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Biomass, Carbon Stock and Carbon Dioxide Removal Across Different Girth Classes of Eucalyptus species in Punjab: Implication for Eucalyptus Plantations

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ABSTRACT

A total of 17 girth classes were considered to estimate the volume, biomass, carbon and carbon dioxide removal in Eucalyptus plantations in Punjab. All the studied parameters showed increment from lower girth classes towards higher girth classes. Mean tree height varied from 10.97 (25-30 cm) to 25.33 m (106-110 cm) and tree volume from 0.03 (G1) to 0.67 m^3 (G_{17}). Dry biomass showed significant variation among different girth classes and it ranged from 1.5 to 36.72 kg in leaf and twig parts, from 2.81 to 86.48 kg in branch parts, from 22.4 to 636.54 kg in the logs in lower to higher girth classes, respectively. There was a strong positive association between girth class and tree biomass (R^2= 0.971). Total carbon sequestration potential per tree ranged between 13.62 (G_1) and 387.47 kg (G_{17}). Carbon dioxide content in a tree ranged from 49.9 to 1422.02 kg, respectively in lower girth class (25-30 cm) to higher girth class (106-110 cm). There was a strong positive trend between girth classes and carbon/ CO_2 content. This study may be useful for estimation of biomass and carbon stock of trees having attained girth ranging from 25 to 110 cm irrespective of age and the site conditions. It will also be useful to estimate the optimum age at which trees should be felled to harvest the maximum carbon.

Key words:

Biomass, carbon stock, carbon dioxide removal, eucalyptus, sequester

INTRODUCTION

Global warming and climate change are important international concerns. The emission of greenhouse gases arebelieved to be largely responsible for global warming. Carbon dioxide is the major greenhouse gas sharing its contribution to nearly 72%. While addressing the concerns, Kyoto protocol has warned that the increasing carbon emissions may be the real danger for the entire world (Chavan and Rasal 2010; Ravindranath et al. 1997). Many efforts are being made to bring down the carbon dioxide levels (Hairiah et al. 2009). The forests and soils constitute a major terrestrial carbon pool with the potential to absorb and store carbon dioxide (CO_2) from the atmosphere. Carbon is stored in trees and plants through transfer of carbon dioxide by photosynthesis (Dilling et al. 2006). However, the factors such as type of forest, age of forest, and its structure and composition affect its overall biomass production and thus the amount of carbon sequestered and stored in it (Millard 2007;

Kanime et al. 2013; Verma et al. 2014; Goswami et al. 2014; Arora et al. 2014). It is estimated that through carbon sequestration, India's forests and tree cover is enough to neutralize 11.25 % of India's total GHG emissions (Jasmin and Birundha 2011). Thus, afforestation and reforestation programmes are viable options for mitigation of climate change. Several forest species are grown in forest plantations; however, species such as *Populus sp., Eucalyptus sp., Casuarina equisetifolia, Acacia mangium and Leucaena leucocephala* are planted in large scale due to their fast growth, local demand by the pulp and paper industries and economic viability, apart from their contribution towards carbon sequestration. Therefore, it is necessary to understand the periodic growth and biomass and carbon sequestration potential of these species. As India is the largest planter of *Eucalyptus* in the world with more than 4 million ha area under its cultivation (MoEF 2012), in the present study, volume, biomass and carbon stocks were estimated for *Eucalyptus* species in different girth classes to understand its potential.

MATERIAL AND METHODS

The present study was conducted at Research Circle,Punjab Forest Department, Hoshiarpur, Punjab.17 girth classes *viz.*, G_1 (25-30 cm), G_2 (31-35 cm), G_3 (36-40 cm), G_4 (41-45 cm), G_5 (46-50 cm), G_6 (51-55 cm), G_7 (56-60 cm), G_8 (61-65 cm), G_9 (66-70 cm), G_{10} (71-75 cm), G_{11} (76-80 cm), G_{12} (81-85 cm), G_{13} (86-90 cm), G_{14} (91-95 cm), G_{15} (96-100 cm), G_{16} (101-105 cm) and G_{17} (106-110 cm) were considered. In each girth class, three well grown trees of seedling origin were randomly considered and marked for biometric observations such as Girth at breast height (GBH) and tree height. Clinometer was used for height measurement. Later, all the marked trees were felled at 5 cm above ground. The leaves, twigs, and branches were removed from the main stem and each of these componentswere weighed in the field and fresh weight was recorded. Representative samples of each of the component were then oven dried at 80±5°C temperature till to get constant weight (Chidumayo 1990). The logs were measured for length and mid girth and the volume of logs by following $P/4*D^2H$ formula was calculated. Sum of volume of logs of each tree was used as merchantable tree volume. Total carbon stock per tree was estimated by using total dry biomass multiplied by factor of 0.51 as per Micales and Skog (1997) and Dury et al. (2002). In addition to this, CO_2 equivalents was assessed using carbon stock value multiplied by 3.67 as described AACM (1997) and Van Kooten (1999).

RESULTS AND DISCUSSION

There was a significant variation among 17 girth classes studied for tree height, volume and dry biomass in *Eucalyptus species* (Table 1). All the studied parameters showed increment from lower girth classes towards higher girth classes. For instance, mean tree height varied from 10.97 (G_1) to 25.33 m (G_{17}) and tree volume from 0.03 (G_1) to 0.67 m^3 (G_{17}). For better understanding of tree biomass, tree parts were divided into leaf & twig parts, branch part, logs (with bark) and these samples were used for dry biomass assessment. Dry biomass of all these components showed significant variation among different girth classes and it ranged from 1.5 to 36.72 kg in leaf and twig parts, from 2.81 to 86.48 kg in branch parts, from 22.4 to 636.54 kg in the logs in lower to higher girth classes (Table 1). Interestingly, the entire tree dry biomass ranged between 26.71 kg and 759.75 kg and it significantly varied among all the girth classes studied. The increment of total tree biomass from lower girth classes to higher girth classes in *Eucalyptus* species is depicted in Fig. 1.

In order to understand the trend between tree girth class and tree biomass, regression analysis was made using regression equation of polynomial at 2 points. Result showed that there was a strong positive association between girth class and tree biomass (R^2= 0.971). Furthermore, regression equation developed in the study [$\mathbf{y} = 0.09\mathbf{x}^2 - 3.295\mathbf{x} + 49.40$, where **y** representing tree biomass and **x** representing tree girth] may be useful for estimating stand biomass in *Eucalytpus.*

Table 1. Tree height, volume and dry biomass of trees of different girth classes in Eucalyptus species

Treatments (Girth classes)	Tree height (m)	Tree volume (m^3)	Dry biomass of different parts of tree (Kg)			
			Leaf and twig	Branch	Logs with bark	Entire tree
G_1(25-30 cm)	10.97	0.03	1.50	2.81	22.40	26.71
G_2 (31-35 cm)	12.42	0.04	3.11	3.59	26.60	33.29
G_3 (36-40 cm)	14.67	0.05	3.71	5.21	41.49	50.40
G_4 (41-45 cm)	13.78	0.07	6.72	10.78	64.75	82.25
G_5 (46-50 cm)	15.77	0.11	8.99	6.68	73.79	89.46
G_6 (51-55 cm)	20.83	0.16	9.53	7.01	131.75	148.28
G_7 (56-60 cm)	19.63	0.19	11.14	11.09	129.51	151.74
G_8 (61-65 cm)	20.00	0.24	11.32	21.09	186.55	218.95
G_9 (66-70 cm)	21.55	0.27	8.40	17.46	197.52	223.38
G_{10} (71-75 cm)	24.40	0.33	17.48	25.65	276.59	319.72
G_{11} (76-80 cm)	21.53	0.39	19.46	38.58	279.10	337.14
G_{12} (81-85 cm)	22.13	0.40	27.92	40.60	326.92	395.45
G_{13} (86-90 cm)	22.52	0.46	19.40	37.90	372.82	430.12
G_{14} (91-95 cm)	25.17	0.49	21.66	31.96	441.01	494.63
G_{15} (96-100 cm)	24.33	0.61	33.49	60.29	460.87	554.64
G_{16} (101-105 cm)	22.27	0.62	35.17	73.61	562.00	670.78
G_{17} (106-110 cm)	25.33	0.67	36.72	86.48	636.54	759.75
CD at 5% P	**2.80**	**0.074**	**15.6**	**21.66**	**61.46**	**73.46**

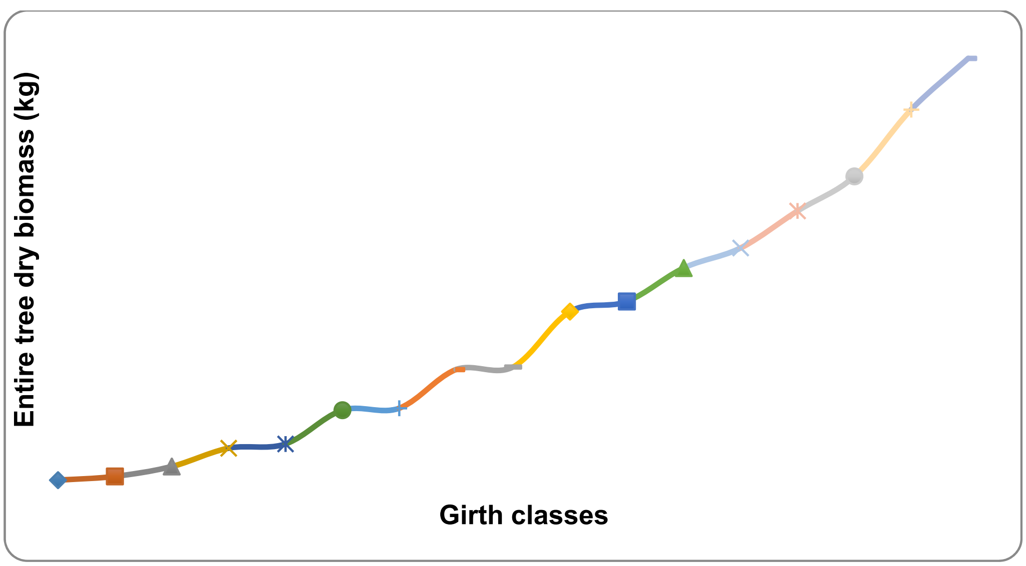

Figure. 1: Dry biomass increment from lower to higher girth classes in Eucalyptus species

Similar to dry biomass, carbon sequestration and CO_2 equivalents were also estimated in different tree components *viz.*, (1) leaf & twig parts (2) branch parts (3) logs (with bark) and (4) entire tree and results are depicted in Table 2. All these parameters showed significant variation among girth classes in *Eucalyptus*. Total carbon sequestration potential per tree ranged between 13.62 kg (G_1) and 387.47 kg (G_{17}). Similarly, CO_2 content in a tree ranged from 49.9 kg to 1422.02 kg, respectively in lower girth class (G_1)to higher girth class (G_{17}). Regression study showed that there was a strong positive trend between girth classes and carbon and CO_2 content indicating that with the increase in girth of a tree there is aincrease in carbon as well as CO_2 content in Eucalyptus. As a corollary of this results,the quantity of carbon sequestered and/or CO_2 accumulation may be estimated using tree GBH by following regression equation derived in the study (Fig. 2b & 2c).

Table 2. Carbon content and Carbon dioxide content in different parts of trees across various girth classes in Eucalyptus species

Treatment (Girth classes)	Tree height (m)	Carbon content (kg)				CO_2 (kg)			
		Leaf & twig	Branch	Logs	Entire tree	Leaf & twig	Branch	Logs	Entire tree
G_1 (25-30 cm)	10.97	0.76	1.43	11.42	13.62	2.80	5.26	41.92	49.99
G_2 (31-35 cm)	12.42	1.58	1.83	13.56	16.98	5.82	6.72	49.78	62.32
G_3 (36-40 cm)	14.67	1.89	2.66	21.16	25.71	6.94	9.75	77.65	94.34
G_4 (41-45 cm)	13.78	3.43	5.50	33.02	41.95	12.57	20.17	121.20	153.94
G_5 (46-50 cm)	15.77	4.58	3.41	37.63	45.63	16.82	12.51	138.12	167.45
G_6 (51-55 cm)	20.83	4.86	3.57	67.19	75.62	17.83	13.12	246.59	277.54
G_7 (56-60 cm)	19.63	5.68	5.66	66.05	77.39	20.85	20.76	242.40	284.02
G_8 (61-65 cm)	20.00	5.77	10.75	95.14	111.66	21.18	39.47	349.16	409.81
G_9 (66-70 cm)	21.55	4.29	8.90	100.74	113.93	15.73	32.68	369.70	418.11
G_{10} (71-75 cm)	24.40	8.92	13.08	141.06	163.06	32.72	48.02	517.68	598.43
G_{11} (76-80 cm)	21.53	9.92	19.68	142.34	171.94	36.42	72.22	522.38	631.03
G_{12} (81-85 cm)	22.13	14.24	20.71	166.73	201.68	52.27	76.00	611.90	740.16
G_{13} (86-90 cm)	22.52	9.89	19.33	190.14	219.36	36.31	70.94	697.82	805.06
G_{14} (91-95 cm)	25.17	11.05	16.30	224.92	252.26	40.54	59.81	825.45	925.80
G_{15} (96-100 cm)	24.33	17.08	30.75	235.04	282.87	62.67	112.84	862.60	1038.12
G_{16} (101-105 cm)	22.27	17.94	37.54	286.62	342.10	65.83	137.77	1051.90	1255.50
G_{17} (106-110 cm)	25.33	18.73	44.11	324.64	387.47	68.73	161.87	1191.41	1422.02
CD at 5% P		**7.98**	**11.05**	**31.35**	**37.47**	**29.28**	**40.55**	**115.00**	**137.50**

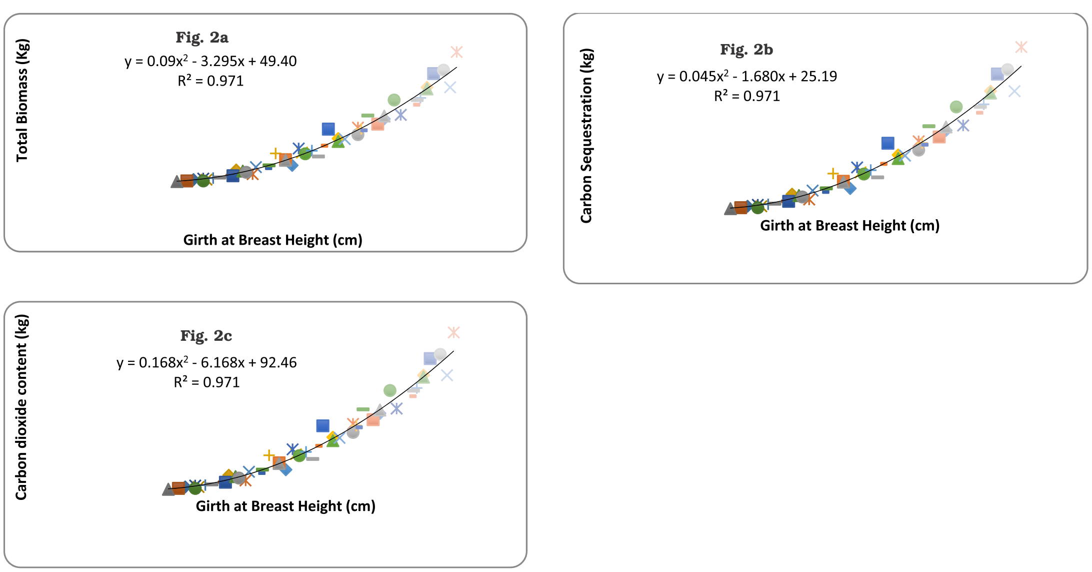

Figure. 2: Accumulation of tree biomass (a), carbon sequestration (b) and CO_2 (c) in different girth classes in *Eucalyptus*

The significance of forested areas in carbon sequestration is conventional, and well recognised. However, hardly any attempts have been made to study the potential of trees of different age groups in biomass accumulation and carbon sequestration among tropical forest species, especially, fast growing species. The carbon pool for the Indian forests is estimated to be 7,044 million tonnes (SFR 2015).Recent report suggested that the increase in the carbon stock is in line with the INDC targets. The INDC target for forestry sector envisages creation of additional carbon sink of 2.5 to 3.0 billion tonnes of CO_2 (Anon. 2016). The fast-growing species such as *Eucalyptus urophylla*, accumulated more carbon in plant biomass. The biomass carbon was about 1.9 times greater than the ten speciesin mixed plantations in China (Chen 2015). Juntheikki (2014) reported that, in Uruguay, currently there were 707,674 hectares of eucalyptus plantations that have the potential to sequester 65 million tonnes of carbon and reduce 238 million tonnes of CO_2. The calculated and simulated carbon storage was 38 and 25 million tonnes of Carbon. In India, Ulman and Avudainayagam (2014) estimated the carbon storage potential of *Eucalyptus tereticornis* plantations of different age group (1 to 4 years) in Tamil Nadu. The carbon content was found to be 38.10 to 42.66 and 115.88 to 129.04 t ha^{-1}, respectively in one and four years plantation. In the present study, the total carbon sequestration potential per tree ranged between 13.62 in girth class of 25-30 cm and 387.47 kg in the girth class of 106-110 cm. The carbon stocks across some of the girth classes in the present study are in line with what was recorded by Dogra (2011) and the detail of comparative data is presented in Table 3.

Table 3. Girth class wise comparison of growth and carbon sequestration in Eucalyptus trees recorded in present study with Dogra (2011) in Punjab.

Girth class (cm)	Tree height (m)	Carbon sequestered (kg/tree)	Girth (cm)	Tree height (m)	Carbon sequestered (kg/tree)
	Present study			Dogra (2011)	
36-40	14.67	25.71	38 (12)*	15.00	26.60
46-50	15.77	45.63	47 (15)	17.00	45.60
51-55	20.83	75.62	53 (17)	20.00	66.70
61-65	20.00	111.66	63 (20)	20.00	91.80
76-80	21.53	171.94	79 (25)	22.00	154.00
91-95	25.17	252.26	94 (30)	24.00	236.80

*Figures in parenthesis are DBH values

The data obtained in the present study has been extrapolated on per hectare basis considering different spatial arrangements in practice under block and agroforestry plantations (Table 4). Prasad et al. (2012) have reported carbon stocks of 24.97 and 27.45 t/ha for Eucalyptus planted as block plantation (3x2 m) and agroforestry systems (7x1.5 m paired row) at the age of 51 months (4 years and 3 months) in Hyderabad, Andhra Pradesh. The extrapolated data presented in Table 4, expresses that carbon stocks of 26.88 (3x2 m), 27.14 (3x3 m) and 23.27 t/ha (7x1.5 m paired row)can be achieved from tree falling in girth class of 31-35 cm and 36-40 cm, respectively. The growth of any plantation depends upon the site conditions and cultural practices. Our estimates may be applicable for the trees attaining girth ranging from 25 cm to 110 cm irrespective of age and management practicesfor estimation of carbon stock and CO_2 content in different eucalyptus plantations under different land use systems.The results will further be useful for estimating the age at which Eucalyptus plantation shall be felled for harvesting the maximum carbon.

Table 4. Estimated biomass and carbon stocks in different spatial arrangements under block and agroforestry plantations across different girth class of Eucalyptus

Girth Classes	Biomass (t/ha)					Carbon stocks (t/ha)				
	2x2 m(2375 trees/ha)	3x3 m(1055 trees/ha)	3x2m(1583 trees/ha)	4x4 m(1188 trees/ha)	7x1.5 mpaired rows (905 trees/ha)	2x2 m(2375 trees/ha)	3x3m (1055 trees/ha)	3x2m(1583 trees/ha)	4x4 (1188 tree/ha)	7x1.5 paired rows (905 tree/ha)
G_1 (25-30 cm)	63.44	28.19	42.28	31.73	24.17	32.35	14.38	21.56	16.18	12.33
G_2 (31-35 cm)	79.06	35.14	52.70	39.55	30.13	40.33	17.92	26.88	20.17	15.37
G_3 (36-40 cm)	119.70	53.20	79.78	59.88	45.61	61.06	27.14	40.70	30.54	23.27
G_4 (41-45 cm)	195.34	86.81	130.20	97.71	74.44	99.63	44.28	66.41	49.84	37.96
G_5 (46-50 cm)	212.47	94.43	141.62	106.28	80.96	108.37	48.16	72.23	54.21	41.30
G_6 (51-55 cm)	352.17	156.51	234.73	176.16	134.19	179.60	79.82	119.71	89.84	68.44
G_7 (56-60 cm)	360.38	160.16	240.20	180.27	137.32	183.80	81.69	122.51	91.94	70.04
G_8 (61-65 cm)	520.01	231.10	346.60	260.11	198.15	265.19	117.86	176.76	132.65	101.05
G_9 (66-70 cm)	530.53	235.78	353.61	265.38	202.16	270.58	120.25	180.35	135.35	103.11
G_{10} (71-75 cm)	759.34	337.46	506.12	379.83	289.35	387.27	172.11	258.12	193.72	147.57
G_{11} (76-80 cm)	800.71	355.85	533.69	400.52	305.11	408.36	181.48	272.18	204.26	155.61
G_{12} (81-85 cm)	939.19	417.40	626.00	469.79	357.88	478.99	212.87	319.26	239.60	182.52
G_{13} (86-90 cm)	1021.54	453.99	680.88	510.98	389.26	520.98	231.53	347.25	260.60	198.52
G_{14} (91-95 cm)	1174.75	522.08	783.00	587.62	447.64	599.12	266.26	399.33	299.68	228.30
G_{15} (96-100 cm)	1317.27	585.42	878.00	658.91	501.95	671.82	298.57	447.78	336.05	256.00
G_{16} (101-105 cm)	1593.10	708.01	1061.84	796.89	607.06	812.49	361.09	541.54	406.41	309.60
G_{17}(106-110 cm)	1804.41	801.92	1202.68	902.58	687.57	920.24	408.97	613.37	460.31	350.66

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