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Assessment of Total Carbon Stock in *Swietenia macrophylla* Woodlot at Jhenaidah District in Bangladesh

Md. Najmus Sayadat Pitol[1], Md. Zulfikar Khan[2*] and Rikta Khatun[2]

[1]Forestry and Wood Technology Discipline, Khulna University, P.O.Box: 9208, Khulna, Bangladesh.
[2]Soil, Water and Environment Discipline, Khulna University, P.O.Box: 9208, Khulna, Bangladesh.

Authors' contributions

This work was carried out in collaboration between all authors. Author MNSP designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors MZK and RK reviewed the study design and all drafts of the manuscript. Authors MNSP and MZK undertook the statistical analysis of the data collected and managed the literature searches and reference-citations. Finally, all the authors read and approved the final manuscript.

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ABSTRACT

Woodlot plantations are supposed to have a massive outlook in carbon sequestration. Presence of large area woodlot plantations in Bangladesh would store a significant quantity of carbon. The purpose of this study was to determine the carbon stocks in woodlot plantations (*Swietenia macrophylla*) in Jhenaidah district, Bangladesh. Sixty sample plots of woodlot plantations were purposively selected from three upazilla (Kotchandpur, Kaligong and Moheshpur) of Jhenaidah district. The plot size was 10×10 m. Every individual tree present in the sampling plot was identified up to special level. Diameter at breast height and total tree height were measured for all individual trees in each sample plot. The estimated average tree density was 1340 ± 104.24 stems ha-1ranging between 800 and 2400 stems ha-1. The estimated mean DBH and tree height were 19.52 cm and 12.57 m respectively. The total biomass in Mahogany (*Switenia macrophylla*) woodlot plantations ranged between 52.48 and 824.44 Mg ha-1 and the basal area in woodlot

**Corresponding author: E-mail: Zulfikar.ku11@gmail.com;*

plantations ranged between 9.92 m2ha-1 and 86.21 m2ha-1. The average total biomass was 287.86 ± 22.64 Mg ha-1 and average basal area was 37.98 ± 2.31 m2ha-1. In this study, the average carbon stock in Mahagony plantation was estimated to 143.93 ±11.32 Mg ha-1 ranging between 26.24 Mg ha-1 and 412.22 Mg ha-1. Three allometric models were developed and validated with equal strength (R2 0.97–0.98) using generalized linear regression. Woodlot plantations in Bangladesh can play a vital role in the UNFCCC's carbon mitigation and adaptation mechanism. So, the long-term sustainability of woodlot plantations must be addressed.

Keywords: Carbon stock; Swietenia macrophylla; woodlot; climate change; global warming etc.

1. INTRODUCTION

Global Warming, climate change and biodiversity conservation are the three concurrent issues in the present world. They are the consequence of the rise of greenhouse gases mainly CO_2 [1,2]. Human are mainly responsible of raising the amount of CO_2 in the atmosphere through the combustion of fossil fuel and deforestation [3,4]. According to UNFCCC (2007), the concentrations of atmospheric CO_2 increased from a value of 278 parts per million to 379 parts per million in 2005, and the average global temperature rose by 0.74°C. The last 25 years this increased rate accelerated and recorded that 11 of the 12 months in a year were warmest [5]. Ecologists are worried about that the global warming will continue and the earth could warm by 3°C by 2100. If most of the countries try to reduce their greenhouse gas emissions, the Earth will continue to warm. It considers that the average global temperature will go up to 4°C instead of 1.8°C by 2100 (UNFCCC). If this raising rate will continue the sea level up to 5 m by melting the polar ice-cap [4] and as a result some South Asian countries will be the victim of sea level rising like Bangladesh.

Bangladesh is one of the vulnerable countries of global warming in South-Asian. The total forest area in Bangladesh, according to Forest Department, is 2.52 million ha approximately, corresponding to 17.4% of its land area. This includes 1.52 Million ha for Forest Department controlled land, 0.73 million ha of Unclassified State Forests (USF) under the control of District Administration and 0.27 million ha of village forest land (mostly homesteads). In recent time, natural forests are decreasing very speedily due to anthropogenic activities such as housing, land conversion of other uses, deforestation, industrialization etc. The deforestation rate is faster than the previous time. But it is good that the amount of plantation forests is increasing during last two decades [6]. From 2005 to 2010, an average of 5 million ha of tree plantations have been established per year in Bangladesh. In 2010, the total amount of plantation forests is 264 million ha that covers up to 7% of the total forest area in the world (FAO, 2010). It assumed that, plantation forests provided about 35% supply of global wood in the year of 2000. It considers that this supply will go up to 44% by the year 2020 [3]. So, the importance of plantation forests is increasing undoubtedly.

Bangladesh, a developing country, is one of the lowest CO_2 emitting countries in the world. Its estimated per capita CO_2 emission is 0.2 ton/year, but the average for the developing countries is 1.6 ton/year. In developed countries, the per capita CO_2 emission is 20-50 times higher than the developing countries. In USA the per capita emission is 20 tons/year. Though Bangladesh is in low Green House Gas (GHG) emission category however provides no relief from the effects of Global Warming. If the sea level will rise in 1.5 meter, about 22,000 km^2 will be inundated and 17 million people affected. Bangladesh will be the worst sufferer of global warming but it is not liable for this. Rather its acting fundamental role in carbon sequestration. For minimizing the effects of global warming, Kyoto protocol, REDD+, carbon trading are well discussed issues. All the agreements try to reduce the emission of CO_2 and enhancing the role of conservation, Sustainable Management of Forests and Enhancement of forest carbon stocks [7].

Bangladesh has already ratified the Kyoto protocol, REDD+ and involved in the carbon trading mechanisms. It encourages the use of green technology and helps in increasing forestation. It is an alternative way to recover the effects of global warming. Basically it is a reward to who are emitting less carbon dioxide and a charge on who are liable for global warming. It is not a day dream that one-day small holder farmers will get money in exchange of planting trees. So, it is very much necessary for Bangladesh to assess the biomass or carbon stock of the woodlot plantations for getting the carbon trading facilities. Considering the above background and justifications, this present study aims to assess carbon stocks of the woodlot plantations at Jhenaidah district in Bangladesh.

2. MATERIALS AND METHODS

2.1 Site Description

2.1.1 Geographic area and location

Jhenaidah is surrounded on the north by Kushtia and Rajbari districts, on the east by Magura district, on the south by Jessore district and on the west by Chuadanga district. The total area of the district is 1,964.77 km^2 (758.60 sq. miles). The district lies between 23º13` and 23º46` North latitudes and between 88º42` and 89º23` East longitudes.

2.1.2 Annual average temperature and rainfall

The average daily temperature ranges from 12°C during December-January to about 31°C during May-August. The annual average temperature is 24°C, with the extreme lowest 8.1°C in January and the highest 40°C in May. Annual average maximum temperature is 37.1°C and minimum 11.2°C. About 90% of the total annual rainfall occurs during June- September and the annual rainfall is 1467 mm. Four main seasons namely the dry or winter season (December to February), the pre-monsoon hot season (March -May), the monsoon or rainy season (June-September) and the post monsoon or autumn season (October-November) are recognized.

2.2 Sample Size and Sampling Design

The most woodlot plantations of the study area are composed of *Switenia macrophylla* and the present study was conducted on woodlots of *Switenia macrophylla*. Purposive sampling was used for the data collection because of the uneven and discrete distribution of woodlots plantation in this region. During the reconnaissance survey, the study areas where woodlots plantation are dominant were selected through snow-ball methods. Twelve villages were selected from the study area (Kotchandpur, Maheshpur and Kaligang Upazila). Five sample plots were selected from each village and total sixty sample plots from twelve villages were selected. The size of each sampling plot was 10 m × 10 m (100 m^2). The plantation plot whose individual's diameter is less than 8 cm was discarded purposively.

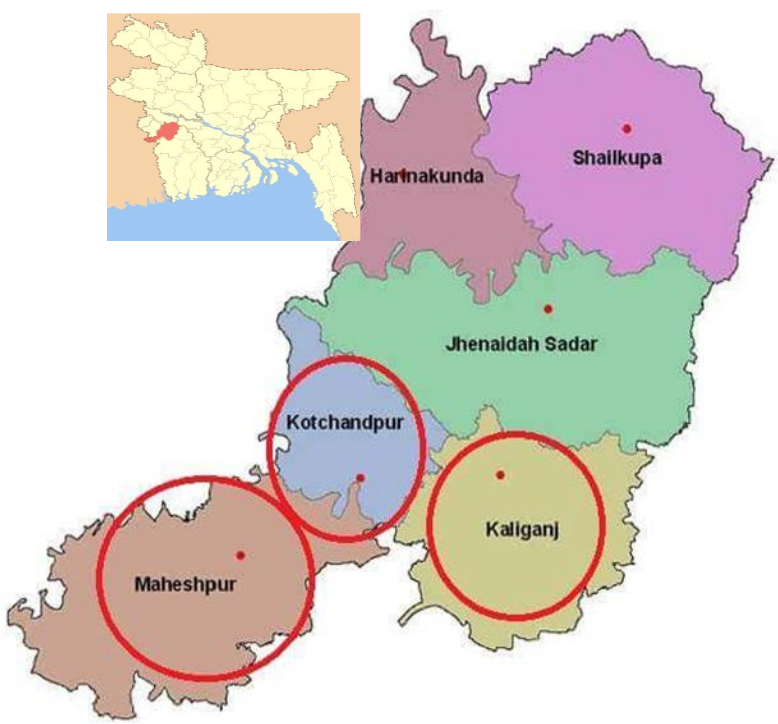

Fig. 1. Study area (Jhenaidah district Map)

2.3 Data Collection Process

2.3.1 Primary data

Primary data were collected by using measuring tape, Spigel Relaskop and diameter tape for further analysis. The sample plot (10m*10m) was alienated by using measuring tape. Diameters at breast height of individual species of the sample plot were measured by using diameter tape and heights of individuals were measured by using Haga Altimeter.

2.3.2 Secondary data

Secondary data and related information were collected from the following sources:Khulna university library, Seminar library, Forestry and Wood Technology Discipline, Khulna University, Published and Unpublished reports, journals, books, Newspapers, Regional center, BBS, Jhenaidah, Agriculture Information Services, Jhenaidah, Internet etc.

2.4 Data Analysis

2.4.1 Allometric computations for aboveground and belowground biomass

Biomass equations relate DBH to biomass and biomass may differ among species as trees in a similar functional group can differ greatly in their growth form between geographic areas [8]. Considering these factors Chave et al. [9] developed allometric equation for tropical trees that was used for wide graphical and diameter range. By using Chave's allometric equation no (1), biomass of the Switenia macrophylla woodlots was estimated. The following Chave's universal allometric equation is:

$$AGB = \rho \times \exp(-1.499 + 2.148 \times \ln(DBH) + 0.207 \times (\ln(DBH))2 - 0.0281(\ln(DBH))3) \quad (1)$$

Where,

AGB = Aboveground biomass,
P = Wood density (g cm-3),
DBH = Diameter at breast height,
ln = Natural logarithm,
1.499 = Constant, 2.148 = Constant,
0.207 = Constant, 0.0281= Constant.

Besides this Below Ground Biomass was calculated using the regression model suggested by Cairns et al. [10] as the most cost effective and practical method of determining root biomass.

$$BGB = EXP(-1.0587 + 0.8836 \times LN(AGB)) \quad (2)$$

2.4.2 Conversion of aboveground biomass to carbon

Estimated biomass was multiplied by the wood carbon content (50%). As almost all carbon measurement projects in the tropical forest assume that all tissues (i.e. wood, leaves and roots) consist of 50% carbon on a dry mass basis [9].

Carbon (Mg) = Biomass estimated by allometric equation × Wood Carbon Content %
= Biomass estimated by allometric equation × 0.5

2.4.3 Density and basal area

Above ground carbon pools was computed using international standard common tree allometries combined with local tables of wood density by tree species. Statistical analysis was done in Microsoft Excel 2007 and SPSS-16 software. Basal area and density were measured to determine the correlation with the biomass of the woodlot.

The basal area ha^{-1} was calculated according to the formula (Equation no: 3)

$$\text{Ba/ha} = \frac{\epsilon\left(\frac{\pi}{4}\right)D2}{\text{Sum of all quadrats area}} \quad (3)$$

Where,

Ba = Basal area in $m^2\,ha^{-1}$
D = Diameter at breast height in meter
Π = 3.14

Following the formulas quantitative structure parameters of investigated trees were calculated

$$\text{Density}\left(\frac{\text{stem}}{\text{ha}}\right) = \frac{\text{Total no.of individuals of one species in all the plots}}{\text{Plot area} \times \text{Total no.of plots studied}} \quad (4)$$

$$\text{Basal area (m2/ha)} = \frac{\text{Total basal area of individual species (m2)}}{\text{Sample plot area (ha)} \times \text{Total no.of plots studied}} \quad (5)$$

3. RESULTS AND DISCUSSION

3.1 Carbon Stocks of the Woodlot

The total biomass (AGB and BGB) in Mahogany (*Switenia macrophylla*) woodlot plantations in Kotchandpur, Kaligong and Moheshpur upazilla were 325.97 Mg ha^{-1}, 199.63 Mg ha^{-1} and 337.99 Mg ha^{-1} respectively (Tables 1, 2 and 3, Fig. 2). In this study, the average carbon stocks in Mahogany (*Switenia Macrophylla*) plantations were estimated to 162.98 Mg ha^{-1}, 99.82 Mg ha^{-1} and 168.99 Mg ha^{-1} in Kotchandpur, Kaligong and Moheshpur upazilla where the average density were 1305 stem ha^{-1}, 1390 stem ha^{-1} and 1325 stem ha^{-1} respectively (Tables 1, 2 and 3, Fig. 2). The average DBH were 19.52 cm, 16.09 cm and 19.56 cm; mean tree height was 12.57 m, 11.62 m and 11.84 m; average basal area were 42.01 m^2ha^{-1}, 29.31 m^2ha^{-1} and 42.66 m^2ha^{-1} in Kotchandpur, Kaligong and Moheshpur upazilla respectively (Tables 1, 2 and 3, Fig. 2). The biomass and carbon stock of Moheshpur (337.99 Mg ha^{-1}, 168.99 Mg ha^{-1}) and Kotchandpur (325.97 Mg $ha^{-1,}$ 162.98 Mg ha^{-1}) upazilla was higher than the Kaligonj (199.63 Mg ha^{-1}, 99.82 Mg ha^{-1}). Because most of the plantations in Kaligonj upazilla were new and the mean DBH was comparatively lower than the two upazilla. Stem density and tree height have lower effects on biomass and carbon stock in woodlot plantations. The stem density was higher in Kaligang upazilla (1390 stem ha^{-1}) then other two upazilla and mean tree height (11.62 m) was very close to Moheshpur (11.84 m) upazilla but biomass and carbon stock were lower than the two upazilla.

In Jhenaidah district, the estimated tree density was 1340 ± 104.24 stems ha^{-1} ranging between 800 and 2400 stems ha^{-1} (Table 4). The estimated mean DBH and tree height were 19.52 cm and 12.57 m respectively (Table 4). The total biomass in Mahogany (*Switenia macrophylla*) woodlot plantations ranged between 52.48 and 824.44 Mg ha^{-1} and the basal area in woodlot plantations ranged between 9.92 and 86.21 m^2ha^{-1} (Table 4) in Jhenaidah district. The average total biomass was 287.86 ± 22.64 Mg ha^{-1} and average basal area was 37.98 ± 2.31 m^2ha^{-1} (Table 4). In this study, the average carbon stock in Mahogany (*Switenia Macrophylla*) plantation in Jhenaidah district was estimated 143.93 ±11.32 Mg ha^{-1} ranging between 26.24 and 412.22 Mg ha^{-1} (Table 4) where 85% above ground and 15% below ground (Fig. 2).

3.2 Basal Area Based Allometric Models and Their Validation

Three types of models were developed for carbon assessment from the plot level mean basal area [Eqs. (1) to (3)]. We found a strong (mean R^2 = 0.97; for Linear 0.97, Polynomial 0.97 and Power 0.98 models) and significant (*P < 0.05*) relationship between mean biomass carbon and mean basal area for *Swietenia macrophylla* woodlot (Fig. 3). All three models were tested against 40 plots with Chave et al. [9] and Cairns et al. [10] for validation. Results of the GLRM revealed that all three models showed significant (*P <0.01*) and strong relationships (R^2=0.97) with established models [9,10] based on biomass carbon content (Fig. 3). We also tested our three models with Rahman et al. [11] and found that all three models showed significant (*P <0.01*) and strong relationships (R^2=0.99) with three established models [11]. Given the high regression R^2 (range: 0.97 to 0.98), our three models are equally strong in calculating the tree biomass carbon content. Therefore, our basal area based allometric models are equally suitable for calculating biomass carbon content from the trees in woodlots.

$$\text{Biomass C} = 4.834 \times BA - 39.72 \quad (1)$$

$$\text{Biomass C} = -21.51 + 3.855 \times BA + 0.01 \times BA^2 \quad (2)$$

$$\text{Biomass C} = 1.256 \times BA^{1.291} \quad (3)$$

3.3 Relationship Assessment

In the plantation forest site, a significant positive correlation was observed among the following variables: DBH and total C, mean tree height and total C and basal area m^2ha^{-1} and total C. Two attributes basal area ha^{-1} (R^2=0.981) (Fig. 6) and DBH (R^2=0.828) (Fig. 4) were strongly related to aboveground carbon stocks, but stand mean height (R^2=0.572) (Fig. 5) was weakly related because similar height of different plots having wide variation in number of trees and DBH.

Table 1. Average height, diameter at breast height, basal area, Stem density, biomass and carbon stock in woodlot plantations at Kotchandpur Upazilla

Contents	Minimum	Maximum	Average	SD	SE
Mean Height (m)	6.54	15.11	12.57	2.24	0.50
Mean DBH (cm)	11.75	26.33	19.52	4.09	0.92
Basal Area (m^2ha^{-1})	9.92	86.21	42.01	17.11	3.83
Stem density ha^{-1}	900	2400	1305	466.19	104.24
Biomass (Mg ha^{-1})	52.48	747.79	325.97	157.24	35.16
Carbon stock (Mg ha^{-1})	26.24	373.89	162.98	78.62	17.58

Table 2. Average height, diameter at breast height, basal area, stem density, biomass and carbon stock in woodlot plantations at Kaligong Upazilla

Contents	Minimum	Maximum	Average	SD	SE
Mean Height (m)	6.77	15.48	11.84	1.99	0.44
Mean DBH (cm)	10.9	33.47	19.56	5.95	1.33
Basal Area (m^2ha^{-1})	15.55	83.37	42.66	21.70	4.85
Stem density ha^{-1}	800	2200	1325	355.22	79.43
Biomass (Mg ha^{-1})	80.84	824.44	337.99	220.85	49.38
Carbon stock (Mg ha^{-1})	40.42	412.22	168.99	110.43	24.69

Table 3. Average height, diameter at breast height, basal area, stem Density, biomass and carbon stock in woodlot plantations at Moheshpur Upazilla

Contents	Minimum	Maximum	Average	SD	SE
Mean Height (m)	6.54	15.55	12.01	2.25	0.29
Mean DBH (cm)	10.9	33.47	18.39	4.9	0.63
Basal Area (m^2ha^{-1})	9.92	86.21	37.98	17.88	2.31
Stem density ha^{-1}	800	2400	1340	378.31	48.84
Biomass (Mg ha^{-1})	52.48	824.44	287.86	175.35	22.64
Carbon stock (Mg ha^{-1})	26.24	412.22	143.93	87.67	11.32

Table 4. Average height, diameter at breast height, basal area, stem density, biomass and carbon stock in woodlot plantations in Jhenaidah district, Bangladesh

Contents	Minimum	Maximum	Average	SD	SE
Mean Height (m)	7.46	15.55	11.62	2.51	0.56
Mean DBH (cm)	11.11	24.37	16.09	3.74	0.83
Basal Area (m^2ha^{-1})	13.08	51.61	29.31	10.45	2.34
Stem density ha^{-1}	800	2000	1390	311.03	69.55
Biomass (Mg ha^{-1})	68.52	450.86	199.63	98.05	21.92
Carbon stock (Mg ha^{-1})	34.26	225.43	99.82	49.02	10.96

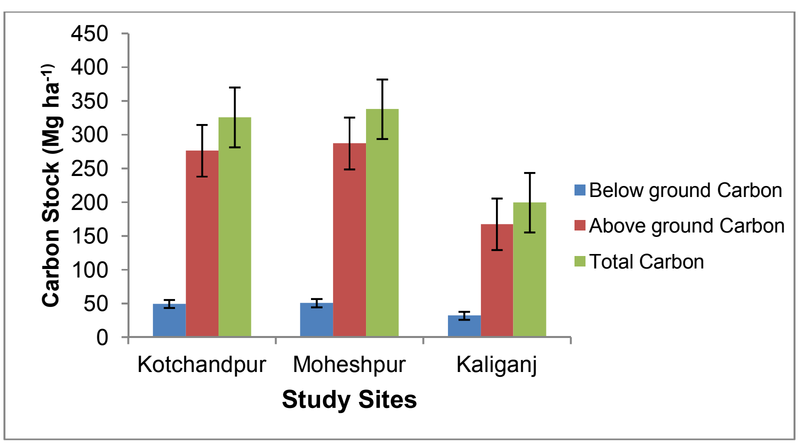

Fig. 2. Carbon content of the woodlot plantations at three Upazilla in Jhenaidah district

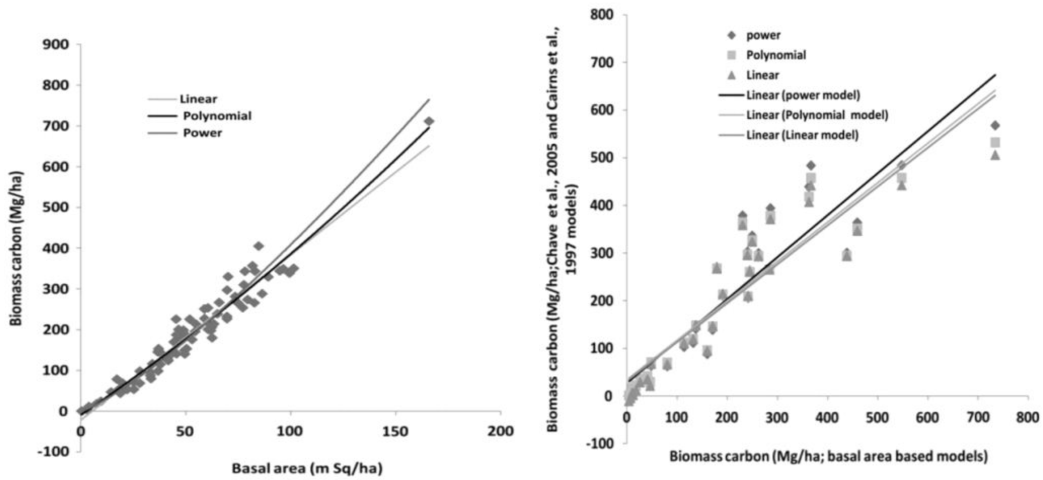

Fig. 3. Basal area-based biomass models at the left side of this study validated with models established by Chave et al. [9] and Cairns et al. [10] at the right side

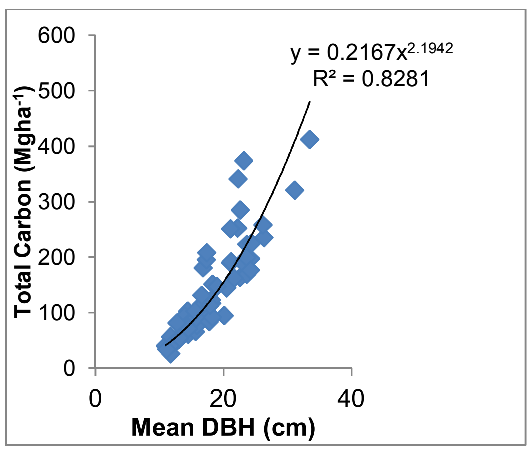

Fig. 4. Mean DBH and total carbon

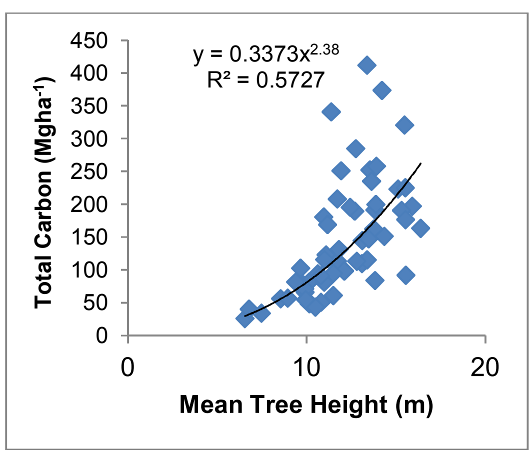

Fig. 5. Mean height and total carbon stock

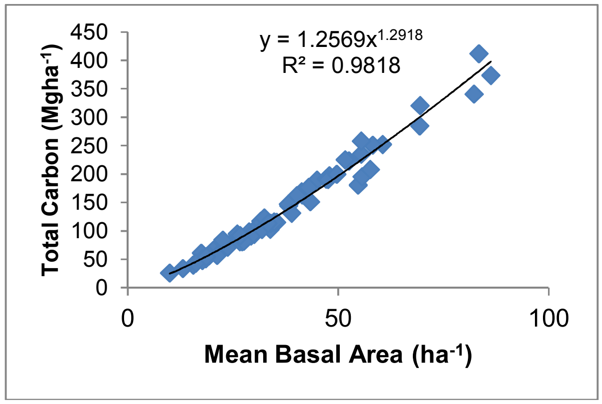

Fig. 6. Mean Basal area and total carbon stock

3.4 Discussion

Managing the atmospheric carbon dioxide emission through minimizing deforestation, maximizing afforestation or reforestation, and checking global warming are the significant concern among scientists and policy makers [12,13]. The United Nations Framework Convention on Climate Change (UNFCCC) is discussing policies and approaching to reduce CO_2 emissions from deforestation. Various mitigation and adaptation methods such as the Clean Development Mechanism (CDM), Reduced Emissions from Deforestation and Forest Degradation (REDD) and Reducing Emissions from Deforestation and Forest Degradation, and enhancing forest carbon stocks in developing countries (REDD+) are recognized by the UNFCCC. These are planned to connect multi-scale stakeholders in conservation and sustainable management of forest resources for mitigating global climate change [7]. Afforestation and reforestation are the fundamental parts of REDD+ as an effective mechanism for reducing global climate change [14,15]. The accurate information on carbon stocks, biodiversity and the socioeconomic status of the communities in developing countries participating in the REDD+ financial mechanism is essential [13]. So, it is vital to obtain more truthful and precise biomass estimates for plantation forests or woodlots in order to develop about understanding of the role of plantation forests or woodlots in Bangladesh as well as in global carbon cycle.

The stem density (1340 tree ha^{-1}) in our study was higher than recorded from other natural and protected forest in Bangladesh. For example, 381 trees ha^{-1} in Chittagong Hill Tracts (South) Forest Division [16], 459 trees ha^{-1} in Chunati Wildlife Sanctuary, Cox's Bazar [17], 464 trees ha^{-1} in Dudpukuria-Dhopachori Wildlife Sanctuary of Chittagong South Forest Division [18], 257 tree ha^{-1} in Ukhiya natural forests of Cox's Bazar Forest Division [19] and 369 stem ha^{-1} in Ramu reserve forests of Cox's Bazar. The basal area (37.98 m^2 ha^{-1}) in our study was higher than 16.88 m^2 ha^{-1} in Chunati Wildlife Sanctuary, Cox's Bazar [17] and 27.07 m^2 ha^{-1} in Dudpukuria-Dhopachori Wildlife Sanctuary of Chittagong South Forest Division [18], but lower than 53.5 m^2 ha^{-1} in Chittagong Hill Tracts (South) Forest Division [16]. This very high density of trees in woodlot plantations compared to many other natural and protected forest systems in Bangladesh may be because of maintaining a certain tree spacing (2 m×2 m) along with the higher survival rate from confirmed protection. Woodlot plantations in Bangladesh may therefore play an important role in producing more timber and revenue for the local community and more importantly sequester carbon compared to other natural and restored ecosystems in Bangladesh.

Our established three basal area based allometric models can be useful for carbon calculation from the plot level mean basal area as all three models showed strong relationships in the GLRM analysis (R^2=0.98). The mean biomass carbon of woodlot plantations (143.93 Mg ha^{-1}) in our study was also higher than the reported average tree biomass carbon content of 83.72 Mg ha^{-1} [14] and 110.94-ton ha^{-1} [15] in hill forest of Bangladesh. Even our estimated carbon stock was higher than USA national average urban forest carbon storage (22. 83 Mg ha^{-1}). Several measures of stand structure and productivity were also assessed to know the relationship with total carbon stock. Two attributes basal area ha^{-1} (R^2=0.981) (Fig. 6) and DBH (R^2=0.828) (Fig. 4) were strongly related to aboveground carbon stocks, but stand mean height (R^2=0.572) (Fig. 6) was weakly related because similar height of different plots having wide variation in number of trees and DBH. According to Kuyah et al. [20] DBH is very strongly (R^2=0.98) related with aboveground biomass. Again Henry et al. [21] has shown tree volume is very strongly related with total aboveground biomass. The more basal area, stem density ha^{-1} and DBH indicate the more amount of biomass and more biomass means more carbon stock. But with similar height of different plots having wide variation in number of trees. For this reason, mean tree height is weakly related with aboveground carbon stock. By increasing woodlot plantation with long rotation with good diameter trees, we can increase the amount of total carbon stocks which can play a vital role in global carbon cycle. We estimated a much higher amount of carbon in woodlot plantations compared to other studies from tropical and subtropical regions due to the higher stem density and basal area (Table 4) in our study. This way woodlot plantation in Bangladesh can play an important role in atmospheric carbon sequestration.

4. CONCLUSION

At present, natural forest is declining very hurriedly at shocking speed due to anthropogenic tricks (such as deforestation, industrialization, burning fossil fuels etc.) that boost global warming. According to FAO, the plantation forests and woodlots are increasing more than before. Bangladesh is probable to be one of the worst suffers of Global Warming due to extreme carbon emission and playing fundamental role in carbon sequestration especially through new plantation forest. Woodlot plantation is one of the major steps of plantation forest which has enormous potential in the lessening of global warming and adjustment to climate change. So, estimation of the forest carbon stocks is very essential which will facilitate us to appraise the quantity of carbon loss through deforestation or the amount of carbon that a forest can accumulate when such forests are regenerated. The woodlot plantations in Bangladesh could provide additional benefits to the local communities such as payment for environmental services for their participation in the UNFCCC's financial based carbon mitigation strategies. Further study on financial and biophysical aspect should be carried out in order to identify the effectiveness of woodlot plantation in the study area. One important limitation of this study is the application of universal biomass allometric equations to calculate total carbon stocks in woodlot plantation. Precision of these assessments could be improved by developing species specific local biomass allometric models. Unfortunately, such allometric equations are not available. Although there have been numerous studies carried out to estimate the forest biomass and the forest carbon stocks, but there is still a further need to develop a robust method to enumerate the estimates of biomass of all forest components, woodlots and carbon stocks more accurately.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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