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Biomass, carbon stock and sequestration potential of *Schizostachyum pergracile* bamboo forest of Manipur, north east India

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Abstract: We examined the biomass, carbon stock and the rate of carbon sequestration in the natural uneven *Schizostachyum pergracile* bamboo forest of Manipur situated along the Indo-Myanmar border, north east India. Allometric relationships were developed between harvested culms and diameter at breast height using a linear regression model to estimate aboveground biomass. Total biomass varied from 143.1 to 202.62 Mg ha^{-1} and annual productivity was 61.85 Mg ha^{-1}. Carbon stock in vegetation ranged from 64.65 to 91.48 Mg ha^{-1} and soil organic carbon was recorded to be 53.25 Mg ha^{-1}. The estimated rate of carbon sequestration was 26.96 Mg ha^{-1} yr^{-1}of which 82% was accounted by aboveground parts and 18% by belowground parts. The present bamboo forest exhibited high rate of carbon sequestration hence suitable for mass plantation in the degraded ecosystems in mitigation action against human induced climate change.

Key words: Aboveground biomass, allometric equation, carbon sequestration, carbon stock, regression model.

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Introduction

Carbon dioxide (CO_2) in the atmosphere has been increasing steadily from 280 ppm since preindustrial times to 396.80 ppm as recorded in February 2013 (Blunden & Arndt 2014). CO_2 is one of the greenhouse gases which trap the long wave radiation reflected from the earth leading to the warming of the Earth's atmosphere (the greenhouse effect) and influences the climate. Carbon management strategy in forests is one of the objectives of the United Nation on Convention on Climate Change (UNFCCC) and Kyoto Protocol at international level and National Action Plan on Climate Change in India to mitigate the climate change (NAPCC 2008). Therefore, there is an urgent need to estimate carbon stock and to enhance C sequestration in forest ecosystems and to emphasize the various strategies to mitigate climate change through management. Thus, plant species with a high CO_2 fixing capacity are of increasing interest worldwide (Zhou *et al.* 2011).

Bamboo can play a significant role in linking climate change mitigation to sustainable economic development in the developing countries. Mechanisms such as Reduced Emissions from Deforestation and Forest Degradation (REDD and REDD+), and Reducing Emission from all Land Uses (REALU) are evolving to alleviate climate change (Alexander *et al.* 2011). These mechanisms may enable countries to generate carbon credits to provide incentive for plantation of bamboo especially in degraded ecosystems and a wider range of lands having different types of soil. Bamboo has a higher potential relative to other forest species for fixing CO_2 from the atmosphere (Wang *et al.* 2009; Yen & Lee 2011; Zhou & Jiang 2004). The growth pattern of bamboos is different from woody plants in having fast growth, high production and rapid maturation from shoot to

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culm in 4–5 years (Scurlock *et al*. 2000).

Bamboo (distributed over 22 genera and 136 species) occupies 12.8% of total forest area of India (Bahadur & Verma 1980). The north east India is called the home of bamboo and the region has 5,480,100 km^2 of area under bamboo cover which is about 39% of the total forest cover of India (FSI 2011). Among the seven states of northeast India, Arunachal Pradesh has the largest bamboo area (16,083 km^2) followed by Manipur (9,303 km^2) and Assam with 7,238 km^2 (FSI 2011). Out of the 136 species of bamboo found in India, 89 species belonging to 16 genera grow naturally or cultivated in tropical and subtropical region of north east India (NMBA 2008) and 53 species are found in Manipur (Devi & Sharma 1993). Therefore, it is pertinent to investigate the role of bamboo in storage and sequestration of carbon dioxide from the atmosphere.

Following the "Kyoto Protocol", several studies have reported on the contribution of forests to the accumulation, storage and sequestration of carbon in different parts of the world (Devagiri *et al.* 2013; Hoover *et al.* 2012; Metzker *et al.* 2011; Ngo *et al.* 2013; Tang *et al.* 2012; Thokchom & Yadava 2013). Bamboo forests are receiving increasing attention due to their high potential for sequestering CO_2 from the atmosphere (Düking *et al.* 2011; Guichang *et al.* 2013; Isagi *et al.* 1997; Li *et al.*1998; Lou *et al*. 2010; Song *et al.* 2011; Wang *et al*. 2013; Xiao *et al*. 2007; Yen *et al*. 2010). In India, limited information is available on the carbon stock and sequestration in the bamboo forests (Das & Chaturvedi 2006; Tripathi & Singh 1996) and especially from north east India (Nath *et al*. 2009; Nath & Das 2012). Therefore, the present study has been undertaken to estimate carbon capture and storage in bamboo forest. The data generated may be useful in the national and global level carbon cycle as well as in computation of carbon credit and accounting. The main objectives of the present study were to (i) assess the carbon stock in aboveground, belowground biomass and soils and (ii) to estimate the rate of C-sequestration in the bamboo forest ecosystem of Manipur, northeast India.

Materials and methods

Study site

The study site of bamboo forest is located at $24^{0}18'12.5''$ N latitude and $94^{0}15'52.9''$ E longitude in Sibong Khuthengthabi at a distance of 105 km from Imphal city in Chandel district of Manipur, near Myanmar border at an altitude ranging from 478 m to 628 m above mean sea level (Fig. 1). It is a hilly terrain having a low altitudinal range where the bamboo species occurs naturally mixed with other species. This site is part of Indo-Burma Hot Spot of world's biodiversity (Myers *et al.* 2000). The bamboo forest site is dominated by *Schizostachyum pegracile* (Munra) Majumdar (syn. *Cephalostachyum pergracile)* and few trees of *Phoenix sylvestrix, Terminalia citrina, Castanopsis hystrix, Curcuma augustifolia* and *Smilax* sp. are also recorded from the site.

The climate of the area is monsoonic with a warm moist summer and a cool dry winter. Meteorological data of the last thirteen years (2000–2012) was collected from the Indian meteorological Department, Imphal Airport, Manipur. The mean maximum temperature varied

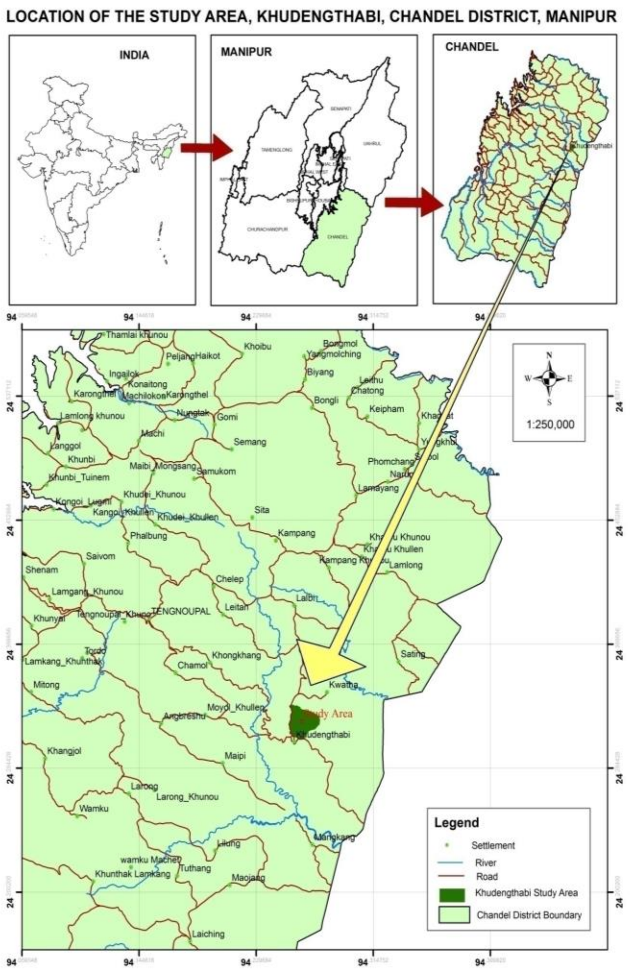

Fig. 1. Map of the study site.

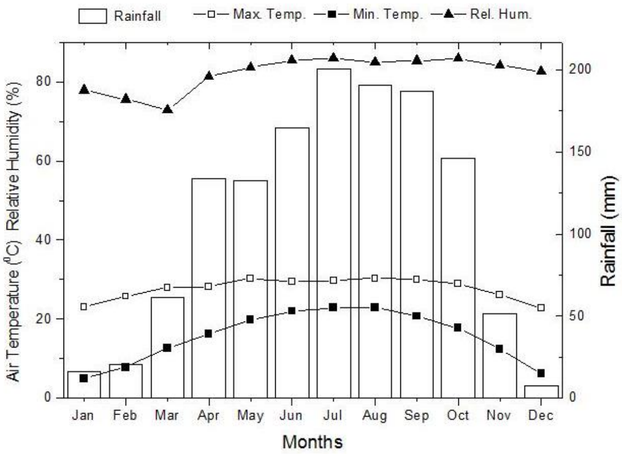

Fig. 2. Ombrothermic diagram based on meteorological data base on mean of thirteen year (2000–2012) collected from the Indian meteorological Department, Imphal Airport, Manipur.

from 22.5 °C (December) to 30 °C (May) and the mean minimum temperature ranged from 5°C (January) to 23 °C (August). The mean monthly rainfall ranged from 15.3 mm in December to 201 mm in June. Annual rainfall was 1168 mm. The average relative humidity of air varied between 73% in March to 86% in July (Fig. 2).

Soil sample analysis

Three replicates of soil samples were collected at random from each of the ten permanent plot at monthly intervals from November 2011 to October 2012 for the analysis of physico-chemical characteristics. The samples were collected from three different depths: 0–10 cm, 10–20 cm and 20–30 cm using a soil corer. The soil samples from each core were placed in a zipper plastic for different soil depths. Collected soil samples were divided in two parts: one part was air dried, crushed and passed through a 2 mm sieve (mineral soil), to remove stone, coarse roots, recognizable plant debris. These powdered soil samples were used for physic-chemical analysis; the second part was oven dried (24 hrs. at 105 °C) for estimating soil moisture by Gravimetric method.

Soil texture was determined by soil hydrometer (15zH5/ 60 gram per litre 68F Zeal Made in England). Soil pH was measured by a pH meter in 1.5 soil water suspension. Bulk density was determined by dividing the oven weight soil sample by its volume and soil moisture content was determined by gravimetric method (oven dry at 105 °C for 24 hrs.).

The soil organic carbon was estimated by Walkley Black Method (Anderson & Ingram 1993) and soil inorganic carbon (SIC) by TOC analyser (Model: multi N/C 2100, Analytikjena, Germany) Total soil nitrogen was measured by 2100 Kjeltec System and available soil phosphorus was determined by the acid-flouride extractant No.1 (Bray & Kurtz 1945) under acid soil condition.

Data Collection

Ten permanent plots (5 m × 5 m), were earmarked randomly within a 1 ha area at the study site. Bamboo clumps within the permanent plot and culms per clump were counted. Bamboo culms were categorized into five culm ages-Current year, 1year old, 2 years old, 3 years old and > 3 years old. Age was identified in the field based on the morphological character of culms (Embaye *et al.* 2005). Current year culms have hairy culm with sheath and no branches and leaves. One year old culms were identified by their dark green and smooth culm, fully covered with sheath and the whole culm was free from any spot by lichen and moss with full developed leaves and branches; 2 years old culms were distinguished by their light green culm with partially covered sheath; 3 years old culms were identified by pale green culm with no sheath and some little spot of moss and lichen and > 3 years old culms were identified by their yellowish culm with dry appearance and rough surface with lots of spot of lichens and mosses in nodes and internodes of culms. All culms were measured 10 cm above the ground for circumference and tallied into five different circumference classes were recognized: 6–9 cm, 9–12 cm, 12–15 cm, 15–18 cm and 18–21 cm. Three culms were harvested from each circumference class belonging to different age . A total of 75 culms were harvested and after harvesting, the samples were divided into leaf, branch and culm component and their fresh weight were taken in the field. A sub-sample of each component was oven dried at 70 °C to a constant weight to calculate dry matter. Culm, branch and leaf biomass were determined from their respective dry weight. Summation of all the biomass components yielded the aboveground standing crop of biomass.

Biomass estimation

Allometric equations were developed for leaf, branches and culm for different age classes using

Table 1. Constants (a), slopes (b), coefficients of determination (r^2) for allometric equation of the culm components in different culm age classes. Values in parentheses are Standard Errors.

Components	a	B	r^2	*P* - value
Culm				
Current	−2.99 (0.09)	1.83 (0.01)	0.97	<0.001
1-yr	−3.56 (0.11)	1.91 (0.02)	0.96	<0.001
2-yr	−3.26 (0.49)	1.84 (0.11)	0.95	<0.001
3-yr	−2.43 (0.20)	1.32 (0.05)	0.83	<0.001
>3yr	−1.88 (0.14)	1.22 (0.03)	0.94	<0.001
Branch				
Current	-	-	-	-
1-yr	0.29 (0.02)	1.01 (0.40)	0.95	<0.001
2-yr	0.11 (0.31)	0.12 (0.49)	0.90	<0.001
3-yr	−0.22 (0.10)	0.16 (0.05)	0.97	<0.001
>3yr	−0.22 (0.15)	0.15 (0.29)	0.94	<0.001
Leaf				
Current	-	-	-	-
1-yr	0.11 (0.35)	0.14 (0.55)	0.88	<0.001
2-yr	0.11 (0.35)	0.06 (0.53)	0.90	<0.001
3-yr	−0.26 (0.06)	0.15 (0.98)	0.98	<0.001
>3yr	−0.25 (0.08)	0.14 (0.21)	0.97	<0.001
Total				
Current	−2.99 (0.09)	1.83 (0.01)	0.97	<0.001
1-yr	−3.12 (0.11)	2.12 (0.02)	0.96	<0.001
2-yr	−3.09 (0.12)	1.95 (0.02)	0.95	<0.001
3-yr	−2.92 (0.17)	1.63 (0.04)	0.89	<0.001
>3yr	−2.34 (0.12)	1.51 (0.03)	0.96	<0.001

the data collected from the harvested culm to predict the biomass (Table 1). Regression linear model for leaf, branches and culm were developed to estimate the biomass of each component from culm diameter and was of the form:

$$Y = a + bx,$$

where Y is the component dry weight (g), x is the diameter at breast height (cm) and a and b are the regression co-efficients.

Belowground biomass was determined by direct excavation from each age group at 1 m^2 in area up to 40 cm soil depth. Age of rhizomes was determined from the colour of the rhizome sheath after the methods of Liao (1988), the penetration in the soil and number of appearance of rhizome bud was also determined. The rhizomes were washed to remove soil and other material and then oven dried at 70 °C to constant weight to calculate the dry matter.

Litter floor mass was studied by randomly laying 10 trays of 50 × 50 cm and collecting litter sample at monthly interval. Samples were thereafter sorted into leaf, sheath and branch and oven dry at 70 °C to estimate dry weight.

Net production was calculated using the following expression:

$B = (B_n - B_{n-1}) + H + L$, where B_n is the stand biomass for nth year, B_{n-1} is the stand biomass of the previous year, H is the biomass increment in culm component with increase in culm ages to its high age classes and L is the total litter production during the period (Thokchom & Yadava 2012).

Estimation of carbon stock

Sample of culm, branch, leaf, rhizome from different age class and different components of litter were oven dried and powdered and analysed for determination of carbon percentage. Carbon concentrations of different components were estimated through TOC analyser (Model: multi N/C 2100, Analytikjena, Germany). The carbon storage in the different components was determined by multiplying the biomass of different components (i.e. culm, leaf, branches or rhizome) with respective concentration of carbon. The total carbon storage in the bamboo forest was the summation of carbon stored in culm, leaf, branches and rhizomes. The soil organic carbon stock was estimated from the bulk density, organic carbon concentration the corresponding with soil depths.

C-Sequestration estimation

The C-sequestration was estimated with the equation given by Thokchom & Yadava (2012):

$$Cs = C_n - C_{n-1} + L$$

Where, C_n is the C-stock for nth year, C_{n-1} is the C-stock of the year preceding the nth year; L is the total litter production during the period.

Statistical analysis

Analysis of data and regression models were developed using statistical software STATISTICA, version 6.0 and Microsoft excel 2010. The culm density of 2011 and 2012 were analysed with repeated measures ANOVA with the year as the repeated measure variable. ANOVA shows significant difference between the aboveground biomass among the different culms of age class.

Results and Discussion

Soil properties

Soil of the study area is acidic and clay loam in texture and dark yellowish brown in colour. The

Table 2. Culm density in different age class of the bamboo forest during the study period.

Age class	Culm density (culm ha^{-1}) 2011	2012
Current	2240 ± 298.07	2500 ± 70.24
1-yr	1920 ± 38.58	2195 ± 110.05
2-yr	1600 ± 76.53	1970 ± 23.42
3-yr	1480 ± 44.96	1670 ± 85.69
>3yr	0	1425 ± 121.82
Total	7240 ± 341.56	9760 ± 423.35

soil pH ranged from 5.5 to 6.4 and the bulk density from 1.19 g cm^{-3} to 1.27 g cm^{-3}, whereas soil moisture varied from 16 to 34% and temperature from 15.5 to 29.8 °C during the study year. The soil organic C ranged from 1.38 to 1.52%, in-organic C ranged from 0.42 to 0.46%, soil total N varied from 0.24 to 0.28% and available P ranged from 0.075 to 0.077% throughout the year.

Culm density, biomass and productivity of bamboo forest

The culm density of the stand was 7240 ± 78 culm ha^{-1} and in the next year, after recruitment of new culms, density increased to 9760 ± 83 culm ha^{-1}. Highest density was recorded in 12–15 cm circumference class and then decreases in subsequence circumference classes (Fig. 3). Current and 1 year old culm exhibited higher culm density and then the density decreased (Table 2).

Total aboveground biomass increased from 116.6 Mg ha^{-1} in 2011 to 165.5 Mg ha^{-1} in 2012 (Table 3).

The proportion of leaf, branch, rhizome and culm to the total biomass were 6%, 7%, 18% and 69%, respectively. An ANOVA indicated a significant difference between the aboveground biomass among the different ages of the culm (df = 29; F = 6.67; $P < 0.05$). Out of the total above-ground biomass, 50% of culm biomass was accumulated mainly in current year and1 year old culms and thereafter it decreased with age. This shows that maximum stand biomass was contributed by the younger culms. Similar trend was also reported in mixed village bamboo groove in Assam (Nath *et al.* 2008).

The aboveground biomass data of the present study are comparable with that reported for other bamboo species (Isagi *et al.* 1993; Li *et al.* 1998; Nath *et al.* 2009; Veblen *et al.* 1980; Wang *et al.* 2013; Yen *et al.* 2010). However, it is lower than the data reported by Kumar *et al.* (2005) in *Bambusa bambos* but greater than the data reported by Othman (1994) in *Gigantochloa scortechinii* and by Taylor & Zisheng (1987) in *Fargesia spathecea.* The study shows that aboveground biomass depends upon size, age and density of culms in the different bamboo forests.

The belowground biomass of the bamboo forest was 26.7 Mg ha^{-1} in 2011 and then increased to 37.1 Mg ha^{-1} in 2012 (Table 3). Belowground biomass increased with the increment of culm ages in the forest site. These results indicate that at the early stages of growth, the plant depends completely upon the leaf area to build the carbon chains and metabolites which allow the growth of each organ (Düking *et al.* 2011). However, the

Table 3. Estimated aboveground and belowground biomass in the bamboo forest site during study period (Mg ha^{-1}).

Age class	Aboveground components: Leaf	Branch	Culm	Productivity: Aboveground	Belowground	Total
2011						
Current	-	-	31.89 ± 2.98	31.89 ± 0.10	4.48 ± 0.36	36.37 ± 0.12
1-yr	3.45 ± 0.54	3.79 ± 0.49	28.12 ± 1.38	35.36 ± 0.14	5.94 ± 1.05	41.31 ± 0.34
2-yr	2.57 ± 0.07	3.20 ± 0.23	22.74 ± 1.98	28.51 ± 0.36	7.54 ± 0.49	36.05 ± 0.12
3-yr	1.88 ± 0.18	2.36 ± 0.08	16.60 ± 3.39	20.84 ± 0.36	8.54 ± 0.15	29.37 ± 0.23
Total	7.90 ± 0.79	9.35 ± 0.63	99.35 ± 1.00	116.6 ± 0.38	26.70 ± 1.76	143.10 ± 0.19
2012						
Current	-	-	33.08 ± 2.16	33.08 ± 0.02	4.87 ± 0.06	37.95 ± 0.35
1-yr	4.20 ± 0.32	4.64 ± 0.29	36.53 ± 2.71	45.37 ± 0.10	5.89 ± 0.03	51.26 ± 0.28
2-yr	3.17 ± 0.07	4.01 ± 0.25	30.76 ± 1.98	37.94 ± 0.20	8.06 ± 0.27	46 ± 0.14
3-yr	2.53 ± 0.55	2.75 ± 0.65	22.34 ± 1.15	27.62 ± 0.35	8.66 ± 0.27	36.28 ± 0.11
>3yr	1.65 ± 0.17	2.09 ± 0.24	17.77 ± 2.33	21.51 ± 0.42	9.62 ± 0.86	31.13 ± 0.22
Total	11.55 ± 0.6	13.49 ± 1.4	140.48 ± 6.32	165.52 ± 0.	37.1 ± 1.99	202.62 ± 0.37

distribution of these assimilates are more efficient with increase of age because the morphological characteristics of the rhizome system guarantee a better supply of assimilates from mature culms to the new shoots and young culms (Riaño *et al.* 2002). In the present study belowground parts contributed 21.62% of the total biomass which is similar to the data reported for belowground in *Guadua angustifolia,* Colombia (Riaño *et al.* 2002). The data of belowground biomass found in the present study were comparable with those reported by Embaye *et al.* (2005) in highland bamboo forest (25.6 Mg ha^{-1}), south east Ethiopia and those reported for *Phyllostachys bambusoides* in Japan (32.6 Mg ha^{-1}) by Isagi *et al.* (1993) but higher than those reported by Shanmughavel & Franchis (2002) in *Bambusa bambos* plantation, Kerela, India (0.938 Mg ha^{-1} to 11.220 Mg ha^{-1}) and by Tripathi and Singh (1996) in *Dendrocalamus strictus* plantation, in Uttar Pradesh, India (11.9 Mg ha^{-1} to 18.8 Mg ha^{-1}). These studies show that natural bamboo forest exhibited higher belowground biomass because of remnant belowground biomass from preceding years.

The total annual net production of the stand was 61.85 Mg ha^{-1}. Allocation of stand productivity revealed that 72.72% of the total production was contributed by new recruitment through changes of culm ages to its higher age classes followed by 10.50% through litter production and 16.78% by belowground production in the study site (Table 4). The total net annual productivity was three times higher than the one reported by Isagi (1994) on *Phyllostachys bambusoides* bamboo (15.7 Mg ha^{-1}) and Tripathi & Singh (1996) in *Dendrocalamus strictus* plantation (15.8 Mg ha^{-1} to 19.3 Mg ha^{-1}). However, the productivity of the present bamboo forest is attributed to stand population structure producing more preponderant new culms with superior height and diameter. Thus, it shows that high rate of aboveground net production in bamboo forest has resulted from favourable environmental conditions having long wet period as well as high rainfall in the region suitable for its growth.

The biomass accumulation ratio has been taken into consideration to assess the production condition in forest ecosystem. The biomass accumulation ratio (biomass/ net production) was 2.7. Thus, it shows that there is a high rate of net production and relatively smaller biomass in the present bamboo forest. The data on biomass accumulation ratio was comparable with the data reported by Tripathi and Singh (1996) in bamboo and savanna (2.4–2.6) but less than that reported by Singh & Yadava (1994) on secondary oak forest (7.7 to 8.9) in Manipur and P*hyllostachys bambusoides* (4.66) reported by Isagi (1994) in Japan. Low value of biomass accumulation ratio in the present bamboo forest reflects greater production efficiency.

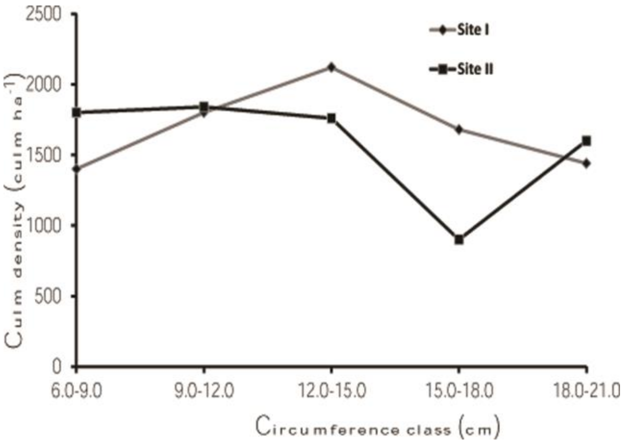

Fig. 3. The culm density in different circumference classes of *Schizostachyum pergracile.*

C storage in the bamboo

The carbon concentration was highest in culms (48.33 ± 0.07%), followed by rhizomes (47.52 ± 0.03%), branches (47.32 ± 0.05%) and leaves (44.37 ± 0.15%). In the litter, maximum value was recorded from branches (44.82 ± 0.02%), sheath (43.97 ± 0.01%) and minimum from leaves (43.25 ± 0.04%). The aboveground carbon stock ranged from 51.95 to 73.86 Mg ha^{-1} and C stock in below ground biomass from 12.70 to 17.62 Mg ha^{-1} (Table 5). C-storage in litter biomass (2.85 Mg ha^{-1}) also plays an important role in C-sequestration in soil and increased the soil fertility.

Table 4. Total annual net productivity of the bamboo study site (Mg ha^{-1} yr^{-1}).

Biomass production from different component			Productivity		
New culm recruitment	Culm age changes	Litter Production	Aboveground	Belowground	Total
32.985 ± 2.01	11.995 ± 1.51	6.495 ± 0.11	51.475 ± 0.62	10.375 ± 0.21	61.85 ± 0.82

Soil organic carbon (SOC) stock was between 15.56 ± 0.11 Mg ha^{-1} (20–30 cm soil depth) and 20.32 ± 0.19 Mg ha^{-1} (0–10 cm soil depth). Soil organic carbon stock decreased with increases in soil depth. The high value of carbon stock in the upper layer may be due to high rate of litter production and faster decomposition of litter. The present data on soil organic carbon stock in the soil of bamboo forest were similar with the findings reported by Nath *et al.* (2009) on village bamboo groove (57.3 Mg ha^{-1}), Assam and Tripathi & Singh (1996) on *Dendrocalamus strictus* (53.3 Mg ha^{-1}) in Uttar Pradesh, India and Zhou & Jiang (2004) on *Phyllostachys pubescens* (59.3 Mg ha^{-1}) but two times lower than the one reported by Isagi (1994) on *Phyllostachys bambusoides* (92.0 Mg ha^{-1}) in Japan.

The total carbon storage in plant-soil system in bamboo stand was 134.14 Mg ha^{-1} of which the vegetation stored 80 Mg ha^{-1} accounting for 60% and soil (0 to 30 cm in depth) stored 53 Mg ha^{-1} accounting 40% of the total carbon storage (Table 6). Tripathi and Singh (1996) also suggested that carbon stock in *Dendrocalamus strictus* bamboo stand in the Indian dry tropic was 75.4 Mg ha^{-1}, of which 23–28% was contributed by vegetation 2 % litter and 71–75% by soil upto the depth of 60 cm which is contradictory to our study. The total carbon storage in the present bamboo stand was 1.8 times the value of *Dendrocalamus strictus* (Tripathi & Singh 1996) and 1.3 times the value of *Phyllostachys pubescens* (Zhou & Jiang 2004). Thus high annual rate of carbon accumulation means the present bamboo forest is one of the most efficient types for carbon fixation.

Rate of carbon sequestration in aboveground and belowground biomass

The rate of carbon sequestration in aboveground biomass was 22.03 Mg ha^{-1} yr^{-1} out of this 99% was contributed by new culms and carbon production through culm age increment and 1% by annual litter production. The rate of C-sequestration in aboveground components was of the order culm > branch > leaf in the study site. In bamboo, the C-sequestration potential is determined by the new culms produced annually so the high rate of carbon sequestration in culm may be attributed to the fast development of new culms. Liese (2009) also reported that in bamboo growth of the leafless new culm originate from its own on-going photosynthesis but from the reserved material produced during previous year and stored in rhizome system and older culm. Our data on rate of C-sequestration (22.03 Mg ha^{-1} yr^{-1}) were comparable with the data reported by Das & Chaturvedi (2006) for *Bambusa bambos* (20.5 Mg ha^{-1} yr^{-1}) and in village bamboo Groove (18.93–23.55 Mg ha^{-1} yr^{-1}), Assam by Nath *et al.* (2008) but greater than that reported Yen & Lee (2011) for *Phyllostachys heterocycle* (8.13 Mg ha^{-1} yr^{-1}), China. Greater C-sequestration ability can be attributed to higher net productivity of *Schizostachyum pergracile* the stand that resulted from high culm density and better management practices such as harvesting of old culms to maintain the vigour of bamboo forest.

Table 5. Carbon stock in the different components of the bamboo forest site during the study period (2011–2012) (Mg ha^{-1}).

Components	2011	2012
Leaf	3.50 ± 0.35	5.12 ± 0.28
Branch	4.43 ± 0.31	6.40 ± 0.68
Culm	44.02 ± 5.02	62.34 ± 5.44
Total (AG)	51.95 ± 5.68	73.86 ± 6.41
BG (Rhizome + Root)	12.70 ± 0.85	17.62 ± 0.93
Total (AG+BG)	64.65 ± 6.54	91.48 ± 7.35

AG = Aboveground ; BG = Belowground

Table 6. Distribution pattern of carbon in plant/soil system at mean standing state (% of the total).

Components	C-Stock (Mg ha^{-1})	Proportion (%) of the total
Aboveground biomass	62.90 ± 6.05	46.9
Belowground biomass	15.14 ± 0.86	11.3
Litter	2.85 ± 0.04	2.1
SOC		
0-10 cm	20.32 ± 0.19	
10 to 20 cm	17.37 ± 0.18	
20 to 30 cm	15.56 ± 0.11	
Total	53.25 ± 0.16	39.7
Total	134.14	

SOC = Soil Organic Carbon

Carbon sequestration in belowground biomass was estimated to be 4.93 Mg ha^{-1} yr^{-1}. The rate of carbon sequestration in belowground biomass was very low in comparison to C-sequestration in aboveground component which is obvious as bamboo is a fast growing species with high productive potential. However, there are hardly any reports on C-sequestration in belowground biomass in bamboo forest as the measurement of root/rhizome biomass is very difficult task. Thus, we conclude that the aboveground components in the present bamboo forest play an important role in sequestering more carbon than that of belowground parts.

Annual carbon sequestration was found to be 26.96 Mg ha^{-1} yr^{-1}. Thus present bamboo forest dominated by *Schizostachyum pergracile* has high potential in sequestering CO_2 from the atmosphere being a fast growing species. Therefore, it is recommended for plantation in the degraded and abandoned shifting cultivation areas in the North east India which could account for high carbon accounting and credit in mitigating climate change.

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