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Research Article

Developing Allometric Models for Carbon Stock Estimation in Eighteen Year Old Plantation Forests of Bangladesh

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Abstract

The aim of the study was to estimate carbon stock of 18-year old plantation (*Acacia auriculiformis*, *Anthocephalus chinensis and Tectona grandis*) and to develop allometric models. Systematic sampling method was used in the study to identify each sampling point through Global Positioning System (GPS). Loss of ignition and Walkley-Black Oxidation methods were used in the study to estimate tree biomass and soil carbon stock, respectively. Result depicted that the total carbon stock was highest 211.09 ton/ha in fast growing *Acacia auriculiformis* plantation. Six allometric models were tested between biomass carbon and different dimensions of tree such as height, diameter at breast height (DBH), basal area and wood density, and the coefficient of determination (R2) values were used to compare the strength of relationships. Although the allometric models were highly significant (P <0.001), there were considerable variation among them as indicated by the R2 values. Model Y = A + BX1 (where, Y is biomass carbon stock in ton, X1 is diameter at breast height in cm) for DBH range ≥10 cm was found best fit with highest coefficient of determination and significance of regression. The allometric models developed in the present study may be utilized for future carbon stock estimation in plantation in Bangladesh and other tropical countries of the world.

Keywords: Allometric Models; Carbon Stock; 18-Year Old Plantation

Introduction

The large portions of natural forests of Bangladesh have already been significantly degraded and fragmented [22], leaving the country with only a small percentage of forest cover [2]. Total plantation area of Bangladesh under reforestation activities is 0.257 million ha, which includes hill forest, bamboo forest, long rotation, short rotation, and mangrove plantations measuring 0.023, 0.004, 0.131, 0.054 and 0.045 million ha, respectively [7]. Plantations have higher annual carbon sequestration rates [8] and establishing plantations on degraded land has been proposed as an effective carbon management approach [23]. Through the Clean Development Mechanism, carbon management approach can be gained by plantation program in developing countries like Bangladesh (UNFCCC, 2004). Developing countries such as Bangladesh are mostly affected by the ominous consequences of "Global Warming" [6]. The global warming issue focuses on the increasing accumulation of greenhouse gases, mainly CO_2 in the atmosphere due to emissions caused by industrial activities and deforestation [3]. Creating and maintaining carbon stocks in the tropical forests is an important global warming response options for tropical developing countries like Bangladesh [24,25,12]. In case of deforestation, harvesting and forest degradation, the world's forest are estimated to be a net source of 1.8 Gt carbon/year, of which 20% is from tropical deforestation [38] so forests play an important role in sequestration of carbon globally [29].

A realistic estimate of the carbon stock at any given time is crucial for two reasons; first one indicates the potentiality of vegetation to release or absorb carbon and second one indicates a time series of the carbon stock in vegetation may be used to strain methods such as inverse modeling in estimating the net carbon flux to or from the global soils [14]. Poverty and lack of appropriate technology in Bangladesh are the barriers for establishing the carbon sinks in the forests through afforestation or reforestation which would demonstrate the 'additionality' under the Clean Development Mechanism (CDM). Bangladesh can participate in the carbon trading effectively, but the country is lacking research on the quantification of carbon credits by reforestation and afforestation.

Quantification of net carbon sequestration by plantation species is a prime research question in deducting the carbon credit of reforested plantations. Bangladesh has a very long history of plantation forestry starting from 1871 with *Tectona grandisin* Chittagong hill forest, along with indigenous species. Many of plantations were established successfully and the area is now viewed as an important example for carbon sequestration in Bangladesh. So, determination of carbon stock in different geoposition of 18-year old plantations of *Acacia auriculiformis*, *Anthocephalus chinensis* and *Tectona grandis*, and develop allometric models for carbon stock estimation is a prime objective of the study.

2. Materials and Methods

2.1 Study area

The study was conducted in Tankawati forest mono plantation area (21°56'–21°59' North and 92°06'–92°13' East) of Chittagong (South) Forest Division, Bangladesh. The study area is situated on western aspect of mid hill position. The plantation area for *Tectona grandis* was 28.4 ha, *Acacia auriculiformis* was 6.3 ha and *Anthocephalus chinensis* was 6.3 ha but actually the mentionable area is not yet covered by the planted species. The elevation of the study areas ranged between 14 m and 87 m above mean sea level [17]. The study area has a moist tropical maritime climate, with high rainfall concentrated during monsoon period from June to September and high temperature (only small seasonal differences) and high humidity (70% to 85%) [21]. The mean monthly temperature in the study area ranges from 21.20°C in November to 28.44°C in April with a mean annual temperature of 26.44°C. The mean monthly maximum temperature ranges from 26.37°C in November to 32.72°C in April and the mean monthly minimum temperature ranges from 16.03°C in November to 25°C in April. The mean minimum and maximum temperature are 21.97°C and 30.51°C, respectively. Average annual fluctuations in temperature are about 6.4°C during the rainy season of May to September with a fluctuation of 10.08°C during the dry season of the year [21]. The highest concentration of precipitation is found from May to September, pre- and post-monsoon periods of rain during April, May and October, November to March constitute the dry season. The mean monthly relative humidity of the study area is high throughout the year. The humidity is very high, 87% in the month of July and low 69% in the month of February [21]. Soils are brown sandy loams, somewhat excessively drained, Barkal soil series and classified according to USDA Taxonomy by Alam et al. [1] as Udic Utochrept.

2.2 Sampling procedure

The study was conducted from January to December 2009 through physical measurement, field observation and laboratory analysis. The three mono plantations of *Acacia auriculiformis, Anthocephalus chinensis and Tectona grandis* were raised in 1991 in the deforested areas of Tankawati forest. Systematic sampling method was used for identification of each intersection point in the field. At first, the geoposition of the plantation area was determined by using GPS, after that 1' (one minute) intervals were inserted in the map from 21°59' North latitude and 92°08'–92°12' East longitude of the studied area (Fig. 1) and a total of 27 sample plots (nine sample plots from each plantation type where sample plot size 10 m × 10 m) were selected for three same aged mono plantations. Primarily, the land use of each intersection point was identified in the field. In the fixed grid lines, number of stems was counted, Spiegel Relaskope and Diameter tape for height and diameter measurement was used, samples were collected from all trees of the plot for laboratory analysis to estimate carbon stock, increment cores were collected by wood borer at breast height (1.3 m). To estimate the biomass of fallen litter in the plantations, sample plots of 2 m × 2 m (a total of 27 sample plots, nine plots for each plantation) were established in the crown-covered area. Fallen litter was collected after 6 months and the average litter fall for 6 months was converted to annual litter fall per ha to estimate the biomass of the litter fall in the plantations. To estimate the carbon stock in soil in the selected geoposition, soil samples were collected from the studied plantations. From each plantation, a total of nine soil plots were sampled from three different depths of top (1 to 14 cm), middle (14 to 30 cm) and bottom (30 to 100 cm). The size of the sample plot was 2 m × 2 m. Each sample was a composite of three sub-samples. Thus for the three plantations, a total of 27 soil samples were studied. Soil samples were collected at a depth of 1m using an Earth Augur. The samples were carefully taken to the laboratory for chemical analysis through Walkey-Black Oxidation method.

2.3 Biomass estimation of the plantations

It is impossible to estimate biomass of plantations by cutting all the trees due to substantial cost issues involved. In order to address this issue some models were developed by various authorities including [13,19,26,10]. Models of Brown et al., [19] was used to determine above ground biomass because literature showed that this method is one of the most suitable methods for tropical forest [5,11,13,32].

The model is as follows: Y = Exp. {-2.4090 + 0.9522 ln (D2HS)} Where, Exp. {....} means 'raised to the power of {....}', Y is above ground biomass in kg, H is height of the trees in meter, D is diameter at breast height (1.3 m) in cm, S is wood density in units of ton/m3 for specific species [31]. Below ground biomass was estimated as 15% of the above ground biomass [20]. The above- and below-ground biomasses were added to get the total biomass of the plantation.

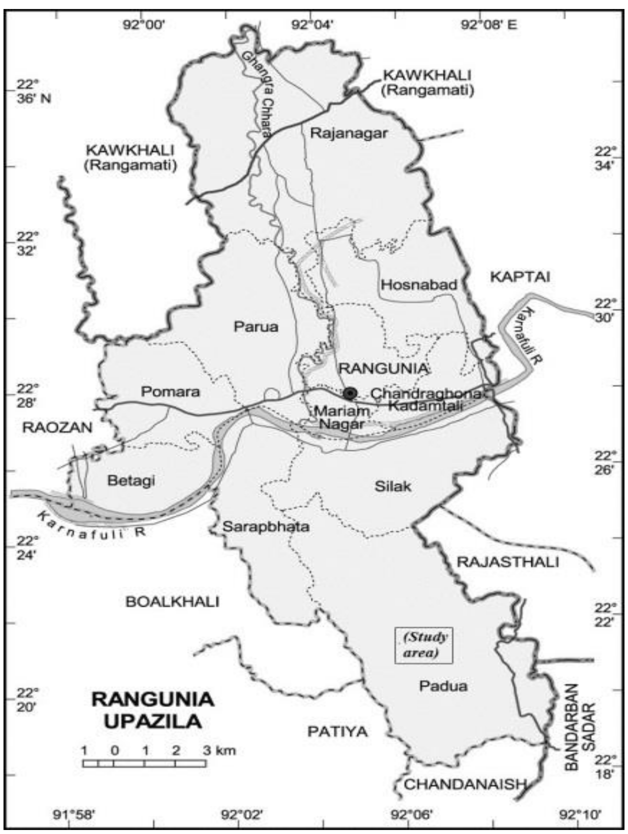


Figure 1. Map showing the study area

2.4 Carbon stock estimation

Loss of ignition method was used to estimate carbon stock of the tree species. In the method, initially fresh weight of tree samples were taken using electric balance then dried at 65°C in oven for 48 hours to take dry weight. Oven dried grind samples were taken (1.00 g) in pre-weighted crucibles, then put in the furnace and that was followed by ignition for 1 hour. After cooling, the crucibles with ash were weighted and then percentage of organic carbon was calculated using a formula described by Allen et al [4], as follows: Ash (%) = (W3-W1)/(W2-W1)×100, C (%) = (100-Ash %)×0.58 (considering 58% carbon in ash free litter material), where, C is biomass carbon stock, W1 is weight of crucible, W2 is weight of oven dried grind sample and crucible, and W3 is weight of ash and crucible.

Bulk density of the soil sample was calculated using the following formula (Brady, 1996): bulk density = oven dry weight of soil/volume of soil. To estimate the percentage of carbon in the soil, samples were analyzed through the Walkley-Black Oxidation method [16].

2.5 Allometric models for estimation of tree biomass carbon

In the study, six allometric models were tested and verified for three tree species, and after verification with other research results of biomass carbon it was found that all models were not suitable for diameter at breast height (DBH) range of ≥10 cm. To get best fit equation, six allometric models for linear and log-log relations for three species were tested by using SPSS software for statistical analysis (version 18), and the best fit model was accepted to estimate tree biomass carbon stock of the respective species based on R2 value and SE.

Model 1.Y = A + BX1 and logy = A + B logX1,
Model 2.Y = A + BX2and logy = A + B logX2,
Model 3.Y = A + BX3 and logy = A + B logX3,
Model 4.Y = A + BX1 + CX2,
Model 5.logy= A + B logX1 + C logX2,
Model 6.Y = A + BX1 + CX2+ DX4

Where, Y is biomass carbon stock (ton), X1 is diameter at breast height (cm), X2 is total height (m), X3 is basal area (m2), X4 is wood density (ton/m3), and A, B, C, D is the regression coefficient, respectively.

3. Result and Discussion

3.1 Carbon stock of 18-year old plantations

The three mono plantations were established at the mid-hill positions but the highest tree biomass carbon and soil organic carbon were found in *Acacia auriculiformis* plantation followed by *Tectona grandis* and *Anthocephalus chinensis* plantations. The total (above- and below- ground) carbon stock were found highest in *Acacia auriculiformis* (110.25 and 100.84 ton/ha, respectively) followed by *Tectona grandis* (91.28 and 80.33 ton/ha) and *Anthocephalus chinensis* (63.70 and 85.26 ton/ha) plantations, respectively (Fig. 2). *Acacia auriculiformis*is fast growing species compared to *Tectona grandis* and *Anthocephalus chinensis*, and Moura-Costa (1996) found that fast growing species accumulate higher amounts of biomass than slow growers during the same time period. As trees grow through time, they accumulate carbon in their biomass thereby increasing the amount of carbon stored in the tree plantation areas. Hossain [15] found that *Acacia auriculiformis* plantation showed better survival and growth in different areas of Bangladesh and the yield is 15-20 m3/ha/yr at 10-12 years rotation, but it is less than 7-8 m3/ha/yr in a wide range of plantations for *Tectona grandis* and *Anthocephalus chinensis*. In Chittagong University campus (hilly area) of Bangladesh, the total above-ground biomass in mid-hill position for 4-year old *Acacia auriculiformis*, 8-year old *Dipterocarpus turbinatus* and 4-year old *Pinus caribaea* plantations were found 76, 32 and 62 ton/ha, respectively [27]. They also found variations in biomass carbon stock among the plantations in same hill position, and it was also the highest in fast growing *Acacia auriculiformis* plantation. Sa et al [30], found that plantation of leguminous tree *Acacia auriculiformis* had 2-3 fold higher above-ground carbon stock capacity than a plantation of other species of the same age. So, in same age's plantations in same position, plantation of *Acacia auriculiformis* stocked more carbon than other species.

Highest litter carbon stock 2.46 ton/ha was found in the plantation of deciduous tree species of *Tectona grandis* rather than other two plantations (Fig. 2). Shin et al [36], also found that 3.00 ton/ha carbon stock in the fallen litter of 20-year old

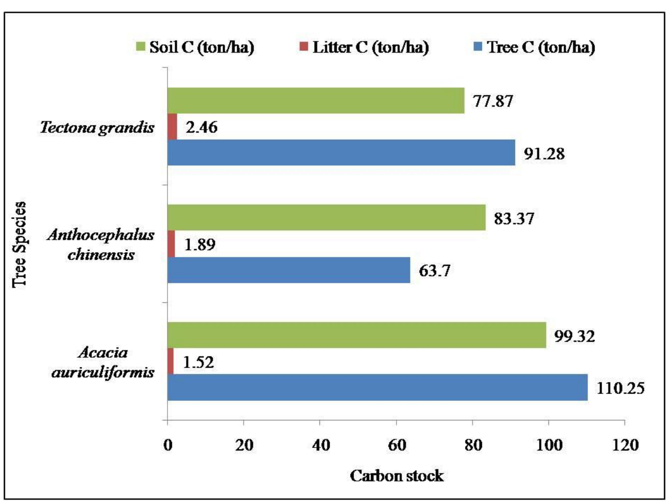


Figure 2. Carbon stocks (ton/ha) of 18-year old plantations.

Tectona grandis plantation in mid-hill position. So, the variation of litter carbon stock per hectare was mainly influenced by different species.

The distribution of soil carbon stock also varied among the three species and it was found to be the highest in *Acacia auriculiformis* (99.32 ton/ha) and the lowest in *Tectona grandis* (77.87 ton/ha) (Fig. 2). Osman et al [28], concluded that soil organic matter increases with the age of the plantation, until canopy closure, but is dependent on the ability of the species to produce litter. Among the three species *Acacia auriculiformis* produce more litter than the other two species and after decomposition of litter enrich the carbon stock in soil. Singh et al [34], mentioned that the deposition and release of carbon through litterfall and its decomposition was highest in legume species of *Acacia auriculiformis*, *Albizia procera*, and *Albizia lebbeck* plantations. *Tectona grandis* (non-legume) contribution to carbon stock in the soil was poor due to its deposition of less organic matter in the soil [33,34].

A study conducted on the gross carbon stock distribution in Acacia mangium (11-year old, exotic species) and *Syzygium grandis* (13-year old, native species) stands on the Chittagong hill forest showed that the exotic species stocked more carbon than the native one and it was 193.55 ton/ha and 140.47 ton/ha, respectively [36]. Lasco and Pulhin [18] mentioned that carbon densities of tree plantation are varying with age, species and site. Fig. 2 showed the carbon stock ton/ha of three same ages' tree plantations in same site of the studied forest, and a difference in the carbon density of three tree plantations was found there. These findings are found to be consistent with the estimates made in Chittagong hill forest where exotic species is observed to higher than the carbon stock by native species.

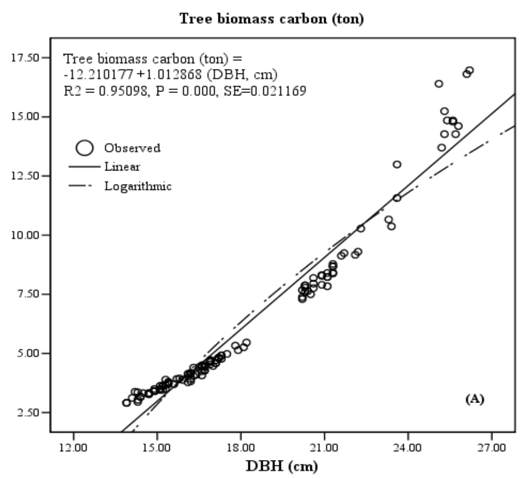
3.2 Development of allometric models to estimate biomass carbon stock

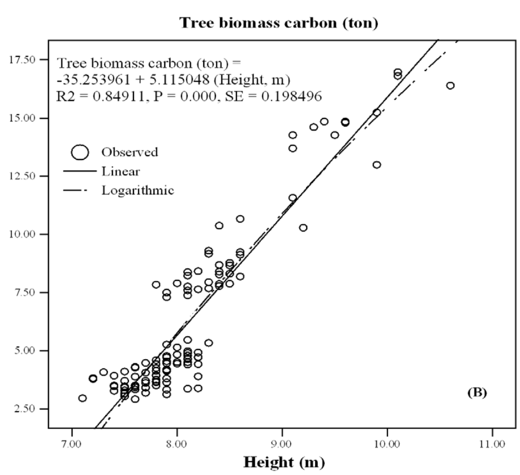
In the study, six allometric models were tested and developed for three plantations of *Acacia auriculiformis*, *Anthocephalus chinensis* and *Tectona grandis* for DBH range of ≥10 cm. Though four sets of allometric models considering DBH, total height, basal area, both DBH and total height for linear relations were tested for each species, the results predicted that DBH was the good predictor of tree biomass carbon stock estimation for plantations. Regression for height, basal area, DBH and height all are significant relating biomass carbon stock (P <0.001) but produced lower coefficient of determination (R2) value. Only DBH relating to tree biomass carbon stock was produced higher R2 value than other allometric models, and 0.95098 for *Acacia auriculiformis*, 0.94609 for *Anthocephalus chinensis*, and 0.94116 for *Tectona grandis* plantations (Fig. 3, Table 1). So the result revealed that DBH was the best predictor of tree biomass carbon stock measurement for the 18-year old plantations of *Acacia auriculiformis*, *Anthocephalus chinensis*, and *Tectona grandis*.

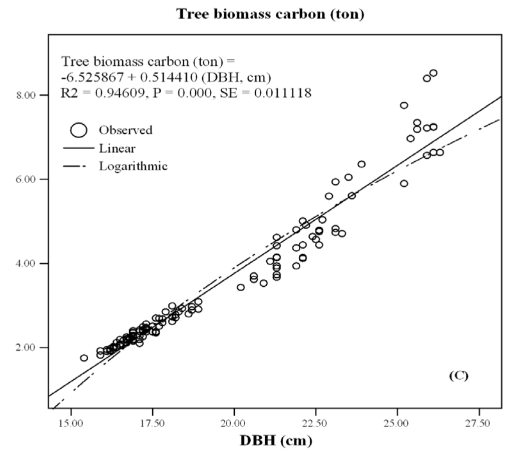
Table 1. Parameter A, B, C, R2, P, SE and Sb for three 18-year old plantations

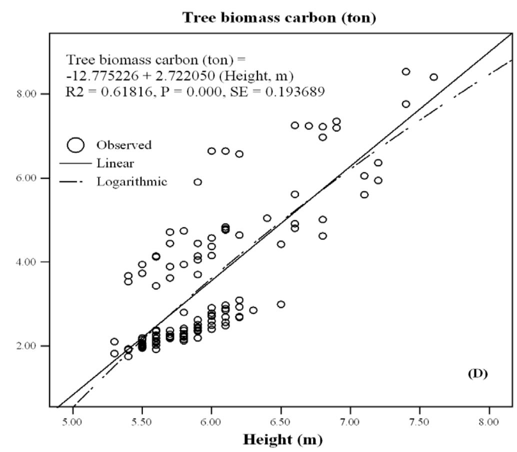
Sl. #	Species	A	B	C	R2	P	SE	Sb
1a	*Acacia auriculiformis*[a]	-12.210177	1.012868		0.95098	0.000	0.79834	0.021169
1b	*Acacia auriculiformis*[b]	-35.253961	5.115048		0.84911	0.000	1.40069	0.198496
1c	*Acacia auriculiformis*[c]	-2.983150	3.417323		0.92998	0.000	0.95419	8.725385
1d	*Acacia auriculiformis*[d]	-21.578	0.724	1.802	0.939	0.000	0.52249	0.1022
2a	*Anthocephaluschinensis*[a]	-6.525867	0.514410		0.94609	0.000	0.39228	0.011118
2b	*Anthocephaluschinensis*[b]	12.775226	2.722050		0.61816	0.000	1.04397	0.193689
2c	*Anthocephaluschinensis*[c]	-0.835384	1.212458		0.88227	0.000	0.57968	4.835581
2d	*Anthocephaluschinensis*[d]	-9.923	0.427	0.852	0.920	0.000	0.24216	0.1054
3a	*Tectonagrandis*[a]	-10.303667	0.800979		0.94116	0.000	0.67301	0.017702
3b	*Tectonagrandis*[b]	-15.344317	2.686953		0.70786	0.000	1.49964	0.152573
3c	*Tectonagrandis*[c]	-1.230774	2.260484		0.89594	0.000	0.80504	6.635037
3d	*Tectonagrandis*[d]	13.441	0.643	0.808	0.929	0.000	0.49333	0.1032

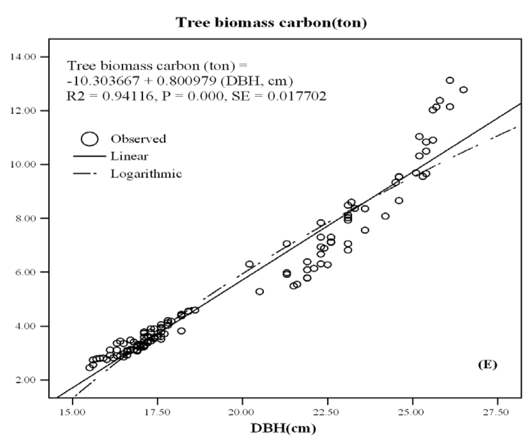
Notes: The allometric models are as follows: Y = A + BX1 a, Y=A+BX2b, Y=A+BX3c, Y=A+BX1+CX2d Where, Y is biomass carbon stock (ton), X1 is diameter at breast height (m), X2 is total height (m), X3 is basal area (m2), A, B, C is regression coefficient, respectively; R2 is coefficient of determination; P is level of significance, SE is standard error; and Sb is error of regression coefficient 'b'.











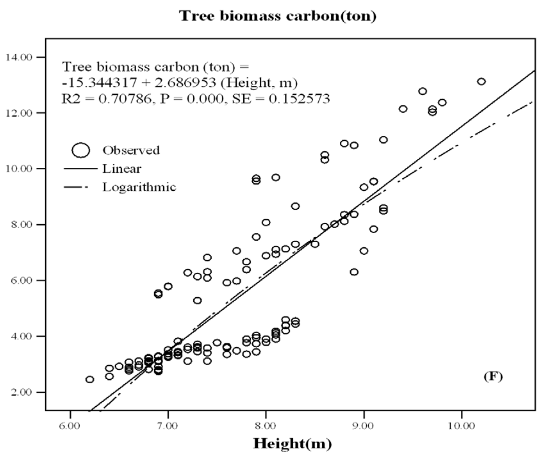


Figure 3. Allometric models were developed for tree biomass carbon estimation of *Acacia auriculiformis*[A, B,] *Anthocephalus chinensis*[C, D]and *Tectona grandis*[E,F]*plantations.*

4. Conclusion

The results clearly shows the capacity of three 18-year old plantations of *Acacia auriculiformis*, *Anthocephalus chinensis* and *Tectona grandis* to sequester atmospheric carbon and that reforestation makes a significant contribution to carbon sequestration and generating carbon credits in Bangladesh. The carbon stock of three plantation species indicates that Bangladesh has a capacity for carbon sequestration. *Acacia auriculiformis* and *Tectona grandis* both are exotic tree species in Bangladesh but now becoming common species due to most of the land coverage through plantation and their economic values, and therefore it is essential to conduct study for estimating carbon stock. A continued increase in carbon stock and their accumulation rates under all plantation species along with plantation age indicated a progressive development of soil.

From different models, it is found that Y = A + BX1 , where Y is biomass carbon stock in ton and X1 is diameter at breast height in cm for DBH range of ≥10 cm cm is the most suitable model to estimate tree biomass carbon. To overcome the problem of global warming and climate change, sustainable forest management is the best way to achieve optimum carbon sequestration; and easy, more applicable and fast scientific methods are required to estimate the carbon stock in plantation forest. In the present study, the estimation of carbon stock by using allometric models can be directed to researchers and administrators to analyze for global carbon credit, which can be helpful to develop the forestry and environmental sectors like Bangladesh and other tropical countries with similar environment.

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6. References

1. Alam M L, Saheed S M, Shinagawa A. Chemical Properties of General Soil Types of Bangladesh. Mem. Fac. Agr. Kagoshima Univ. 1993, 29: 75–87.

2. Alamgir M, Al-Amin M. Regeneration status in a proposed biodiversity conservation area of Bangladesh. Proceeding Pakistan Academic Science, 2007, 44(3): 165–172.

3. Althoff P, Chandler D E. Carbon inventory in a Eucalyptus camaldulensis plantation compared with natural vegetation in Brazil. Fields Tests of Carbon Monitoring Methods in Forestry Projects. Forest Carbon Monitoring Program. Winrock International Institute for Agricultural Development, USA. 1999.

4. Allen S E, Grimshaw H M, Rowland A P. Chemical analysis. In: Moore P D and Chapman S B (eds.), Methods in Plant Ecology. America: Blackwell Scientific Publications. 1986, 285–344.

5. Alves D S, Soares J V S, Amaral E M K, Mello S A S, Almeida O, Fernandes S, Silveira A M. Biomass of primary and secondary vegetation in Rondonia, western Brazilian Amazon. Global Change Biology. 1997, 3: 451–462.

6. Anon. 2000. Environmental Matters. World Bank, 65.

7. Anon. National Forest and Tree Resources Assessment 2005-2007-Bangladesh. Nipun Printing Industries Ltd. 2000, 280.

8. Bass S, Dubosis O, Moura Costa P, Pinard M, Tipper R, Wilson C. 2000. Rural Livelihood and Carbon Management. Natural Resource Issues Paper No. 1. International Institute for Environment and Development Eco Securities Ltd. University of Aberdeen, London. 94.

9. Brady, N C. The Nature and Properties of Soils. Prentice, Hall of India Private Limited, New Delhi-110001. 1996. 75–76

10. Brown S A J, Gillespie J R, Lugo A E. Biomass estimation methods for tropical forests with application to forest inventory data. Forest Science. 1989, 35(4): 881–902.

11. Brown S. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper No. 134, Rome, Italy. 1997, 165.

12. Brown S, Masera O, Sathaye J. Project–based activities. In: Watson R T et al. (eds.), Land Use, Land-Use Change, and Forestry. Cambridge University Press, Cambridge. 2000.

13. FAO (Food and Agriculture Organization). Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper No. 112. Rome, Italy. 1997, 134.

14. Goodale C L, Apps M J, Birdsey R A, Field C D, Heath L S, Houghton R A. Forest carbon sinks in the Northern Hemisphere. Ecological Applications. 2002, 12(3): 891–899.

15. Hossain M K. Growth Performance and Critics of Exotics in the Plantation Forestry of Bangladesh. The paper submitted to the XII World Forestry Congress, held at Quebec City, Canada. 2003.

16. Huq I S M, Alam M D (eds.). A handbook on Analyses of Soil, Plant and Water. BACER-DU, University of Dhaka, Bangladesh. 2005, xxii: 246.

17. Islam K R, Kamaluddin M, Bhuiyan M K, Badruddin A. Comparative performance of exotic and indigenous forest species for tropical semi evergreen degraded forest land reforestation in Chittagong, Bangladesh. Land Degradation & Development. 1999, 10: 241-249.

18. Lasco, R D, Pulhin F B. Carbon Budgets of Forest Ecosystems in the Philippines. Journal of Environmental Science and Management. 2009, 12(1): 1–13.

19. Luckman A, Baker J, Mora T, Corina da Costa F, Frery C A. A study of the relationship between radar backscatter and regeneration tropical forest biomass for spaceborne SAR instruments. Rem. Sen. Env. 1997, 60: 1–13.

20. MacDicken K G. A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects.Winrock International Institute for Agricultural Development, Arlington. 1997.

21. Mabud A. Integrated Forest Management Plan for the Chittagong Forest Division (2000-2009). Forest Department. Bangladesh Ministry of Environment and Forests. Dhaka. Bangladesh. 2001.

22. Mollah A R, Kundu D K. Site-Level Field Appraisal for Protected Area Co-Management: Lawachara National Park. 2004, 34.

23. Montagnini F, Porras C. Evaluating the role of plantations as carbon sinks: An example of integrative approach from the humid tropics. Environmental Management. 1998, 22: 459–470.

24. Moura–Costa P. Tropical forestry practices for carbon sequestration. In: Zchulte A, Schone D (eds.), Dipterocarp Forest Ecosystem: Towards Sustainable Management. World Scientific, Singapore. 1996, Pp. 308–334.

25. Myers N. The world's forests: problems and potentials. Environmental Conservation. 1996, 23: 156–168.

26. Negi J D S, Sharma S C, Sharma D C. Comparative assessment of methods for estimating biomass in forest ecosystem. Indian Forester. 1988, 114(3): 136–146.

27. Osman K T, Islam M S, Haque S M S. Performance of some fast growing trees in the University of Chittagong Campus. Indian Forester. 1992, 118(11): 858–859.

28. Osman K T, Rahman M M, Barua P. Effect of some tree species on soil properties in Chittagong University campus, Bangladesh. Indian Forester. 2001, 127(4): 431–442.

29. Rawat V, Singh D, Kumar P. Climate Change and its impact on forest biodiversity. Indian Forester. 2003, 129(6): 787–789.

30. Sá, T D de A, Vielhauer K, Kanashiro M, Denich M, Vlek P L G. Towards improving natural resources use in Eastern Amazonia through a modified sequential agroforestry system. Apresentadocomopainel no II CongressoBrasileiroemSistemasAgroflorestais, Belém, Brasil. 1998.

31. Sattar M A, Bhattacharjee D K, Kabir M F. Physical and Mechanical Properties and Uses of Timbers of Bangladesh. Seasoning and Timber Physics Division, Bangladesh Forest Research Institute, Chittagong, Bangladesh. 1999, 57.

32. Schroeder P, Brown S, Birdsey J M R, Cieszewski C. Biomass estimation for temperate broadleaf forests of the US using inventory data. ForestScience. 1997, 43: 424–434.

33. Singh A N. Structure, functioning and impact of young plantations of four native woody species on coal mine spoil. PhD Thesis, Banaras Hindu University, Varanasi. 1999.

34. Singh A N, Raghubanshi A S, Singh J S. Comparative performance and restoration potential of two Albiziaspecies planted on mine spoil in a dry tropical region, India. Ecological Engineering. 2004a, 22: 123–140.

35. Singh A N, Raghubanshi A S, Singh J S. Impact of native tree plantations on mine spoil in a dry tropical environment. Forest Ecology and Management. 2004b, 187: 49–60.

36. Shin M Y, Miah M D, Lee K H. Potential contribution of the forestry sector in Bangladesh to carbon sequestration. Journal of Environmental Management. 2007, 82: 260–276.

37. UNFCCC (United Nations Framework Convention on Climate Change). Report of the conference of the parties on its ninth session held at Milan from 1 to 12 December; art two: action taken by the conference of the parties at its ninth session. Website of Bangladesh Forest Department. 2004.

38. Watson R T, Noble I R, Bolin B, Ravindranath N H, Verado D J, Dokken D J (eds.). Land Use, land Use Change, and Forestry. Cambridge University Press, Cambridge. 2000.