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Biomass and carbon stock in bamboo forest of Manipur, North East India.

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Abstract: Aboveground biomass and carbon stock have been determined in the *Schizostachyum pergracile* bamboo forest located at 24°18'12.5"N latitude and 94°15'52.9"E longitude in Chandel District of Manipur near Myanmar border. Allometric relationships were developed between harvested culms and diameter at breast height (DBH) using a linear regression model for the estimation of aboveground biomass. Aboveground stand biomass varied from 101.06 to 144.74 Mg ha^{-1} during 2011-2012. Carbon stock ranged from 47.93 to 69.32 Mg ha^{-1} and the rate of carbon sequestration was 22.05 Mg ha^{-1} yr^{-1} and mainly contributed by culms (84%) followed by branches (9%) and leaves (7%).However carbon stock attained maximum value in current and one year old forest stand and decreases in subsequent years. Thus thinning of bamboo stand is recommended after 4-5 years to enhance carbon sink in the present bamboo forest.

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

INTRODUCTION

Bamboo is distributed mostly in Asia especially in the tropics and subtropics. Asia has more than 1.8×10^7 ha of bamboo, which is over 80% of the world's total(Yen *et al.*, 2010).In India bamboo occupies 12.8% (Bahadur & Verma, 1980) of the total forest area of the country comprising 22 genera and 136 species of bamboo (Sharma,1980). The North East India is recognised as one of the largest reserves of bamboo in India. Out of 136 species of bamboo in India, 89 bamboo species belonging to 16 genera grow naturally or cultivated in tropical and subtropical region of North East India (NMBA, 2008) and 53 bamboo species are reported from Manipur.

Bamboos play an important role in countries plagued by erosion, interlocking bamboo rhizome and limit landslides, conserve soil moisture and protect the area from draught. Among the industrial uses bamboo are the most important raw material for pulp, paper board and rayon industry. Hence bamboo resources in their natural habitat are

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dwindling due to over exploitation, gregarious flowering, shifting cultivation practices and extensive forest fire.

Carbon sequestration is an important part of an overall carbon management strategy to help in reduction and to mitigate global CO_2 emission. The United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol has international agreement on incorporation of forestry activities to this major environmental challenge. The United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol has international agreement on incorporation of forestry activities to this major environmental challenge. Recently IPCC has also emphasized in understanding the role of forests in carbon capture and storage under anthropogenic change.

Bamboo forests represent a major reservoir of terrestrial carbon and system with a potential to ameliorate the rate of increases in atmospheric CO_2 concentration as it can accumulate a large biomass in a short period implicating a high potential for carbon storage(Veblen *et al*., 1980; Shanmughavel & Francis, 1996; Isagi *et al*., 1997; Chen *et al*., 2009; Nath *et al*., 2008, 2009; Yen *et al*., 2010) . Recently bamboo forests have been receiving greater attention owing to high productive potential in sequestering CO_2 from the atmosphere in different part of the world(Liese 2009; Lou *et al.,* 2010; Duking *et al.,* 2011; Zhou *et al.,* 2011; Nath & Das, 2011; Yen *et al.,* 2010; Yen & Lee, 2011; Song *et al.,* 2011; Wang *et al.,* 2013).

However studies on biomass and carbon stock in bamboo forest in India are very scarce (Tripathi and Singh, 1994; Chandrashekara, 1996; Singh and Singh, 1999; Das and Chaturvedi, 2006; Nath *et al*., 2008) and no information is available in the carbon stock and rate of carbon sequestration in bamboo forest of Manipur which constitute 21.57% of the total forest cover of the stock(FSI, 2011). In the present study we examined the role of natural bamboo forest dominated by *Schizostachyum pergracile* in storage and sequestration of CO_2 from the atmosphere and future emission prospects in the light of International agreement on climate change.

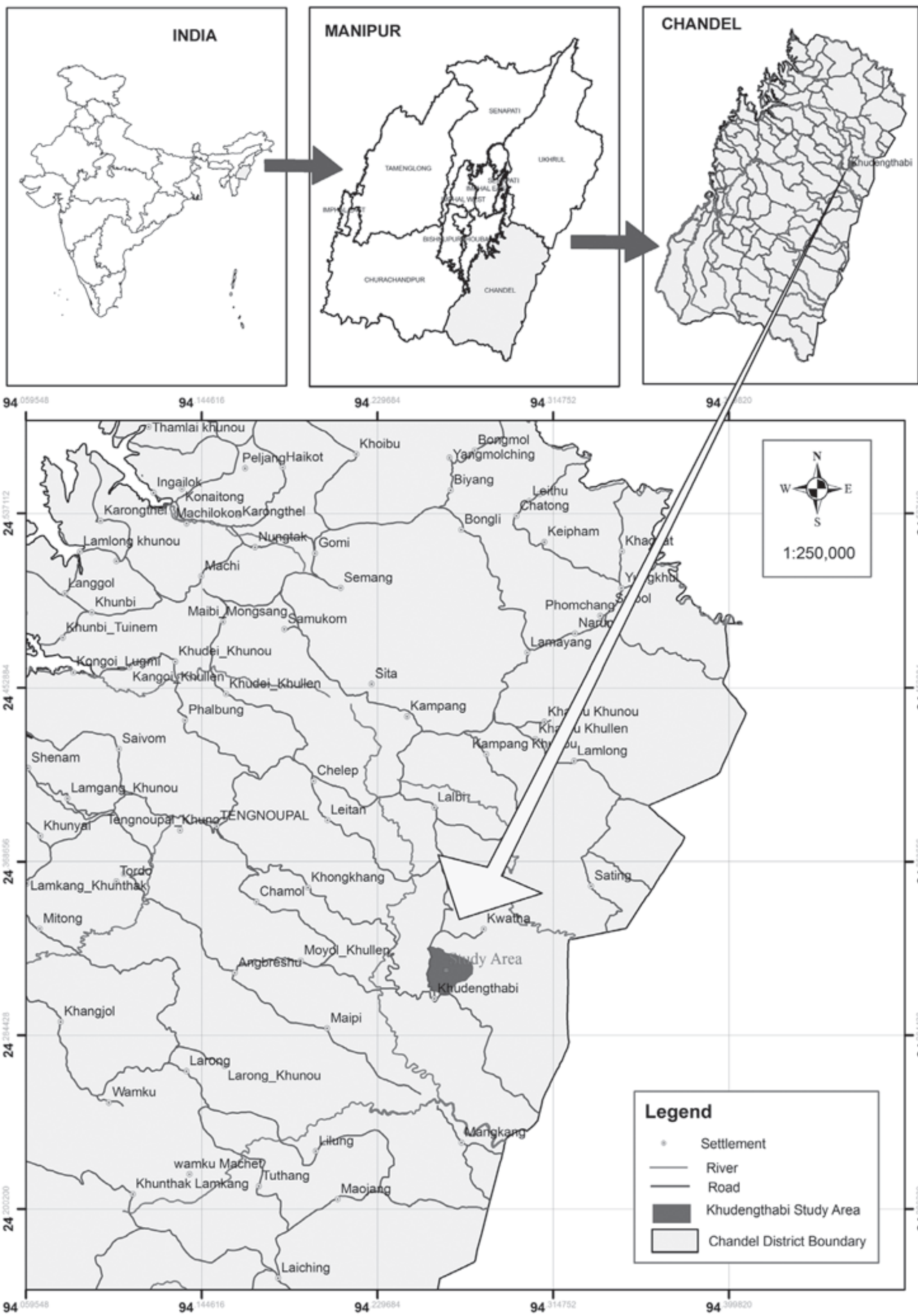
MATERIALS AND METHODS

Material

Schizostachyum pergracile (Munro) Majumdar synonymous of *Cephalostachym pergracile* Munro was originated from Southern Thailand and widely distributed in Nepal, Northern Thailand and Yunan province, China and most common in well drained loamy soil of Myanmar. In India it widely grows naturally and cultivated mainly in North East India, Orissa, Madhya Pradesh and Andhra Pradesh (FAO, 2005). It is a medium-sized densely growing bamboo up to 10-30m tall with culms having thin walled and numerous branches emerging from higher nodes. This species was listed among the 20 priority bamboo species for international action for utilisation,

Figure 1

LOCATION OF THE STUDY AREA, KHUDENGTHABI, CHANDEL DISTRICT, MANIPUR



cultivation, product and processing, germplasm and genetic resources and agro ecology (Rao *et al*., 2008).

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 with an altitude of 542m above MSL at Sibong Khuthengthabi, 105 km from Imphal city in Chandel District of Manipur near Myanmar border (Fig. 1). Climate of the area is monsoonal with warm moist summer and cool dry winter with an annual rainfall of 1334mm. The mean maximum temperature varied from 23.27^0C (January) to 31.40^0C (May) and the mean minimum temperature ranges from 5.09^0C (January) to 22.79^0C (August). The soil is laterite, well drained, clay loam texture (sand 29.74%, clay 37.17% and silt 23.09%) and acidic in nature.

Data collection

Five experimental plots of 5m×5m size were earmarked randomly in the study sites in the bamboo forests. Biomass was determined by harvesting randomly selected culms of different diameter of different ages. Depending on culm diameter five different diameter classes: 6-9 cm, 9-12 cm, 12-15 cm, 15-18 cm and 18-21 cm were recognised representing the whole diameter range and from each diameter class 3 culms were harvested for all the five age classes. After harvesting culm samples were divided into leaf, branch and culm component and their respective fresh weight were taken in the field. A sub sample of each component was oven dried at 70^0C to a constant weight to calculate the dry matter of each component. Culm, branch and leaf biomass were determined from their respective dry weight to fresh weight ratio. Summation of all the biomass components yielded the aboveground standing biomass. DBH of all the individual culms were measured at the breast height of 1.37m above the ground and group into five age classes – Current year,1 year, 2 year, 3year and >3year. Age was identified in field based on the morphological characters of culms (Embaye *et al*., 2005). Current year have hairy culm with no branches and leaves. 1 year old culms were identified by their dark green and smooth culm, fully covered with sheath and the whole culm is free from any spot by lichen and moss with full developed leaves and branches and 2 year old culms were distinguished by their light green culm with partially covered sheath.3 year old culms were identified by pale green culm with no sheath and some little spot of moss and lichen and >3 year 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.

Biomass estimation

Culm, branch and leaf biomass were determined from their respective dry weight to fresh weight ratio and regression model were developed for different culm components and diameter at breast height for all the different culm age classes.

Litter floor mass

Litter floor mass was studied by randomly laying 50cm × 50cm and collected litter sample at monthly interval and thereafter sorted into leaf, sheath and branch component and oven dry at 70^0C to estimate the oven dry weight.

Carbon concentration

Sub sample of culm, branch and leaf from different age class and different component of litter were powdered and analysed for determination of carbon content. A total of 50% of ash free was calculated as the carbon (C) content (Allen, 1989). The ash content was determined by igniting 1gm of powdered sample at 550^0C for 6 hr in a muffle furnace (Allen, 1989). The carbon storage in the different culm components was determined by multiplying the biomass with the carbon concentration. The total carbon storage in the aboveground standing biomass was determined by summing the C-content values for leaf, branches and culm component.

Net production

Allometric equations used for quantification of stand biomass were used to calculate the stand productivity. During the study period current, 1, 2, 3 years old culm of each year were converted into 1, 2, 3 and >3 years old culm age respectively in the next year. The new culms that recruited during June and July and after the completion of height growth were marked in November and treated as current year culms of that year. Conversion of different culm ages to its next higher age classes were characterised by accumulation of dry matter. The net biomass accumulation for the period 2011(B1) to 2012 (B2) was calculated by “B=B2-B1”. The equation for the production estimation is:

$$B = (B_n - B_{n-1}) + H + L,$$

where B_n is the stand biomass for n^{th} year, B_{n-1} is the stand biomass of the previous year of n^{th} year, H is the biomass increment in culm components with increase in culm ages to its high age classes and L is the total litter production during the period.

C-sequestration

The C-sequestration for the period 2011(C1)-2012(C2) was calculated as “C =C2-C1”. The equation for C-sequestration

$$C_s = C_n - C_{n-1} + L,$$

where C_n is the C stock for n^{th} year, C_{n-1} is the C stock of the year proceeding the n^{th} year, L is the total litter production during the period.

RESULT AND DISCUSSION

The culms density of the stand were recorded to be 7120 culms ha^{-1} in 2011 thereafter increased to 9680 culms per ha^{-1} in 2012. Culm population were represented by four culm ages in 2011 and by five culm ages in 2012. Current year together with 1 year culms represent 50-58% of the total stand and then gradually declined successive age classes (Table 1).

Table 1. Culm population density and estimated total aboveground biomass of different culm ages during the study period (2011 and 2012) in the bamboo forest of Manipur, North-East India.

Parameter	Study period	Current year	Culm age (year) 1-yr	2-yr	3-yr	>3 yr	Total
Culm population density (No. of culms ha^{-1})	2011	2240	1920	1520	1440	-	7120
	2012	2560	2240	1920	1520	1440	9680
Total aboveground biomass (Mg ha^{-1})	2011	29.78	27.15	24.14	19.99	-	101.06
	2012	31.56	38.44	32.18	23.15	19.47	144.74

Allometric equation were developed for leaf, branches and culm for different age classes using the data collected from the harvested culm. Regression linear model for leaf, branches and culm were developed to describe the relationship between culm biomass and DBH was of the form

$$Y = a + b X,$$

where Y is the component dry weight (g), X is the diameter at breast height (cm) and a and b are the regression co-efficient. Allometric equations describing culm DBH and dry weight of different culm components at different culm age classes using regression linear model are present in Table 2.

The total aboveground standing biomass of the bamboo forest were 101.06 Mg ha^{-1} for 2011 and 144.74 Mg ha^{-1} for 2012 to which culm, branch and leaf parts contributed 84%, 9% and 7% respectively (Table1). This finding indicates that culms contributed high percentage of biomass to the total aboveground biomass of the stand. 50 percent of the culm biomass was accumulated mainly in the current year together with the one year and then thereafter it decreased with the increase of age of culms indicating maximum stand biomass is contributed by the younger culm age . The biomass was higher in 2012 in comparison for 2011 due to selective cutting every year resulting in recruitment of new culms ranging. However it is important to emphasize that the bamboo forest in our present study are under management and in order to maintain

Table 2. Regression of the culm components in different culm age classess.

Components	a	b	R^2	Standard Error	p-value
Leaf					
Current	-	-	-	-	-
1-yr	0.036	0.040	0.947	1.060	<0.001
2-yr	0.018	0.036	0.920	1.330	<0.001
3-yr	-0.281	0.050	0.985	0.544	<0.001
>3yr	-0.276	0.047	0.984	0.847	<0.001
Branch					
Current	-	-	-	-	-
1-yr	0.282	0.031	0.985	0.555	<0.001
2-yr	0.086	0.036	0.939	1.159	<0.001
3-yr	-0.260	0.055	0.967	0.825	<0.001
>3yr	-0.260	0.052	0.968	0.847	<0.001
Culm					
Current	-3.108	0.581	0.966	0.850	<0.001
1-yr	-3.548	0.592	0.953	0.996	<0.001
2-yr	-2.934	0.511	0.937	1.179	<0.001
3-yr	-2.583	0.443	0.883	1.560	<0.001
>3yr	-2.583	0.380	0.954	1.011	<0.001
Total above ground					
Current	-3.108	0.581	0.966	0.850	<0.001
1-yr	-3.228	0.663	0.967	0.839	<0.001
2-yr	-2.829	0.584	0.961	0.924	<0.001
3-yr	-3.128	0.549	0.920	1.292	<0.001
>3yr	-2.255	0.480	0.964	0.890	<0.001

the vigour of bamboo forests one-fifth of older culms are removed by selective cutting every year to improve recruitment of new culms. It was also advocated by Yen *et al.* (2010) while studying *Phyllostachys makinoi* bamboo forest in China. Current year and 1 year old culms have higher culm density which subsequently resulted in an increased biomass and carbon stock in the bamboo forest. Higher number of culms increased the total leaf area implying greater capture of solar radiation and hence more photosynthetic production leading to increase in stand biomass. From the present study it is possible to conclude that the biomass in current and 1-yr culms is comparatively faster than that in older culms. The rapid increment in biomass in current and 1-yr old culms could be due to increase in girth and height of culms. On the other hand, continued but slow increment in biomass in older culms could be due to allocation of biomass for culm wall thickness (Chen *et al.*, 2009; Yen *et al.*, 2011).

Table 3. Aboveground net production of the bamboo forest, Chandel, Manipur (Mg ha^{-1})

Study period	Biomass production from different component			Total production (Mg ha^{-1})
	New culm recruitment	Culm age changes	Litter production	
2011-2012	31.56	13.13	6.42	51.11

Annual aboveground production of the stand was recorded to be 51.11 Mg ha^{-1} (Table 3). Allocation of stand productivity revealed that 31.56 Mg ha^{-1} of the total production was contributed by new culm recruitment followed by 13.13 Mg ha^{-1} of biomass accumulation through changes of culm ages to its higher age classes and 6.42 Mg ha^{-1} through litter production. Out of the total litter production leaf litter contributed 45%, sheath 31% and branch 24% .

Aboveground annual net production of the bamboo stand is higher than the values reported for *Phyllostachys pubescens*, Japan (24.6 Mg $ha^{-1}yr^{-1}$; Isagi *et al.,* 2003), *Dendrocalamus strictus*, Singrauli, U.P., India (24.7 Mg $ha^{-1}yr^{-1}$;Singh & Singh, 1999), Village bamboo grove, Assam (42.5 Mg $ha^{-1}yr^{-1}$; Nath *et al.,* 2008). Greater productivity of the present bamboo stand can be attributed to stand population structure producing more preponderant new culms with superior height and diameter. Similar observation has been reported while working on the home garden bamboo stand in Assam.

The mean carbon concentration in the different components of culm was in the order of culm (48.28%) > branch (47.28%) > leaf (44.26%). No significant difference in carbon percentage was observed in relation to the age of culm. Concentration of carbon in the litter components was highest in branch (44.81%) followed by sheath (43.96%) and leaf (43.21%).

Carbon stock in the aboveground biomass was recorded to be 47.35 Mg ha^{-1} in 2011 and 69.32 Mg ha^{-1} in 2012. Allocation of carbon was more in the culm component (84%) than in the branch (9%) and leaf (7%) as shown in Table 4. The data of our study are comparable with reported data of the aboveground biomass and carbon stock of *Phyllostachys pubescens* (90.2-135.8 $Mgha^{-1}$; Isagi *et al.,* 2003, 52.3 $Mgha^{-1}$; Isagi, 1994), *Bambusa oldhamii* (103.97 $Mgha^{-1}$ and 51.93 $Mgha^{-1}$; Mendoza *et al.,* 2004), *Phyllostachys makinoi* (105.33 $Mgha^{-1}$ and 49.81 $Mgha^{-1}$; Yen *et al.,* 2010), *Phyllostachys pubescens* (96.54-105.76 $Mgha^{-1}$ and 48.27-52.88 $Mgha^{-1}$; Wang *et al.,* 2013).

The rate of carbon sequestration was recorded to be 21.68 Mg $ha^{-1}yr^{-1}$ bamboo aboveground biomass which 99% was contributed by new culms and carbon production through culm age increment and 1% by annual litter production (Table 5). Our data

Table 4. Estimated carbon storage in bamboo of different culm ages during the study period (2011 and 2012) in the bamboo forest of Manipur, North-east India.

Culm age (yr)	Components	Carbon Stock ($Mg\ ha^{-1}$) Study period 2011	2012
Current year	Leaf	-	-
	Branch	-	-
	Culm	14.38	15.24
	Total	**14.38**	**15.24**
1-yr	Leaf	1.36	1.76
	Branch	1.63	2.10
	Culm	9.40	14.49
	Total	**12.39**	**18.35**
2-yr	Leaf	1.12	1.43
	Branch	1.44	1.82
	Culm	8.97	12.13
	Total	**11.53**	**15.38**
3-yr	Leaf	0.77	0.95
	Branch	1.14	1.08
	Culm	7.16	9.04
	Total	**9.07**	**11.07**
>3-yr	Leaf	-	0.78
	Branch	-	0.91
	Culm	-	7.59
	Total	**-**	**9.28**

Table 5. Rate of carbon sequestration in the bamboo forest at Chandel, Manipur ($Mg\ ha^{-1}yr^{-1}$)

Observation period	Carbon sequestration through different culm component				Carbon sequestration through different litter product				Total carbon sequestration
	Leaf	Branch	Culm	Total	Leaf	Sheath	Branch	Total	($Mg\ ha^{-1}yr^{-1}$)
2011-2012	1.67	1.70	18.02	21.39	0.27	0.01	0.01	0.29	21.68

on C-sequestration is comparable to reported data for *Bambusa bambos*, Eastern India (20.5Mg $ha^{-1}yr^{-1}$; Das & Chaturvedi, 2006) and village bamboo grove, Assam (18.93-23.55 Mg $ha^{-1}yr^{-1}$; Nath *et al.,* 2008) but higher than *Phyllostachys heterocycla,* Central Taiwan (8.13Mg $ha^{-1}yr^{-1}$;Yen and Lee, 2011). High rate of C-sequestration in the present forest may be attributed to higher net productivity of the stand that resulted from high culms density and better management practices such as harvesting of old culms to maintain the vigour of bamboo forest.

CONCLUSIONS

The present natural bamboo forest dominated by *Schizostachyum pergracile* will play an important role in carbon sink and is recommended for plantation for the rehabilitation of degraded ecosystems especially shifting cultivation area in North-eastern region. Present finding revealed that management of bamboo forest is an important source of CO_2 sink. Finally we must emphasize that thinning is necessary method to maintain the vigour of bamboo forest. Furthermore in a well managed bamboo forest, every year the mature and older culm should be cut to promote vigour every year so that the biomass and carbon storage should be high and can be sequestered more carbon. Since bamboo forest is superior species for carbon sequestration the government and the public should pay more attention to bamboo forests for improving high productivity and developing more sustainable management practises and product which allow bamboo to play an increasingly important role in mitigating climate change.

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