr old trees and the total leaf carbon varied from 1.67 t C ha^{-1} in 1 yr old trees to 7.14 t C ha^{-1} in 5 yr old trees. The carbon content of leaf increased with an increase of age. The outcome of the present investigation was supported by the results of Dhruw *et al*., (2009) [4]; Vishnu and Patil, (2016) [29]; Jithila and Prasadan (2018) [9].

Carbon Content in Below Ground Biomass

The below ground biomass carbon *viz*., root carbon content of eucalyptus trees of 1 to 5 yr old was estimated. The per cent carbon content of root ranged from 28.77 per cent in 1 yr old trees to 45.96 per cent in 5 yr old trees. The total root carbon content ranged from 2.30 t C ha^{-1} in 1 yr old trees to 17.36 t C ha^{-1} in 5 yr old trees. In the current study, the root carbon contributes 42 to 45 per cent which was in accordance with the study of Ravi (2012) [24] who estimated the carbon content which was ranged from 43 to 45 per cent in roots of *Casuarina equisetifolia*. Gifford (2000) [6] also supported the present study and stated that carbon content of roots was found to be 50.4 per cent as of the root contribution to the total biomass(Table 1 & 2).

Total Biomass Carbon

Increased establishment of tree plantations on degraded lands due to anthropogenic problems in the tropics has long been suggested as a way of reducing the rate of increase in atmospheric CO_2 (Dyson,1977). The results observed that there was a significant difference in total biomass carbon between ages of plantations. The total biomass carbon ranged from 0.66 t ha^{-1} in 1 yr old to 70.91 t ha^{-1} in 5 yr old trees (Table 2 and Fig. 1). It was noticed that there was a gradual increase in total biomass carbon with an increase of age. Lugo *et al*., (1988) compared the carbon sequestration among different plantations of tropics and reported that 5-16 yr old Eucalyptus plantation stored the carbon content ranged from 4.5-14 Mg C ha^{-1} yr^{-1} and 5-30 year old tropical pine sequestered 3-12 Mg C ha^{-1} yr^{-1}.

Table 1: Total carbon content in above and below ground biomass of Eucalyptus plantations at different ages (%)

Age of plantations (yrs)	Carbon content (%)			
	Stem wood	Branch wood	Leaf	Root
1	40.20	33.48	37.65	28.77
2	42.65	34.83	38.01	38.37
3	45.89	40.23	40.29	39.39
4	46.63	45.45	41.52	42.93
5	48.97	47.48	43.44	45.96
S.Ed	0.379	0.162	0.004	0.443
CD (0.05)	0.803	0.343	0.009	0.939

Table 2: Total biomass carbon of Eucalyptus plantations at different ages (t C ha^{-1})

Age of plantations (yrs)	Above ground biomass carbon (t C ha^{-1})				Below ground biomass carbon (t C ha^{-1})	Total biomass carbon (t C ha^{-1})
	Stem carbon	Branch wood carbon	Leaf carbon	Total	Root carbon	
1	4.24	2.45	1.67	8.37	2.30	10.66
2	7.58	3.25	2.45	13.28	4.14	17.41
3	13.76	3.85	3.05	20.65	7.87	28.53
4	19.68	7.07	5.90	32.65	10.73	43.39
5	37.97	8.44	7.14	53.55	17.36	70.91
S.Ed	0.122	0.172	0.003	0.192	0.071	0.205
CD (0.05)	0.259	0.364	0.006	0.406	0.150	0.435

The carbon content ranged from 2 - 4 Mg C ha^{-1} yr^{-1} was reported in 25-75 year old teak plantation. Miehle *et al.*, (2006) [5] stated that the carbon sequestration capacity of *Eucalyptus globulus* plantations was found to be 1.62 t C ha^{-1}. Kulvinder and Sanjay (2016) [12] also reported that *Ficus religiosa* sequestered 17.51 t ha^{-1} carbon in both above and belove ground biomass.

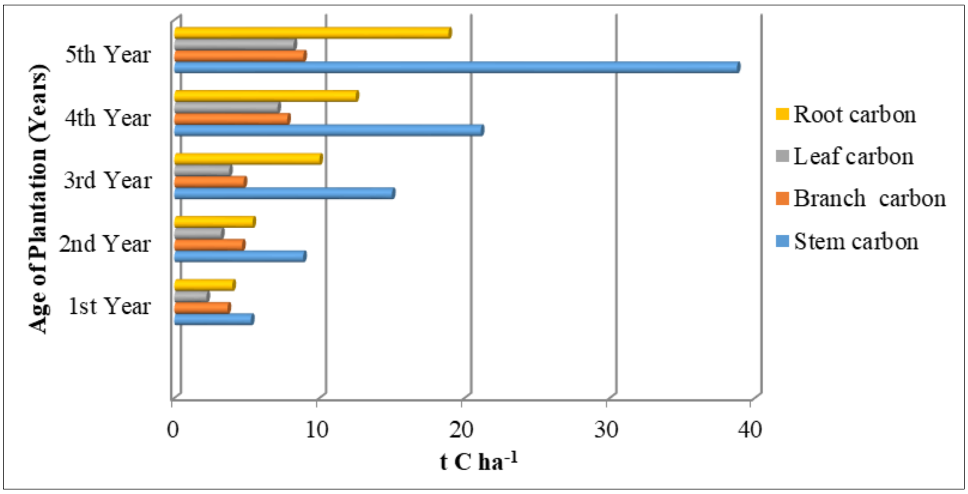

Fig 1: Total biomass carbon of Eucalyptus plantations at different ages (t C ha^{-1})

Soil Organic Carbon: The results showed that the per cent soil organic carbon of eucalyptus plantations differed between ages. The maximum soil organic carbon with a value of 0.60 per cent was recorded under 5 yr old plantation and minimum (0.56%) under 1 yr old plantation. An increasing trend of values was observed with increase in age. Among the two distances (from the tree base), significantly maximum per cent soil organic carbon was recorded at closer distance (0.50 m) and minimum at wider distance (1.0 m) at all the five ages of tree plantations. The results revealed that the percent soil carbon varied from 0.61 to 0.71 and 0.51 to 0.62 in 0.5 m and 1.0 m distance from the tree base respectively.

Among the soil depth, lower soil depth (0-15 cm) recorded maximum per cent soil organic carbon than higher soil depth (15-30 cm) at all ages of plantations and it varied from 0.65 per cent to 0.77 per cent and 0.47 per cent to 0.56 per cent at 0-15 cm and 15-30 cm soil depth respectively. The organic carbon was high in the surface soil and decreased with depth as reported by Balagopalan and Jose (1986) [2] in the *Eucalyptus* plantations Banerjee *et al.*, (1989) [3] in Sal plantations and Ravi (2012) [24] in Casuarina plantations.

The total soil organic carbon content also followed the same trend as that of soil organic carbon due to age, distance and soil depth. The total soil organic carbon content varied from 21.59 to 25.14 t C ha^{-1} and 18.05 to 21.95 t C ha^{-1} at 0.50 m and 1.0 m distance respectively (Table 3). Raisada and Jayaram (1995) [22] indicated the significant differences in soil organic carbon among the different ages of Eucalyptus hybrid plantation and this variation appeared to have been caused by root exudation under leaf litter accumulation. Subramaniyan *et al.*, (2017) [27] reported Carbon in upper 40 cm of soil in mature plantations of coffee showed soil stock of 97.27and 95.78 Mg C^{-1} ha^{-1} in shaded and open grown coffee systems respectively.

Table 3: Soil organic carbon in Eucalyptus plantations at different ages (%)

Age of plantations (yrs)	Lateral distance from the tree base (m)	Soil organic carbon (%)		
		Soil depth (cm)		Mean
		0-15 (P1)	15-30 (P2)	
1	0.5	0.67	0.54	0.61
	1.0	0.62	0.40	0.51
	Mean	0.65	0.47	0.56
2	0.5	0.70	0.56	0.63
	1.0	0.64	0.41	0.52
	Mean	0.67	0.48	0.58
3	0.5	0.75	0.60	0.68

	1.0	0.68	0.42	0.55
	Mean	0.72	0.51	0.62
4	0.5	0.76	0.60	0.68
	1.0	0.73	0.47	0.60
	Mean	0.75	0.54	0.65
5	0.5	0.79	0.63	0.71
	1.0	0.75	0.49	0.62
	Mean	0.77	0.56	0.67
Control (Open Field)		0.62	0.50	0.56

	SED	CD (0.05)		SED	CD (0.05)
T	0.013	0.026	TD	0.018	0.036
D	0.008	0.016	DP	0.012	0.023
P	0.008	0.016	TP	0.018	0.036
TDP	0.026	0.051			

World soil contains an important pool of active carbon that plays a major role in the global carbon cycle (Pilania *et al*., 2014; Subramaniyan *et al*., 2017; Jithila and Prasadan, 2018) [20, 27, 9]. Soil organic matter is a key component of terrestrial ecosystem and any variation in its abundance and composition has important effect on many of processes that occur within the system. Gupta and Pandey (2008) [7] found that soils under Eucalyptus plantation was found to have 10.03 t C ha^{-1} (48.87%) which had higher carbon pool as compared to barren land.

Table 4: Soil organic carbon in Eucalyptus plantations at different ages (t ha^{-1})

Age of the plantations (yrs)	Lateral distance from the tree base (m)	Soil organic carbon (t ha^{-1}) Soil depth 0-30 (cm)
1	0.5	21.59
	1.0	18.05
	Mean	19.82
2	0.5	22.30
	1.0	18.41
	Mean	20.36
3	0.5	24.68
	1.0	19.97
	Mean	22.32
4	0.5	24.68
	1.0	21.78
	Mean	23.23
5	0.5	25.14
	1.0	21.95
	Mean	23.55

	SED	CD (0.05)
T	0.455	0.922
D	0.288	0.583
TD	0.643	1.304

Total Carbon

The calculated total carbon (i.e. soil organic carbon and calculated total biomass carbon) was lower in 1 yr old plantation with a value of 30.48 t C ha^{-1} and higher in 5 yr old plantation with a value of 94.46 t C ha^{-1}(Table 5). Plants and the pedosphere can be the effective sinks for carbon (Ravi, 2012; Suryawanshi *et al*., 2014; Padmakumar *et al*., 2018, Divya *et al*., 2022) [24, 28, 18]. The potential of pedosphere to sequester carbon can play an important role in the overall management of carbon (Paul *et al*., 1997; Poutter and Klooster, 1997) [19, 21]. The total biomass carbon and soil carbon were 10.66 t C ha^{-1} and 19.82 t C ha^{-1} respectively which was in accordance with Ramachandran *et al*., (2007) [23] who reported the above and below ground biomass and soil carbon of natural forest area of Kolli hills as 2.74 Tg and 3.48 Tg respectively.

The estimated total biomass carbon varied from 15.17 t C ha^{-1} to 74.77 t C ha^{-1} in first year to fifth year of eucalyptus plantations (Table 6). The estimated total carbon (i.e., soil organic carbon and estimated total biomass carbon) diverged from 34.99 t C ha^{-1} in one year old plantations to 98.32 t C ha^{-1} in 5 yr old plantations (Table 7 and Figure 2). Soil and vegetation therefore represent potential sinks for carbon sequestration. Several authors have suggested afforestration as a possible means of mitigating global climate change (Shivanna *et al*., 2006; Arya *et al*., 2018; Jithila and Prasadan, 2018; Mishra and Prasad, 2018; Jogattappa *et al*., 2020) [26, 9, 16, 11]. This present study revealed that plantations are of paramount importance in the reduction of ambient carbon dioxide levels and mitigation of global climate change. From the present study, it was found that Eucalyptus plantations have sequestered significant amount of carbon in different components of trees. This finding was supported by Ashalatha *et al*., (2015) [31] under *Melia dubia* based agroforestry system in Tamil Nadu.

Table 5: Total carbon content of Eucalyptus plantations at different ages (t C ha^{-1})

Age of the plantations (yrs)	Soil organic carbon (t C ha^{-1})			Biomass carbon (t C ha^{-1})					Total carbon (t C ha^{-1}) A+B
	0.5 m 0-30 cm	1 m 0-30 cm	Mean (A)	Main stem	Branch wood	Leaf	Root	Total (B)	
1.	21.59	18.05	19.82	4.24	2.45	1.67	2.30	10.66	30.48
2.	22.30	18.41	20.36	7.58	3.25	2.45	4.14	17.41	37.77
3.	24.6	19.97	22.32	13.76	3.85	3.05	7.87	28.53	50.85
4.	24.68	21.78	23.23	19.68	7.07	5.90	10.73	43.39	66.62
5.	25.14	21.95	23.55	37.97	8.44	7.14	17.36	70.91	94.46

S.Ed 0.349 0.122 0.172 0.003 0.071 0.205 0.885
CD (0.05) 0.739 0.259 0.364 0.006 0.150 0.435 1.877

Table 6: Total biomass carbon of Eucalyptus plantations at different ages (t C ha^{-1})

Age of the plantations (yrs)	Stem carbon (t C ha^{-1})	Branch carbon (t C ha^{-1})	Leaf carbon (t C ha^{-1})	Root carbon (t C ha^{-1})	Total biomass carbon (t C ha^{-1})
1	5.28	3.67	2.22	4.00	15.17
2	8.88	4.67	3.22	5.39	22.16
3	15.00	4.78	3.78	10.00	33.56
4	21.12	7.78	7.11	12.50	48.51
5	38.77	8.89	8.22	18.89	74.77

*Assumes carbon as 50 per cent of biomass
S.Ed 0.001 0.190 0.002 0.037 0.186
CD (0.05) 0.002 0.404 0.005 0.079 0.393

Table 7: Total carbon content of Eucalyptus plantations at different ages (t C ha^{-1})

Age of the plantations (yrs)	Soil organic carbon (t C ha^{-1})	Biomass carbon (t C ha^{-1})					Total carbon
	Mean (A)	Main stem	Branch wood	Leaf	Root	Total (B)	(t C ha^{-1}) A+B
1.	19.82	5.28	3.67	2.22	4.00	15.17	34.99
2.	20.36	8.88	4.67	3.22	5.39	22.16	42.52
3.	22.32	15.00	4.78	3.78	10.00	33.56	55.88
4.	23.23	21.12	7.78	7.11	12.50	48.51	71.74
5.	23.55	38.77	8.89	8.22	18.89	74.77	98.32

S.Ed 0.349 0.001 0.190 0.002 0.037 0.186 0.883
CD (0.05) 0.739 0.002 0.404 0.005 0.079 0.393 1.872

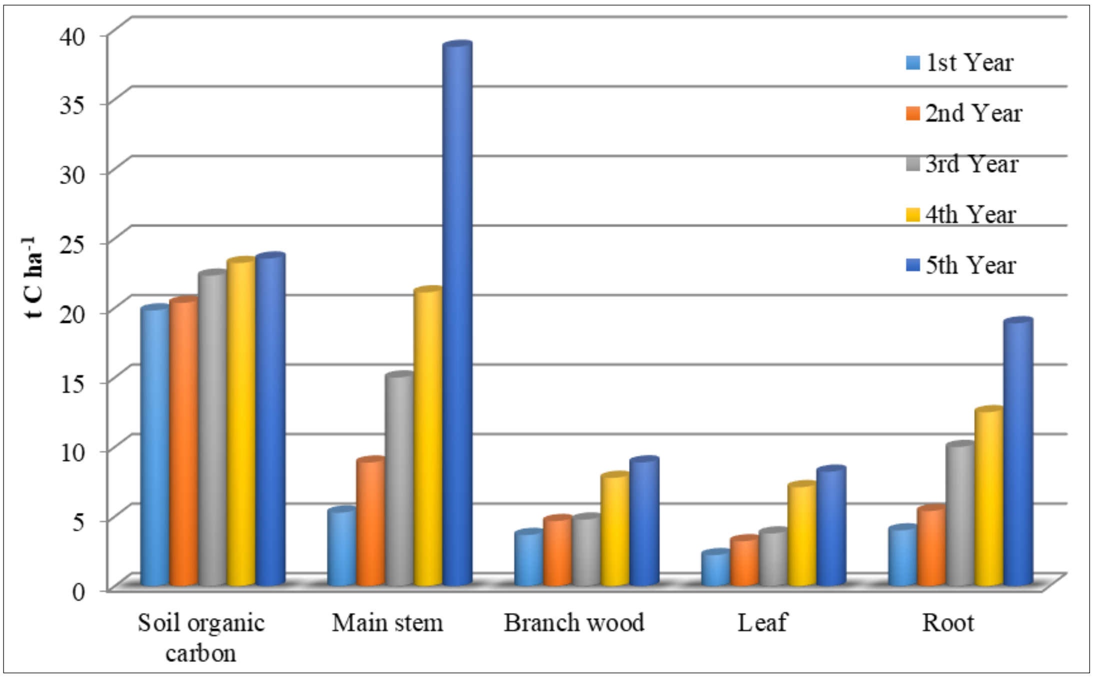

Fig 2: Total carbon content of Eucalyptus plantations at different ages (t C ha^{-1})

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