Carbon storage in a bamboo (Bambusa vulgaris) plantation in the degraded tropical forests: Implications for policy development

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1. Introduction

In recent years, global climate change mitigation has received much more attention of scientists, resource managers and policy makers. The Intergovernmental panel on climate change (IPCC), in order to face climate change challenges, has promoted strategies for climate change mitigation and adaptation (IPCC, 2014). Forests have the potential to reduce carbon from the atmosphere and thus mitigate climate change (Zhang et al., 2007; Jackson and Baker, 2010; Canadell and Raupach, 2008). Considering the carbon sequestration potential of forests, the forestry community perceived the importance of promoting different forestry practices that can provide climate change mitigation benefits (UNFCCC, 2007). Taking this view ahead, the united nations framework convention on climate change (UNFCCC) and the Kyoto protocol have introduced clean development mechanism (CDM), which allows the development of carbon forestry activities in the developing world as a means of mitigating climate change impacts (UNFCCC, 2002). Under the CDM scheme, industrialized countries finance forestry (reforestation and afforestation) projects in developing countries (UNFCCC, 2004) with a view to provide with two fold benefits. Firstly, it will assist to mitigate climate change impact (Nabuurs et al., 2007) and secondly, it will be a way of potential profitable business (Richards et al., 2006; Sampson, 2004; Ruddell et al., 2006; Helms, 2007). However, the CDM projects mainly focused on the establishment of plantations in the degraded forest land with fast growing species particularly in the tropics. During the selection process of fast growing tree species, bamboos were totally neglected (Lobovikov et al., 2009; Kant, 2010; Buckingham et al., 2011) although all bamboo species are fast growing (Lobovikov et al., 2009) and can act as a potential source of carbon sink (Dewar, 2003).
can to ent has reforestation to sequester lands usually impacts of bamboos CO2 flux tion Henley al., and having degraded reforestation (CDM). Nevertheless, a Lou, the can has of degraded forests of which lies in the tropics (ITTO, 2002). The International Tropical Timber Organization (ITTO, 2002) classified 60% of the world’s tropical forest as degraded forest, including secondary forests, degraded primary forests and degraded forest land. Bangladesh is a tropical country having 2.53 million ha area covered by forests (BFD, 2007; FAO, 2011). Nevertheless, the forests of Bangladesh are subjected to high degradation due to population pressure, illicit felling, shifting cultivation, land use change and the conflict between tribal people and settlers. These degraded forest lands and other waste lands provide with the scope of replanting with suitable species like bamboo. In Bangladesh, bamboo is called ‘poor man’s timber’, which is the most important source of non-timber forest products (NTFP), and plays an important role in regional markets (Khan and Khan, 1994; Alamgir et al., 2007; Mukul, 2011; Nath et al., 2011; Rana et al., 2010; Mukul and Rana, 2013). Because of their wide range of site suitability and economic value, bamboo are frequently planted in the degraded forest sites, around homesteads and other waste lands of Bangladesh. Thirty three species of bamboo have so far been identified in the country (Bystriaikova et al., 2003; Latif, 2008; Banik, 1998).

The total area of bamboo forest in Bangladesh is ~491,491 ha (APFSOS, 1998) with a huge pool of existing village and forest bamboo, it can be assumed that Bangladesh can play a vital role in carbon sequestration and thereby contributing to climate change mitigation through bamboo plantations. Many scientists raised such a high expectation of climate effectiveness of bamboos (Henley and Lou, 2009; Widenjo, 2007; Lobovikov et al., 2009; Lou et al., 2009; INBAR Media Release, 2010; Janssen and Lou, 2010) although their limitations in climate change mitigation was also reported (Dukung et al., 2011) because of their short life span and CO2 flux due to respiratory cost. However, after calculating the respiratory cost of leaf culm and branches, the study on an unused Phyllostachys pubescens stand in Japan reported an above-ground net production of 18.14 tC ha⁻¹ y⁻¹ which falls within the average range of productivity of forests under similar climate conditions (Isagi et al., 1997). In addition, it is important to note that most tree species need decades to reach maturity, where as bamboos usually mature in 7–10 years which suggest that bamboos might have more potential to mitigate climate change and their possible impacts through durable bamboo product.

Although bamboos have long been thought to have good carbon sequestration abilities (Dewar, 1990; INBAR, 2009a), there has been little published information available to support this (INBAR, 2009b; Dhutra, 2008; Nath et al., 2009; Sultana, 2009; Anon, 2006). Most studies concentrate on biomass production and nutrient cycling (Isagi et al., 1994; Isagi et al., 1997; Embaye et al., 2005; Tripathi and Singh, 1994; Shanmughavel and Francis, 1996; Hunter and Junqi, 2002). The study of the potential roles of different species in carbon sequestration are restricted only in some tree species (Uddin, 2002; Momtaz, 2003; Alamgir and Al-Amin, 2008; Shin et al., 2007; Khan, 2009). Lack of a well established method of biomass estimation of bamboo species, not only for world context but also in the context of Bangladesh, might be another reason of the unavailability of information about the carbon stock potential of bamboo species. Some equations for tree species were developed by researchers (Brown et al., 1989; Negi et al., 1988; FAO, 1997; Alves et al., 1997; Brown, 1997; Schroeder et al., 1997). It is, therefore, necessary to develop models, which can be used for future research in Bangladesh to estimate biomass organic carbon for a matured bamboo species. A complete and detailed study of biomass allocation, carbon concentration and linear regression model for bamboo culm has seldom been done for any bamboo species. The current study was conducted at Lawachara forest reserve of North-Eastern Bangladesh to examine the stand biomass and carbon of Bambusa vulgaris plantations, a common bamboo species of Bangladesh. The specific objectives of this study were to:

1. Estimate the above and below ground biomass of B. vulgaris stand at Lawachara forest reserve.
2. Determine the carbon stock of B. vulgaris stand in above and below ground biomass at Lawachara forest reserve.
3. Determine the soil carbon stock of B. vulgaris plantation at Lawachara forest reserve.
4. Develop regression equations for the estimation of biomass organic carbon content of B. vulgaris for 5 year bamboo plantation at Lawachara forest reserve.

2. Materials and methods

2.1. Study site

The study was conducted at Lawachara forest reserve (24°30’–24°32’N and 91°37’–91°39’E) (Fig. 1) under Moulibibazar district in Bangladesh. The total area of the reserve is 1250 ha. It is a part of West Bhanagach Reserved Forests of Moulibibazar forest division. Lawachara forest reserve is a mega biodiversity region with many flora and fauna species. Floral composition mainly belongs to evergreen and semi-evergreen tree species (Ahsan, 2000). Among the fauna, Hoook Gibbon (Hoolock hoolock) and Capped Langur (Trachypithecus pileatus) are the keystone species (Nishorgo, 2006). Topography is undulating with hillocks of 10–50 m (Riadh, 2007) interspersed with numerous streams flowing through the forest. The soil is alluvial brown sandy clay loam to clay loam dating from the Pliocene epoch (Abmad, 1970; Hossain et al., 1989). The site experienced a moist tropical climate (Uddin and Hassan, 2010) with long wet (April–October) and relatively short dry (November–March) seasons (Fig. 2). The mean annual rainfall and temperature of the study site were 2344 mm and 24.8 °C, respectively.

The forest serves as the home of several indigenous communities. Members of the Khasia, Manipuri, and Tripura indigenous groups, who reside within and around the forests, depend on the forest resources for their livelihood and subsistence (NSP, 2008; Akhter et al., 2013; Sohel et al., 2015; Mukul, 2014). Because of over-exploitation of resources and large-scale selection fellimg in 1920 and 1950 (Feeroz, 1999) the forests are highly degraded and need immediate restoration. Hence, Lawachara forest is a representative site of degraded tropical forest.

2.2. Above and below ground biomass estimation of B. vulgaris

Bamboo biomass was determined by harvesting randomly selected culms from a five -year-old B. vulgaris plantation at Lawachara forest reserve. A total of 12 culms were harvested from
six randomly selected plots of 10 m x 10 m (2 culms from each plot). The number of total culms in each plot was counted and diameter at breast height (DBH) and total height were measured by using a diameter tape and haga-ultimeter respectively. After harvesting, the culm samples were divided into leaf, branch and culm components and their respective fresh weights were taken in the field. Several sub-samples of each component were then collected and their fresh weights were measured. All the sub-samples were then oven-dried at 65°C for 48 h and to get the oven-dried weight. For each sub-sample, a ratio of oven-dry to fresh weight was calculated and an average ratio calculated. Multiplication of the total fresh weight of each component by the corresponding oven-dry to fresh-weight ratio will result in an estimate of the dry weight of the component. The sum of the entire components represents oven-dried weight or biomass of that bamboo species. Then total stand biomass for B. vulgaris was determined and then computed on a hectare basis.

Root biomass was not calculated in this study; instead, we followed already established method of below ground biomass estimation for bamboo species. Shanmughavel et al. (2001) and Sekwat (1990) reported the amount of below ground biomass as 9–29% of the above ground biomass for different tropical tree species. Similar findings are rare for the bamboo species. However, a research study in China has shown that the rhizome is 5% of the culms (Stokes et al., 2007). In the current study this relationship was used for estimating the rhizome biomass of bamboo.
2.3. Determination of Carbon content in the above and below ground biomass of B. vulgaris

Oven-dried grinded samples were taken (1.00 g) in pre-weighted crucibles. The crucibles were positioned in the furnace at 550 °C for one hour and were cooled slowly inside the furnace. After cooling, the crucibles with ash were weighed and the percentage of organic carbon was calculated as Allen et al. (1986)

\[
\text{Ash} = \frac{(W3 - W1) \times 100}{(W2 - W1)}
\]

\[
C = (100 - \text{Ash}) \times 0.58 \quad \text{(considering 0.58% carbon in ash}
\]

free stem, branch and foliage materials)

where C is the organic carbon, W1 the weight of crucibles, W2 the weight of oven dried grind samples × Crucibles, W3 is the weight of ash × Crucibles.

The total carbon storage in the above ground standing biomass was obtained by summing the carbon concentration values of leaf, branch and culm components. In order to measure below ground biomass carbon we considered only the rhizome biomass. Rhizome biomass was not directly measured in the present study rather it was calculated as 5% of the above ground biomass following Bijaya (2008). The reason behind using this, the investigated bamboo species by Bijaya (2008) is a sympodial species which is also similar for the present study species. Although there are some limitations in using previous models, the logic behind using Bijaya (2008) for estimating rhizome biomass lies in the fact that the climatic and other site conditions (moist monsoon zone lasting from March to August) of their study site is very similar to that of the present study site. In addition, rhizome mass fraction is relatively low in comparison to other parts of B. vulgaris. The average carbon content of the above ground biomass measured by using the equation of Allen et al. (1986) was 54% of the oven-dried mass. This conversion factor was used to determine the rhizome carbon content of B. vulgaris stand at Lawacharra forest.

2.4. Determination of soil organic carbon content in B. vulgaris plantation

Soil samples were collected from three soil depths: 0–1 cm, 1–3 cm, 3–14. These three soil depths were designated as O, A and B horizon by Al-Amin (2002). From each plot, three soil samples were collected from three horizons. Soil samples were collected in polythene bags using soil core. The samples were weighed before air-dried and there after all the foreign materials were removed by passing through a sieve (2 mm). The amount of soil of known volume is weighed. Soil samples were then oven-dried at 105 °C for 72 h. Soil bulk density was calculated following the following formula (Brandy, 1996).

\[
\text{Bulk density (gm/cc) = Oven-dry weight of the soil sample/}
\]

\[
\text{volume of that soil sample}
\]

For the determination of Soil organic carbon content further heating of soils was done keeping the soil in the crucibles. Firstly, the weight of the crucibles was taken by using electric balance and then exactly 5 gm of oven-dried soil was taken in each crucible. The crucibles with the soil were then transferred to the muffle furnace and kept it at 550 °C for one and half hour. The crucibles were then cooled. After cooling, the crucibles with ash were reweighed to determine loss of ignition percent (LOI%). The formula for calculating LOI% is given below:

\[
\text{LOI} = \frac{W1}{W} \times 100
\]

Here, \(W1\) = loss in weight \(W\) = Weight of oven dry soil

Percentage carbon were calculated from the following equation

\[
\%C = 0.476 \times (\%LOI - 1.47)
\]

Finally, the total organic carbon content of each horizon was calculated following the following formula:

\[
\text{OC1 (Organic carbon g/cm}^2\text{)} = \left(\frac{C_1}{100}\right) \times B_1
\]

\[
\text{OC2 (Organic carbon g/m}^2\text{/horizon) = OC} \times D_1 \times 10000
\]

\[
\text{OC3 (Organic carbon tonne/ha/horizon)} = \frac{(\text{OC} \times 10000)}{1000000}
\]

where \(C_1\) = Organic carbon presence (%); \(D_1\) (Depth of horizon) = Final depth – Initial depth (cm); \(B_1\) = bulk density (gm/cm²)

2.5. Statistical analysis

Before doing analysis, the normality of data was checked by using Kolmogorov–Smirnov test. To show the differences in the carbon contents among the three soil depths one-way analysis of variance (ANOVA) was used. A simple linear regression method was used to develop the equation for the estimation of biomass and biomass organic carbon content of five-year-old B. vulgaris stand at Lawacharra forest reserve. All the analyses were performed by using Minitab 16.

3. Results

3.1. Stand structure and biomass of B. vulgaris plantation

The average stand density of B. vulgaris was calculated to be 2933.33 culm ha⁻¹. The mean height and mean diameter at breast height (DBH) of B. vulgaris were measured as 21.92 m and 20.57 cm respectively. The biomass of bamboo included leaves, branches, culms and rhizomes. The total biomass of B. vulgaris was measured to be 97.8 tha⁻¹ which included 79.59 tha⁻¹ biomass of culms, 10.95 tha⁻¹ biomass of branches, 2.60 tha⁻¹ biomass of leaves and 4.66 tha⁻¹ biomass of rhizomes. Biomass content was much higher in the culms (82%) of bamboo than in the branches, leaves and rhizomes together (18%) (Fig. 3).

3.2. Above and below ground biomass organic carbon content of B. vulgaris

Total biomass carbon content in B. vulgaris was found to be 52.96 tha⁻¹. It was found that aboveground carbon storage was much higher in culms (43.04 tha⁻¹) than in the branches (5.98 tha⁻¹), leaves (1.42 tha⁻¹) and rhizomes (2.52 tha⁻¹) of B. vulgaris (Fig. 4). The total above ground carbon storage was summed up to be 50.44 tha⁻¹ which was reasonably higher than the below ground biomass carbon content (2.52 tha⁻¹). The oven-dried biomass in the culms, branches, leaves and rhizomes contained 54%, 55%, 55% and 54% carbon respectively.

3.3. Soil carbon content of B. vulgaris plantation

The total carbon stock in the soils of B. vulgaris plantation was found to be 24.71 tha⁻¹ and hence the total biomass and soil carbon stock of B. vulgaris plantation at Lawacharra forest was calculated to be 77.67 tha⁻¹. The soil organic carbon content differed significantly (p=0.001) across soil depth. The upper soil depth (0–1 cm) soil carbon was significantly different from the deeper soil depth.
Soil nutrient across three different soil depths (Table 1). Among the three different soil depths, deeper soil depth 3–14 cm contained most of the soil organic carbon (18.72 t ha\(^{-1}\)).

The soil bulk density and the length of soil horizon were the determinants of total soil organic carbon content of each soil horizon. The soil bulk density was significantly different \((p=0.003)\) across soil depth. There was no significant difference between the bulk density of both deeper soil layer 0–1 cm and 3–14 cm soil depth, where as a significant difference was observed between the upper soil layer bulk density of 0-1 cm from both deeper soil layers. The highest soil bulk density was found in 3–14 cm depth and the lowest in 0–1 m depth (Table 1).

While comparing soil bulk density and organic carbon percent a significant correlation \((p=0.02)\) was found of that soil in the study site (Fig. 3). We obtained a negative correlation \((r = -0.54)\) between bulk density and organic matter of soil samples. Our studies indicate that as the bulk density increases organic carbon percentage tends to decrease (Fig. 5).

3.4. Regression equations for the estimation of biomass and biomass organic carbon content of five-year-old B. vulgaris plantation

By regressing, the total biomass organic carbon \((Y)\), against the corresponding green biomass of bamboo \((X)\), a regression model was obtained on which predictions of the biomass organic carbon can be made. So, the simple linear regression equation for biomass organic carbon estimation on the basis of DBH and height would be,

\[ Y = 11.403 + 0.0006(D^2)H \] where \( r^2 = 0.88 \)

Here, \( Y \) = Biomass organic carbon (in kg), \( D = \) DBH (cm), \( H = \) Height (m)

From the equation \( r^2 \) value of 0.88, therefore the performance of the model is statistically sound and can be used for biomass organic carbon estimation.

4. Discussion

4.1. Potentialities of carbon stock of B. vulgaris

From the study, it was found that the total carbon stock of \( B. vulgaris \) is quite high in comparison to some fast growing tree species like \( Acacia auriculiformis \) (age 11 year, 10.21 t ha\(^{-1}\) yr\(^{-1}\)) and \( Eucalyptus camaldulensis \) (age 18 year, 10.12 t ha\(^{-1}\) yr\(^{-1}\)) of Chittagong Hill Tracts of Bangladesh (Shin et al., 2007). Besides, from the study it was found that the total carbon sequestration by \( B. vulgaris \) was 77.67 t ha\(^{-1}\) (−15.53 t ha\(^{-1}\) yr\(^{-1}\)). The estimated carbon stock was calculated for a five-year-bamboo plantation. However, this did not cover biomass and carbon accumulation within or between years. The carbon stock of \( B. vulgaris \) was also higher than \( A. auriculiformis \) of LNP which was 54.54 t ha\(^{-1}\) (Khan, 2009). The findings of the present carbon stock of \( B. vulgaris \) also support the findings of Internation Network for Bamboo and Rattan (INBAR) and it shows that managed bamboo stands can sequester higher amounts of CO\(_2\) than natural bamboo forests and plantations of other fast growing tree species (INBAR, 2009a,b). Another study conducted by Lobovikov et al. (2009) shows that bamboos perform roughly equivalent to fast growing plantation species on good sites, with an increment biomass of between 5 and 12 t ha\(^{-1}\) yr\(^{-1}\). This study shows a negative correlation between organic carbon percent and bulk density. Curtis and Post (1964) also found a reverse correlation between organic matter and bulk density. However, positive correlation has also been reported (Leifeld et al., 2005; Catherine and Ouimet, 2008). The forest cover of LNP has decreased by about 25% (NSP, 2004) which was 382.75 ha of the total national park. Earlier, bamboo was abundant in the forest. Now, their stocks are seriously depleted, primarily due to

Table 1

<table>
<thead>
<tr>
<th>Depth</th>
<th>S. no.</th>
<th>Mean OC (%)</th>
<th>BD (g/cm(^3))</th>
<th>OC (t/ha)</th>
<th>Total OC (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1 cm</td>
<td>6</td>
<td>2.19 ± 0.18</td>
<td>1.04 ± 0.05</td>
<td>2.27 ± 0.23</td>
<td></td>
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<tr>
<td>1–3 cm</td>
<td>6</td>
<td>1.74 ± 0.30</td>
<td>1.07 ± 0.04</td>
<td>3.72 ± 0.69</td>
<td>24.71</td>
</tr>
<tr>
<td>3–14 cm</td>
<td>6</td>
<td>1.50 ± 0.27</td>
<td>1.13 ± 0.1</td>
<td>18.72 ± 3.48</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. Biomass fraction (%) among culms, branches and rhizomes of \( B. vulgaris \) at Lawacharra forest in Moulvibazar district, Bangladesh.

Fig. 4. Total organic carbon content in above and below ground biomass component and in the soils of \( Bambusa vulgaris \) plantation at Lawacharra forest reserve, Moulvibazar, Bangladesh.

Fig. 5. The relationship between soil organic carbon (OC%) and bulk density (BD).
### Table 2
Comparison of carbon stock of various bamboo species and timber species in tropical and subtropical region.

<table>
<thead>
<tr>
<th>Species</th>
<th>Geographic location</th>
<th>Climate</th>
<th>Aboveground biomass carbon (t/ha)</th>
<th>Belowground biomass carbon (t/ha)</th>
<th>Soil carbon storage (t/ha)</th>
<th>Age (Years)</th>
<th>Total carbon (t/ha)</th>
<th>References</th>
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<tbody>
<tr>
<td><strong>Studied bamboo species</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Bambusa vulgaris</td>
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<td>Tropical</td>
<td>50.44</td>
<td>2.52</td>
<td>24.71</td>
<td>5</td>
<td>77.67</td>
<td>Present study</td>
</tr>
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<td><strong>Comparison with bamboo species</strong></td>
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<td></td>
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<td></td>
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<tr>
<td>Phyllostachys pubescens</td>
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<td>Subtropical</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>60</td>
<td>217</td>
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<td>Japan</td>
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<td>101.2</td>
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<td>52.3</td>
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<td>1.66</td>
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<td>–</td>
<td>–</td>
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<td>–</td>
<td>–</td>
<td>54</td>
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<td>38</td>
<td>INBAR (2009c)</td>
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<td>52</td>
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<td>–</td>
<td>55</td>
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<td><strong>Guadua angustifolia</strong></td>
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<td><strong>Comparison with valuable tropical tree species or forest ecosystem</strong></td>
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<td>Tectona grandis</td>
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<td>91.28</td>
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<td>Anthocephalus chinensis</td>
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<td>63.7</td>
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<td>Shin et al. (2007)*</td>
</tr>
<tr>
<td>Acacia auriculiformis</td>
<td>Bangladesh</td>
<td>Tropical</td>
<td>19.38</td>
<td>2.90</td>
<td>83</td>
<td>6</td>
<td>–</td>
<td>Shin et al. (2007)*</td>
</tr>
<tr>
<td>Dipepercarpus turbinatus</td>
<td>Bangladesh</td>
<td>Tropical</td>
<td>8.98</td>
<td>1.34</td>
<td>86</td>
<td>6</td>
<td>–</td>
<td>Shin et al. (2007)*</td>
</tr>
<tr>
<td>Swietenia mahagoni</td>
<td>Bangladesh</td>
<td>Tropical</td>
<td>28.81</td>
<td>4.32</td>
<td>90.66</td>
<td>11</td>
<td>–</td>
<td>Shin et al. (2007)*</td>
</tr>
<tr>
<td>Acacia auriculiformis</td>
<td>Bangladesh</td>
<td>Tropical</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>n/a</td>
<td>54.54</td>
<td>Khan (2009)</td>
</tr>
<tr>
<td>Tropical evergreen forest</td>
<td>Colombia</td>
<td>Tropical</td>
<td>112</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Sierra et al. (2007)</td>
</tr>
<tr>
<td>Tropical forest</td>
<td>Thailand</td>
<td>Tropical</td>
<td>60.0–179.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Ogawa et al. (1965)</td>
</tr>
<tr>
<td>Tropical forest</td>
<td>Sri Lanka</td>
<td>Tropical</td>
<td>77</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Brown and Lugo (1982)</td>
</tr>
<tr>
<td>Tropical dry deciduous forest</td>
<td>India</td>
<td>Tropical</td>
<td>87</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Chaturvedi et al. (2011)</td>
</tr>
</tbody>
</table>

N.B. n/a means not available; * indicates average value of carbon from bottom, middle and top portion of trees and soil sample.
extensive extraction. To reduce this pressure on forests, policy makers suggest the establishment of a buffer sustainable resource use zone around the protected area with provision for fuelwood plots, woodlots and other plantations required for house building purposes. Besides, it will facilitate extra income to those illegal poachers, which might be helpful in forest protection. Here, bamboo plantations can play a significant role. As it is a short rotation species, they can provide a quick return. Side by side, carbon sequestration by this bamboo species is also happening.

4.2. Carbon storage potential of bamboo species of tropical forest

Bamboo covers an area of ~37 million ha in the world (Kant, 2010). Many bamboo species studied so far have notable carbon storage potential. For example, a study conducted by Lou et al. (2010) found that aboveground carbon stock of a 9–10-year-old Moso bamboo (P. pubescens) plantation in China ranges from 25 to 32tha⁻¹. Bamboo species of P. pubescens and Phyllostachys bambusoides from natural forests in Japan have an aboveground carbon stock of 78.6tha⁻¹ and 52.3tha⁻¹, respectively (Isagi et al., 1997; Isagi, 1994). Another study conducted in a four year
old mixed village bamboo plantation (B. vulgaris, B. balcooa, B. cachearensis) in India shows that the aboveground carbon stock is about 61.05tha\(^{-1}\) (Nath et al., 2009). Such carbon stock by bamboo is nearly similar or higher than many fast growing timber species (details in Table 2). For example, aboveground carbon stocks of A. auriculiformis, Dipterocarpus turbinatus and Swietenia mahagoni are 19.38tha\(^{-1}\), 8.98tha\(^{-1}\) and 28.81tha\(^{-1}\), respectively (details Shin et al., 2007). A detailed comparison of different bamboo species and timber species carbon storage from various climatic and geographic regions is provided in Table 2. Previous studies on bamboo from tropical and subtropical countries show that various bamboo species have close or higher carbon than many valuable fast growing timber species or tropical forest ecosystem (Table 2). Carbon storage of B. vulgaris found in the present study was also near equivalent or higher compared to other bamboo species of tropical and subtropical regions.

Apart from the prospects of the bamboo carbon storage capacity, some criticisms exist as well, which need to be considered. Dükings et al. (2011) reported that the short lifecycle of bamboo can act as carbon flux, which can raise questions on the potentialities of bamboo carbon sequestration. Another study conducted by Isagi et al. (1997) found that the carbon sink and flux were almost equal in bamboo forest. The lifecycle of bamboo culms is short; between 5 and 10 years (Lou et al., 2010). Therefore, after harvesting and dying it releases carbon to the atmosphere through burning and decomposing. However, to make bamboo a potential and prolonged carbon sink, durable bamboo products such as construction and building materials, furniture, panel products, pulp and paper industry can play a significant role (Dükings et al., 2011; Liese, 2009). In recent years, many durable bamboo products are available in the market (Fig. 6), contributing significantly to the economic and social well-being of remote rural people who are mainly involved in the manufacturing process (Alamgir et al., 2007; Mukul et al., 2011; Rana et al., 2010; Nath et al., 2011). Converting bamboo biomass into biochar has great potential to store carbon in the soil (Scholz and Hasse, 2008; INBAR, 2014; Köhl and Fruhwald, 2009) but require more research. Biomass productivity of bamboo can be increased by planting bamboo in black soil (Nath et al., 2015a,b). Bamboo can also be used as bio-energy such as charcoal, which can reduce pressure of deforestation for household energy supply (INBAR, 2014). Reducing deforestation will help to increase forest carbon sinks. Given the strong potential of bamboo for carbon sequestration, the expansion of bamboos, coupled with a broader range of durable products, could provide a wonderful contribution to climate change mitigation. However, this aspect of bamboo was not studied in depth in this paper. The contribution of durable bamboo products as a carbon sink needs further studies to highlight its potential.

4.3. Implications for land use policy development for bamboo plantation

The climate change mitigation cost through forestry under the CDM can be quite modest, US$ 0.1–US$ 20/tC in some tropical developing countries and somewhat higher US$ 20–US$ 100/tC in developed countries (Hoogeveen, 2007). However, very few studies on prices of carbon credits have been conducted in Bangladesh. A study conducted by Shin et al. (2007) assumed that for Bangladesh the price would range from US$ 15–20 per MgC based on the scenarios in Southeast Asian countries and Senegal, assuming the same socio-economic conditions. Another study conducted by DoEF (2008) estimated the mitigation cost through forestry projects in Bangladesh can be US$ 10/tC. Here, bamboo can play a significant role in climate change mitigation. While most timber species need decades to reach maturity, bamboos usually mature in 7–10 years. Besides, bamboos perform equivalent to fast growing plantation species on good sites. Therefore, policy makers who deal with natural resource management of Bangladesh and CDM implementing authorities should think to integrate bamboo plantations in the land use policy, both for forest and non-forest areas.

5. Conclusion

Forests have the capacity to sequester carbon from the atmosphere in large amounts. The Kyoto protocol also recognizes that forests may be the best land use system as a sink of carbon (Ross, 2000). Bamboos, on the other hand, have been overlooked in the current climate change regime. Bamboos were missing in the forest’s definitions under the CDM. They have been ignored in IPCC Assessment Reports and in current IPCC guidelines for greenhouse gas emission inventories. So far Philippines and Cambodia have amended their forest definition to include bamboos (Lobovikov et al., 2009, 2011). The present study shows that bamboo species make a significant contribution to carbon sequestration. It is also expected that a good amount of revenue can be earned by selling carbon credits in the carbon market through CDM projects, which can accelerate the economic, social and environmental development of Bangladesh. Therefore Bangladesh should amend their forest definition to include bamboos, and CDM policy should incorporate bamboos in afforestation and reforestation projects rather than leaving it to the individual country. This study only considers variables directly related to the storage of organic carbon in the culm, branch and leaf. But there are some other factors such as litter fall and microorganism distribution and their effect that were not considered. Although the estimation of organic carbon of bamboo is a laborious and time-consuming job, it will help to develop the methodology and estimation procedure for measuring organic carbon stocks of Bambusa vulgaris in future research work. Finally, if bamboo is considered for CDM projects, the poor man’s timber could become the poor people’s carbon sink.

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