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BIOMASS AND CARBON STOCK IN *OCHLANDRA SETIGERA* GAMBLE, A BAMBOO SPECIES ENDEMIC TO NILGIRI BIOSPHERE RESERVE

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ABSTRACT
In the era of climate change, bamboos can act as a superior carbon sink because of its fast growth rate and wide climatic adaptability. The clump structure, standing stock biomass and carbon storage of *Ochlandra setigera* located in the Nilambur Forest Division of Kerala was assessed in the present study. Sample plots were laid out and clump structure was recorded. The biomass and carbon storage were estimated by destructive sampling. The total number of culms of *O. setigera* during the first and second year of study was 29,477.28 and 31,404.24 per ha, respectively. The distribution of culms in height classes followed the logistic distribution whereas; girth class distribution of culms was best described by the Weibull (3P). The standing stock biomass of *O. setigera* was 73.4 ±30.3 t ha^{-1} and the stem and rhizome recorded the highest contribution towards the total biomass. The carbon storage of natural stand of *O. setigera* was 30.7 ±13.2 t ha^{-1}. Soil carbon storage was to the tune of 117.538 ±29.919 t ha^{-1}. The soil C concentration and stock decreased with depth and the top two layers (0-40 cm) recorded more than 80 % of the total carbon stock. With great biomass production and carbon storage in biomass and soil, *O. setigera* can play an important role in carbon sink forestry and there is an urgent need for conservation this species.

KEYWORDS: Clump, culm, soil carbon, rhizome.

INTRODUCTION

Bamboos belonging to family Poaceae are the perennial woody grasses gifted with vigorous growth and quick biomass production within a short period. They play a major role in biodiversity conservation, contribute to soil and water management (Bystriakova *et al*., 2003) and play the major role in carbon sequestration (Nath *et al*., 2015). North East India, the Western Ghats, Eastern Himalaya, and Andaman and Nicobar Islands are riches bamboo biodiversity areas of the country (Kumar, 2011b). Western Ghats of India is one of the 34 biodiversity hotspots of the world. Nearly 24 species of bamboo from eight genera occur in the Western Ghats and at least four of them are economically important. The Western Ghats are recognized for high degree of endemism because, out of the 22 naturally occurring bamboo species in this area, 17 are reported to be endemic (Kumar, 2011a) Most of the bamboos in Western Ghats are facing serious threats due to indiscriminate harvesting and loss of habitats associated with the land use changes(Kumar 2011a). *Ochlandra setigera* Gamble is a reed bamboo endemic to Nilgiri Biosphere Reserve. Due to restricted habitat and over-exploitation, this species has to be conserved with top priority (Kumar, 2011b). Its distribution is limited to Malappuram and Palakkad districts of Kerala and Gudallur of Tamil Nadu at an elevation of 600-1000 m. The culms are used in handicraft items and tying firewood bundles. The leaves are used as fodder. However, little is known about the growth, development and ecology of this species. We have already reported the litter production, decomposition and nutrient release dynamics in this species (Thomas *et al*., 2014). With the global climate change, just like other woody biomass sources, bamboo has turned into a globally important resource (Scurlock *et al*., 2000). Studies indicated that bamboo biomass storage is comparable with the most woody species in terms of carbon sequestration potential (Nath *et al*., 2015). Hence, it has a great role in mitigating global climate change and sustainable economic development in the developing world in terms of carbon trading. However, studies on biomass production and carbon storage bamboos are scanty. The present study focuses on the biomass production and carbon storage in *Ochlandra setigera* Gamble, a bamboo species endemic to Nilgiri Biosphere Reserve

MATERIALS AND METHODS

The study was conducted on natural populations of *Ochlandra setigera* near Nadukani, Nellikutha Forest Station (11°34'57.6'' N and 76°15'32.6'' E), Vazhikadavu Forest Range in Nilambur Forest Division of Kerala. Nilambur has a warm humid climate, receiving rain from the southwest and northeast monsoons. *Ochlandra setigera* is a perennial, gregarious small straggling bamboo species with its culms reaching a height of 5−8 m, the diameter 1.5−2.2cm and an internodal length of 23−35 cm. Three sample plots of 25m x 25 m (625 $m^{2)}$ containing 35-40 clumps per plot) were randomly laid out in study area. From each sample plot, sixteen clumps were marked and the 4 clumps in the centre of plot were selected for biometric observation at yearly intervals to avoid the boarder effect. The growth was assessed for two consecutive years (2011 & 2012). During the data collection, after recording the clump attributes, the culms in the clumps were grouped into age classes depending on their maturity from the current year culms to oldest culms. The clump characteristics like clump, length, breadth and circumference, and number of culms per clump were recorded. The individual culm attributes viz., height; girth at breast height (GBH), internodal length (between fifth and sixth nodes) and the number of nodes per culm were also observed.

Carbon storage potential of *O. setigera* was deduced from its biomass accumulation potential. For reasons of economy, as well as the restriction on harvest imposed by Kerala Forest Department, three representative samples were selected from large, medium and small clumps and each was destructively sampled during April of 2012. Total fresh weight (FW) of each component was determined on site with a scale and five sub-samples of 500 g each was taken to the Laboratory. The samples were oven dried to constant weight at 70°C. The biomass was obtained from the fresh weight of various biomass components and their moisture content that was determined on subsamples. The carbon concentration of biomass components was determined by the Euro vector (EA 3000) CHNS Elemental analyser. The soil carbon sequestration at different depths (0-20, 20-40 and 40-60 cm) was also estimated. Soil samples were taken from the pits dug up to 60 cm depth. The soil samples in five replications were collected and brought to the laboratory. The soil organic carbon (SOC) content was determined using Walkey and Black method (Jackson, 1973). Total soil organic carbon content was estimated using the following formula (Chabbra *et al*., 2002):

SOC= Organic carbon content % x bulk density (kg/ m^3) x Thickness of horizon (m).

The total soil carbon storage was expressed on per hectare basis.

SPSS 17, Microsoft Excel 2007 and Easy fit software were used to describe and analyze the data. The distribution fitting including histogram and probability density functions were generated in Easyfit software 5.6 of Mathwave data analysis and simulation for Windows. Two-way analysis of variance was carried out to describe the variation in culm attributes during the two periods and the rest were analyzed using one way ANOVA. Multiple linear regressions were fitted with SPSS 17. Scatter plots and linear regression equations were fitted with Microsoft Excel 2007.

RESULTS AND DISCUSSION

The number of culms per ha of *Ochlandra setigera* during the first (2011) and second observations (2012) was 29,477.28 and 31,404.24, respectively. From the distribution of culms in different height classes during 2011 (Table 1) it can be observed that the highest number of culms (14686.56) fall into 6-8 m class followed by 4-6 m (11353.44).

TABLE 1. Frequency distribution of culms in height and girth classes of *Ochlandra setigera* (per ha basis)

Height class	0-2 m	2-4 m	4-6 m	6-8 m	8-10 m	10-12 m
2011	104.16	1197.84	11353.44	14686.56	2239.44	0.00
2012	0.00	1510.32	12030.5	13488.7	4374.72	0.00
Girth class	0-2 cm	2-4 m	4-6 cm	6-8 cm	8-10 cm	10-12 cm
2011	0.00	416.64	8749.44	15624	3072.72	1614.48
2012	0.00	520.8	9895.2	13436.6	7395.36	156.24

The number of culms in the lowest and highest height classes was nominal. It was obvious that more than 88 % of the culms belonged to 4-6 (38.0 %) and 6-8 (50%) m height classes and the lowest height class contained only 4% of the culms and the highest height class contained 8% of the total. During 2012 also, the highest number of culms occurred in 6-8 m class (13488.72) followed by 4-6 m class (12030.48), both classes contributing more than 80% of total culms. The 10-12 m height class recorded 14% of total culms and the lowest class 5%.

The common distributions like Normal, Exponential, Gumbel, Log logistic, Weibull distributions were fitted to the combined data of both years, and the logistic distribution was the best fit (α=8.3263 β=6.0598) with a test statistic of 111.96 (Fig 1). This distribution resembles the normal distribution in shape but has heavier tails.

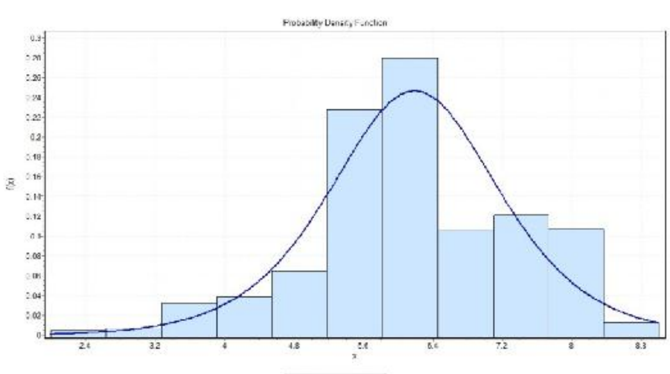

FIGURE 1. Histogram and fitted Logistic distribution for number of culms in different height classes

In the context of distribution of culms in different girth classes, during 2011, the maximum number of culms were in 6-8 cm class (15,624) followed by 4-6 cm (8,749.44) and 8-10 cm (3072.72) classes (Table 1). The contribution of different girth classes to total number of culms was in the order 6-8 cm (53.00 %) > 4-6 cm (29.68%) > 8-10 cm (10.42 %) > 10-12 cm (5.48%) > 2-4 cm (1.41%). During 2012, frequency distribution showed that the highest number of culms belonged to girth class 6-8cm (13436.64) followed by 4-6cm (9895.2) and 8-10cm (7395.36). Regarding the percent contribution of girth classes, the highest contribution was from 6-8cm (42.79 %) followed by 4-6cm (31.50 %) and 8-10cm (23.54) all together contributing more than 97% of total culms. The Weibull (3P) distribution was the best fit to explain the girth classes (η=2.54, β =4.32, γ=2.69) with a test statistic of 640.17 (Fig. 2).

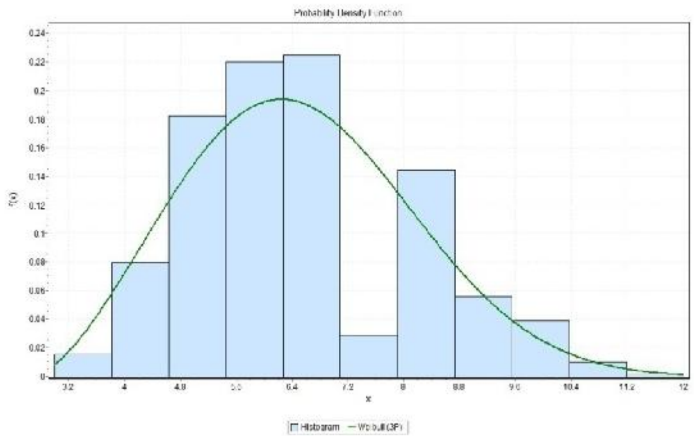

FIGURE 2. Histogram and best fit Weibull distribution for number of culms in different girth classes

A similar pattern of distribution of culms in the diameter structures (a right asymmetric distribution) was observed in bamboo stands located at Benin (Tovissodé *et al*. 2015). On contrary, the number of culms in different girth classes followed a normal distribution in *Yushania alpine* (Bitariho & McNeilage, 2008). As these are natural population being illegally harvested by the people, the distribution may become normal if no conservation measures are taken. With regard to clump attributes, the total number of culms increased from 107.92 ±58.76 to 114.58 ±64.80 during the period of study (Table 2).

TABLE 2. Clump attributes of *Ochlandra setigera*

Year	Clump size (m)			Number of culms				
	Length	Breadth	Circumference	Total	First	Second	Third	Old
2011	1.63 ± 0.43	1.19± 0.32	4.28± 1.27	27.8± 1.9	7.3± 4.4	5.0± 3.8	4.6± 1.6	10.8± 4.4
2012	1.60±0.78	1.44± 0.37	4.63± 1.25	31.5± 14.1	16.9± 10.4	3.7± 2.7	3.3± 1.3	7.5± 4.1

The number of culms per clump of this species was higher compared to *O. wightii* (Jijeesh and Seethalakshmi, 2011). The average clump circumference was high in this species due to the higher number of culms compared to other Ochlandra species. The formation of new culms also was higher in number (on an average 30 and 40 respectively). Analysis of variance did not reveal any significant difference in clump attributes due to the year of formation as shownin figure 3 depicts the distribution of culms in different age classes of *O. setigera*.

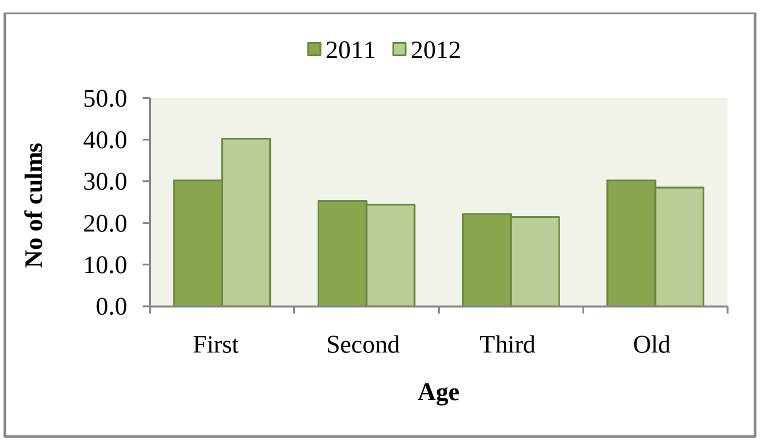

FIGURE 3. The distribution of culms in each age class of *Ochlandra setigera* during 2011 and 2012

With the increase in age, the number of newly recruited culms increased which was almost 7% higher during 2012. Correspondingly the number of old culms decreased in the clumps as age increased indicating the death of the culms. There was a reduction in the number of culms in the second and third-year classes also. Das and Chathurvedi (2006) had reported that the rate of production of new culms is linearly related to clump size and the higher culm recruitment in the present study might be due to the larger clump size. Studies on the population structure of *Schizostachyum dullooa* and *Dendrocalamus strictus* (Nath *et al*., 2006 and Jha and Das, 2008) also had exhibited preponderance younger age class which was in conformity with our results. On contrary, the stand age structure of *Yushania alpina* was heavily skewed towards older culms (Embaye *et al*., 2005). The present population structure did not follow the 3:3:3:1 pattern is suitable for culm production, which might be due to the disturbances by both man and animal and lack of scientific harvesting process in the protected forest area. Table 3 depicts the between clump variation in culm attributes of *O. setigera* during the study period.

TABLE 3. The changes in culm attributes of *Ochlandra setigera* during the study period.

Clump no	Year	Number of culms	Height(m)	GBH (cm)	No. of internodes	Internodal Length (cm)
1	2011	194	5.5±0.8	6.0±1.3	16.1±3.2	42.0±5.4
	2012	199	5.5±0.8	6.0±1.3	16.1±3.2	42.0±5.4
2	2011	121	6.0±0.5	7.1±1.5	18.0±2.2	41.2±3.8
	2012	124	6.0±0.5	7.1±1.5	18.0±2.2	41.2±3.8
3	2011	57	5.6±0.8	6.1±1.4	19.9±3.7	41.9±5.8
	2012	51	5.6±0.8	6.1±1.4	19.9±3.7	41.9±5.8
4	2011	170	4.0±0.5	4.7±0.9	15.0±2.1	38.8±5.8
	2012	175	4.0±0.5	4.7±0.9	15.0±2.1	38.8±5.8
5	2011	29	6.3±1.4	5.8±1.5	18.2±3.5	41.4±6.2
	2012	30	6.3±0.8	6.2±1.4	19.0±2.6	42.9±3.4
6	2011	140	7.4±0.8	7.0±1.4	21.1±2.7	39.6±4.6
	2012	180	7.4±0.8	7.0±1.4	21.1±2.7	39.6±4.6
7	2011	57	6.5±1.0	6.6±2.0	19.5±3.7	40.7±4.2
	2012	102	6.5±1.0	6.6±2.0	19.5±3.7	40.7±4.2
8	2011	57	6.8±0.9	7.0±1.2	21.6±3.9	40.7±4.0
	2012	80	6.8±0.9	7.0±1.2	21.6±3.9	40.7±4.0
9	2011	150	6.3±0.9	6.7±1.9	18.1±2.9	42.3±6.2
	2012	126	6.1±1.3	6.4±1.5	15.8±4.0	41.5±4.4
10	2011	8	6.5±1.0	7.3±2.0	18.8±3.3	44.6±5.0
	2012	10	6.4±1.0	7.2±1.9	18.5±3.4	44.6±4.9
11	2011	175	4.4±2.0	5.9±1.7	9.1±4.4	45.4±3.6
	2012	217	4.5±1.9	5.8±1.6	9.5±4.2	45.4±3.4
12	2011	74	6.7±1.0	6.9±1.6	19.1±3.1	36.9±3.5
	2012	81	6.2±1.2	6.4±1.8	18.2±3.4	36.6±3.7

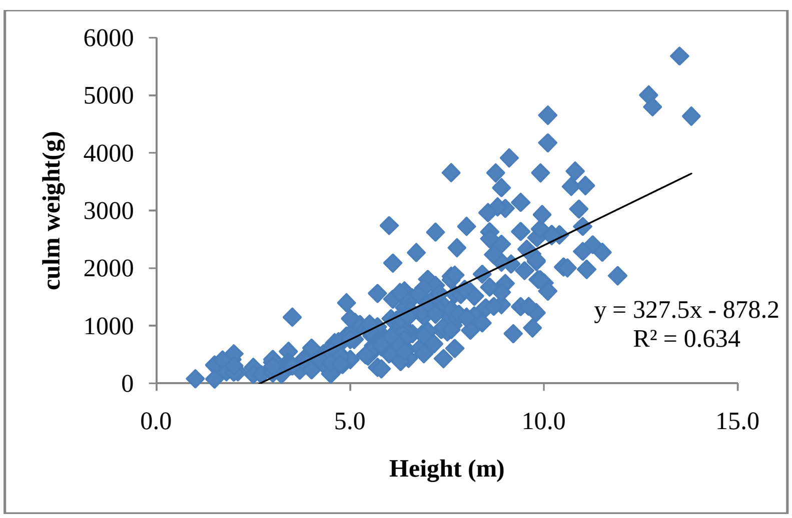

FIGURE 4. Relationships between height (X) and culm dry weight (Y) of *Ochlandra setigera*

Analysis of variance indicated that the between clumps variation was significant in culm height, girth, number of nodes and internodal length (p=0.01). The main effect of year of observation and interaction effect of time and clump were not significant for any of the culm attributes. The height of the culms ranged from 4.0±0.5 to 7.4±0.8 m, the GBH from 4.7±0.9 to 7.3±2.0 cm, no of internodes from 9.1±4.4 to 21.6±3.9 and the intermodal length from 36.9±3.5 to 45.4±3.6 cm. The average height, GBH, number of nodes and intermodal length of the culm used for destructive sampling were 6.82±2.55 m, 8.52±2.14 cm, 20.90±7.53 and 36.18±6.14 cm respectively and the average biomass of stem and leaf+ branch and the total of the culms were 1.07±0.82, 0.28±0.29 and 1.36±1.05 kg respectively. We tried to relate the culm height and GBH to culm dry weight. The regression equation connecting height and culm dry weight was y = 327.5x-878.2 with an R^2=0.634 and that with GBH and weight was y=342.7x-1566. R^2 = 0.487. The height of the culms emerged as the better predictor of culm dry weight than the GBH (Fig 4).

The moisture content of bamboo and its correction factor for different biomass components indicated that comparatively higher moisture content was observed in the middle part of culm followed by rhizome and roots (Table 4).

TABLE 4. The moisture content and correction factor of clump components in *Ochlandra setigera*

Clump components	Moisture content	Moisture correction factor
Leaves + branches	42.7±3.1[a]	0.57±0.03[a]
Rhizomes	49.7±4.1[a]	0.50±0.04[a]
Roots	49.7±1.3[a]	0.50±0.01[a]
Culm Top	44.1±8.5[a]	0.56±0.08[a]
Culm Middle	51.4±2.6[a]	0.49±0.03[a]
Culm Base	49.5±3.6[a]	0.51±0.04[a]

Values with same superscript with in a column are homogenous
The values given are mean and standard deviation

Analysis of variance did not reveal any significant differences in moisture content and the correction factor of different biomass components. The standing stock biomass of the individual clumps indicated that the total biomass of the clump was 117.5 ±48.4 kg of which the stem recorded the highest biomass of 78.4 ±20.5 kg followed by rhizome (34.8 ±22.7 kg), leaves+branches (17.8 ±8.8 kg) and root (2.2 ±1.3). The contribution of stem biomass to total biomass was almost 59 % and that of rhizome was 26% and the contribution of roots was 2% only. Per ha biomass production of bamboo species was calculated by multiplying with clump density (625 plants per ha). Total standing stock biomass of *O. setigera* was 73.4 ±30.3 tha^{-1} (Table 5). The distribution of biomass ha^{-1} in the components was stems (40.0 ±12.8), leaves + branches (6.5 ±1.1), rhizome (30.3±15.7) and root (1.4±0.8).

TABLE 5. Per clump biomass production, per hectare biomass production and carbon storage of *Ochlandra setigera*

Biomass production per clump of *Ochlandra setigera* (kg)					
	Stem	Leaves + branches	Rhizome	Root	Total
Sample 1	92.1	28.0	65.0	4.0	189.1
Sample 2	88.3	23.4	26.9	1.6	140.1
sample 3	54.8	11.0	24.5	2.0	92.3
Mean	78.4	17.8	34.8	2.2	117.5
SD	20.5	8.8	22.7	1.3	48.4
Per hectare biomass production of *Ochlandra setigera* (t ha^{-1})					
Sample 1	57.6	17.5	40.6	2.5	118.2
Sample 2	55.2	14.6	16.8	1.0	87.6
sample 3	34.2	6.9	15.3	1.3	57.7
Mean	40.0	11.1	21.7	1.4	73.4
SD	12.8	5.5	14.2	0.8	30.3
Per hectare carbon storage of *Ochlandra setigera* (tha^{-1})					
Sample 1	22.0	5.7	21.5	1.2	50.4
Sample 2	21.1	4.8	8.9	0.5	35.2
sample 3	13.1	2.2	8.1	0.6	24.0
Mean	15.3	3.6	11.5	0.7	30.7
SD	4.9	1.8	7.5	0.4	13.2

In most of the biomass studies, only the above ground components are taken into consideration. The above ground standing biomass of 46.6 t ha^{-1} of the natural stands of *O. setigera* was greater than the corresponding reported values of 28t ha^{-1} for *Dendrocalamopsis oldhami* (Yuming *et al*., 1998)*;* whereas it is lower than 110 t ha^{-1} for *Yushania alpina* (Embaye *et al*. 2005) and 286 t ha^{-1} for *B. bambos* (Shanmughavel and Francis 1996). *O. setigera* is a thin-walled reed bamboo species. Therefore, differences in the stand biomass of the present study with other bamboo species can be attributed to the differences in the culm size, culm height, culm density of the species studied and location. Nath *et al*. (2009) recorded an above ground stand biomass of 121.51 t ha^{-1} for a stand consisting of *Bambusa cacharensis*, *B. vulgaris* and *B. balcooa* which was also higher compared to the present study. The biomass accumulation in the present study was higher compared to the biomass production potential of seven species of bamboo viz. *Dendrocalamus strictus, Bamboosa bamboos, B. nutan, B. asper, B. bulgaris, B.*

tulda and *B. balcooa* in Allahabad district (Pathak *et al*., 2015). Devi *et al*. (2018) reported that the total above ground biomass of *Melocanna baccifera* was 106.68Mg/ha and *Bambusa tulda* was 97.00Mg/ha which were higher compared to present study. Carbon concentration (per cent of dry mass) of clump components of the bamboos is given in Fig 5.

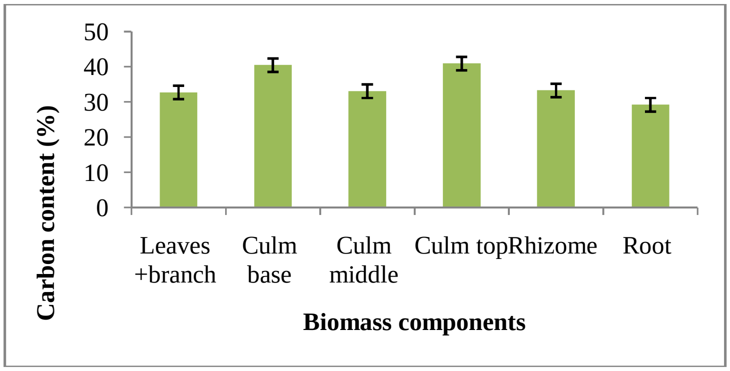

FIGURE 5. Carbon concentration (per cent of dry mass) of clump components of *Ochlandra setiger*

Culms and rhizome recorded higher carbon content. The carbon storage of natural stand of *O. setigera* was 30.7 ±13.2 t ha^{-1} [stem (15.3 ±4.9), leaves +branches (3.6 ±1.8), Rhizome (11.5 ±7.5) and root (0.7±0.4)]. Higher carbon storage was observed in above ground components than below ground (Table 5).

Soil carbon content and carbon stock of *O. setigera* at different depths are given in Table 6.

TABLE 6. Soil carbon content and carbon stock of *Ochlandra setigera* at different depths

Soil depth (cm)	Soil carbon (%)	Soil carbon stock (t ha^{-1})
0-20	2.470±0.185^{a}	63.232±4.728^{a}
20-40	1.248±0.179^{b}	31.949±4.575^{b}
40-60	0.873±0.185^{b}	22.357±4.728^{b}
Total	-	117.538±29.919

Values with same superscript with in a column are homogenous
The values given are mean and standard deviation

The soil C concentration and stock decreased with depth and the top two layers recorded more than 80 % of the total carbon stock. Analysis of variance revealed the significant difference in soil carbon concentration and stock at five per cent level. The carbon storage of natural stand of *O. setigera* was 30.7±13.2 t ha^{-1}. Nath & Das (2007) stated that the bamboo forms an imperative component of the agrosilvicultural system in North East India and substantially contribute for the C balance of the ecosystem through assimilating atmospheric CO_2. Report of Nath *et al*. (2008) on aboveground carbon sequestration potential of a bamboo stand consisting of *Bambusa balcooa, B. cacharensis*, and *B.vulgaris* to the tune of 21.36 t ha^{-1} was lower compared to our study. Estimates of aboveground C storage in the present study was lower than the C storage in the tropical rain forest that ranges from 136.67 to 202.35 t ha^{-1} and for seasonal forest from 63.33 to 156 t ha^{-1} (Bolin *et al*., 1986].

Below ground carbon sequestration is the most neglected part in biomass studies. Nath *et al*. [18] reported that the soil carbon stock of bamboo plantation up to 30 cm depth was 57.3 t ha^{-1} which was lower compared to top 0-20 cm layer in the present study. Carbon stored in the soil decreased with increase in depth and most of it is confined to the organic matter bound soil layer (0–40 cm). The soil carbon sequestration in the present study was comparable with those reported for tropical forests (123 Mg ha^{-1}) by Prentice *et al*. [Prentice *et al*. 2001). Hence, the soil carbon sequestration of the bamboo plantations needs special attention while calculating the carbon offsets.

CONCLUSION

The present study concludes that *Ochlandra setigera* is endowed with higher biomass production and carbon stocks, both in soil and plant. The total biomass production of *O. setigera* in the present study was 73.4±30.3 t ha^{-1}t ha^{-1} which was comparable to other bamboos but lower compared to natural forests. The total carbon storage including soil and plant in the present study (114.9 t ha^{-1}) can contribute to climate change mitigation as far as they are not burned and utlisation is limited to durable products.

RECOMMENDATIONS

From the present study it was obvious that O.setigera can contribute to global climate change mitigation. However, a natural population of this species is under threat and it has to be conserved with great priority.

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