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RESEARCH PAPER

# Allometric models to estimate biomass organic carbon stock in forest vegetation

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**Abstract**: A study was conducted in the forest area of Chittagong (South) Forest Division, Chittagong, Bangladesh for developing allometric models to estimate biomass organic carbon stock in the forest vegetation. Allometric models were tested separately for trees (divided into two DBH classes), shrubs, herbs and grasses. Model using basal area alone was found to be the best predictor of biomass organic carbon stock in trees because of high coefficient of determination ($r^2$ is 0.73697 and 0.87703 for > 5 cm to ≤ 15 cm and > 15 cm DBH (diameter at breast height) rang, respectively) and significance of regression (*P* is 0.000 for each DBH range) coefficients for both DBH range. The other models using height alone; DBH alone; height and DBH together; height, DBH and wood density; with liner and logarithmic relations produced relatively poor coefficient of determination. The allometric models for dominant 20 tree species were also developed separately and equation using basal area produced higher value of determination of coefficient. Allometric model using total biomass alone for shrubs, herbs and grasses produced higher value of determination of coefficient and significance of regression coefficient ($r^2$ is 0.87948 and 0.87325 for shrubs, herbs and grasses, respectively and *P* is 0.000 for each). The estimation of biomass organic carbon is a complicated and time consuming research. The allometric models developed in the present study can be utilized for future estimation of organic carbon stock in forest vegetation in Bangladesh as well as other tropical countries of the world.

**Keywords**: allometric models; organic carbon stock; tree; herbs; shrubs; grasses

## Introduction

It is well established that global climate is changing day by day as a result of natural variability and anthropogenic causes. This includes the change in the atmospheric composition, hydrological cycle, solar inputs and finally in the land surface (Negi et al. 2003). Global changes are occurring in many ways: atmosphere, land-use and now also in climate (Mooney et al. 1999; Huang et al. 2000; IPCC 1996, 2001, 2002; CPCB 2002). In recent years, the few global issues that have received more attention of scientists, resource mangers, policy makers and public undoubtedly are climate change (Tiwari et al. 1987). Increasing carbon emission is one of today's major concerns, which was well addressed in Kyoto Protocol (Ravindranath et al. 1997) because it is the main causal factor for global warming (Lal 2001). Developing countries like Bangladesh are mostly affected by the consequences of "Global Warming" (Anon 2000). If the increase of air temperature continues at the present rate, by the end of the year 2030, sea level will rise by 20 cm, and at the end of this century it will rise by one meter. As a result, low lying countries of the world may go under water partly or wholly and consequently Bangladesh will be greatly affected (Miah 2002).

Each year, as forests grow and their biomass increase, they absorb carbon from the atmosphere and store it in the plant tissue (Matthews et al. 2000), so forests play multiple and significant roles in regulating atmospheric concentrations of carbon dioxide (Rotter et al. 2002). Active absorption of $CO_2$ from the atmosphere through photosynthesis, and its subsequent storage in the biomass of growing trees or plants is the carbon storage (Baes et al. 1977). It was reported that a hectare of actively growing forest can sequesters 2–5 t of carbon per year (Brown 1996), so forests play an important role in sequestration of carbon globally (Rawat et al. 2003). A realistic estimate of the carbon stock at any given time is crucial for two reasons. First, it indicates the potentiality of vegetation to release or absorb carbon. Secondly, a time series of the carbon stock in vegetation can be used to strain methods such as inverse modeling in estimating the net carbon flux to or from the global soils (Goodale et al. 2002).

Global warming is a burning issue and forest is acting as an important carbon pool. However, very few researches have been conducted sporadically to measure the potentiality of forest of

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Bangladesh in carbon sequesters process. This may be due to an unestablished method of biomass determination of forest vegetation particularly in the context of Bangladesh. Some equations were developed by many researchers (Brown et al. 1989; Negi et al. 1988). Such equations are species specific and others, particularly in the tropics, are more general in nature (Alves et al. 1997; Brown 1997; Schroeder et al. 1997). Some equations were developed by Negi et al. (1988) for determination of biomass of forest vegetation of India. It is a necessity to develop models, which can be used for future research in Bangladesh and also in other tropical countries for the respective species, to estimate organic carbon in the biomass of forest vegetation. Distribution of natural forest throughout Bangladesh is not uniform. Forest distribution is concentrated only in the 12 districts in Bangladesh and there is no forest distribution in 28 densely populated districts (Anon 1992). Major part of the hill forest is situated in the Chittagong, Cox's Bazar and Sylhet Forest Division. The present study was conducted in the geoposition of Chittagong (South) Forest Division, Chittagong, Bangladesh, since the environment of these areas is more or less similar.

## Methodology

### Study area

The study is conducted at the forest area of Chittagong (South) Forest Division within the geoposition between 91°47' and 92°15' East longitude and 21°45' and 22°30' North latitude. It covers about 540 $km^2$ (Mabud 2001). The study area has a moist tropical maritime climate, with high rainfall concentrated during the monsoon period from June to September. The relative humidity remains high, 70% to 85% with only minor variation throughout the year. Temperature also remains high with only small seasonal differences. Pre-monsoon storms from March to May forming in the Bay of Bengal often cause severe damage to onshore plantation (Mabud 2001). 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 (Mabud 2001). 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 relative humidity is generally high throughout the year with the exceptions of January and February. The average annual humidity is 75% with monthly ranges from 65% in February to 90% in June to July (Mabud 2001).

### Methods

The study was carried out over one year period from January 2004 to January 2005 through physical measurement, field observation and laboratory analysis. In the study Grid lines at 2.5' intervals was inserted in the map from 91°47' to 92°15' East longitude and 21°45' to 22°30' North latitude. In this way 102 intersection points was pointed in the map. In the field each point was identified by using Global Positioning System (GPS). Primarily, the landuse of each intersection point was identified in the field and a total of 31 intersection points in forest area of Chittagong (South) Forest Division was identified. Around each intersection point, four sampling plots of 20 m×20 m were selected for tree species, and in the center of each intersection point, a sampling plot of 2 m×2 m was selected for shrubs, herbs and grasses. Totally 124 sampling plots of 20 m×20 m were set up for tree and 31 sampling plots of 2 m×2 m were set up for shrub, herb and grass investigation. In each sampling plot of trees, DBH and height of each tree were measured and samples were collected from a representative tree of each species for laboratory analysis to estimate organic carbon. In each sampling plot of shrubs, herbs and grasses, number of each species were counted and a representative sample of each species was uprooted.

**Biomass estimation in trees**

About 1 400 individuals of 144 tree species were measured in the sampling plots. It is not possible to cut all the trees to estimate biomass of trees. Consulting models developed by FAO (1997), Luckman et al. (1997), Negi et al. (1988) and Brown et al. (1989), the model developed by Brown et al. (1989) was used to estimate above ground biomass because literature showed that this method is one of the most suitable methods for tropical forest (Alves et al. 1997; Brown 1997; Schroeder et al. 1997; FAO 1997).

The model is as follows:

$$Y = \exp.\{-2.4090 + 0.9522\ \mathrm{In}\ (D^2 \times H \times S)\} \qquad (1)$$

where, Exp. = [ ……] means "raised to the power of […….]", $Y$ is the above ground biomass (kg), $H$ the Height of the trees (meter), $D$ the Diameter at breast height (1.3m) in cm, $S$ theWood density ($t/m^3$). Below ground biomass was calculated considering 15% of the above ground biomass (MacDicken 1997).

### Biomass estimation in shrubs, herbs and grasses

The field samples were separated into the above ground and below ground identifying collar region. The fresh weight of above ground and below ground was taken separately and multiplied with number of individuals of the species in each plot to get total above and below ground biomass of the species in the plot. Mean above ground, mean below ground and mean total biomass of the species was calculated.

### Estimation of organic carbon storage in trees, shrubs, herbs and grasses

After taking the fresh weight, the collected samples were dried in the oven for 48 hours at 65°C to get dried weights. Oven dried grind samples were taken (1.00 g) in pre-weighted crucibles. The crucibles were placed in the furnace at 550ºC for one hour. The crucibles were cooled slowly inside the furnace. After cooling, the crucibles with ash were weighted and percentage of organic carbon was calculated as Allen et al. (1986).

$$A_{sh}(\%) = (W_3 - W_1)/(W_2 - W_1) \times 100 \quad (1)$$

$$C(\%) = (100 - A_{sh}\%) \times 0.58 \quad (2)$$

where, $C$ is the organic carbon, $W_1$ the weight of crucibles, $W_2$ the weight of oven dried grind samples + Crucibles, $W_3$ is the weight of ash + Crucibles.

In order to get total amount of organic carbon in each tree, the amount of organic carbon in the both above and below ground biomass of tree, shrubs, herbs and grasses was calculated separately and added finally. Mean value for organic carbon percentage, above ground organic carbon, below ground organic carbon and total organic carbon was calculated from total individuals of a species and also converted in $t \cdot ha^{-1}$ or $kg \cdot ha^{-1}$ for each species.

### Allometric models for estimation of biomass organic carbon in tree

Six models were tested and verified for all species. During verification with other research results of organic carbon it was found that all equations were not suitable for all diameters at breath high (DBH) classes. So the models were tested separately for different DBH classes. To get best fit equation, six allometric models for all species and five allometric models for twenty dominant tree species for two different DBH classes (>5 cm to ≤15 cm and > 15 cm) were tested by using SPSS software for statistical analysis. The best fit model was accepted to estimate organic carbon in the tree biomass of the respective species based on $r^2$ value and standard error.

For trees at DBH of > 15 cm, the following models were tested for twenty dominant species

**Model 1.** $Y = A + B \times X_1$ and $\log y = A + B \log X_1$

**Model 2.** $Y = A + B \times X_2$ and $\log y = A + B \log X_2$

**Model 3.** $Y = A + B \times X_3$ and $\log y = A + B \log X_3$

**Model 4.** $Y = A + B \times X_1 + C X_2$

**Model 5.** $\log y = A + B \log X_1 + C \log X_2$

In addition to these allometric models for all the species, the following model was also tested for DBH range of >5cm to ≤15 cm and > 15cm.

**Model 6.** $Y = A + B \times X_1 + C \times X_2 + D \times X_4$

where, $Y$ is the biomass organic carbon (tonne); $X_1$ the diameter at breast height (DBH) (cm), $X_2$ the total Height (m), $X_3$ the basal area ($m^2$). $X_4$ the wood density ($t/m^3$), and A, B, C, D is the regression co-efficient, respectively.

### Allometric models for organic carbon estimation of shrubs, herbs and grasses

To develop allometric models for estimating organic carbon stock in shrubs, herbs and grasses, the following three models were tested separately for shrubs and herbs and grasses.

**Model 7.** $Y = A + B X_1$ and $\log y = A + B \log X_1$

**Model 8.** $Y_1 = A + B X_1$ and $\log y_1 = A + B \log X_1$

**Model 9.** $Y = A + B X_2$ and $\log y = A + B \log X_2$

where, $Y$ is the biomass organic carbon stock (g), $Y_1$ is the above ground biomass organic carbon (g), $X_1$ the above ground biomass (g), $X_2$ the total biomass (above ground +below ground) (g), and A, B is the regression co-efficient, respectively.

## Results and discussion

### Allometric models to estimate organic carbon in trees

In the study, allometric equations were tested and developed separately for twenty dominant tree species in DBH range of >15cm. It was found that the developed models of *Alstonia scholaris*, *Artocarpus chaplasha* and *Artocarpus lacucha* were suitable for DBH ranging ≥17cm, ≥17cm and ≥16cm, respectively. Five sets of equation considering DBH, height, basal area, and both DBH and height for linear and log-log relations were tested for each species. However, the results predicted that only basal area was the good predictor for biomass organic carbon (Table 1). Coefficients of determination ($r^2$) for the allometric equations relating to basal area and biomass organic carbon were above 0.9 for all species. Regression of DBH, height, DBH and height all were significant relating to biomass organic carbon ($P$ = 0.000) but produced lower $r^2$-value. Model for basal area relating to biomass organic carbon produced higher coefficients of determination ($r^2$) than other allometric models for each species. In the present study, allometric models for other species except the twenty dominant species were also developed. The result revealed that irrespective of species the basal area of trees was the best predictor for biomass organic carbon. The basal area of species relating to biomass organic carbon had the highest $r^2$ value (0.89041) and highly significant relations ($P$ = 0.000). Though the other tested variables (DBH alone, height alone, DBH and height, DBH, height and wood density together) had highly significant ($P$ = 0.000) relations, their $r^2$ values were lower. The log-log relations of independent variables and biomass organic carbon were also tested for all the species. They produced lower $r^2$ value than normal linear models.

Six sets of equations as DBH alone, height alone, basal area alone, DBH and height, the DBH, height and basal area together, and the DBH, height and wood density together for linear and log-log relations were tested for trees of two DBH ranges (>5cm to ≤15cm and > 15cm). For both DBH ranges, the basal area alone was found to be the best predictors for biomass organic carbon. All the independent variables tested relating to biomass organic carbon was highly significant ($P$ = 0.000) but produced lower $r^2$ value than basal area. The allometric model of DBH range of ≥ 15cm produced $r^2$ value 0.87703 and the allometric model of DBH range of >5cm to <15cm produced $r^2$ value of 0.73697 for basal area relating to biomass organic carbon which was the highest among all the tested models (Fig. 1. and Fig. 2).

For both DBH ranges (>5cm to ≤15cm and > 15cm), log–log relations of biomass organic carbon with DBH alone, height alone, basal area alone, both DBH and height, and DBH, height and wood density together were tested, but it was found that they produced lower $r^2$ value than linear basal area.

**Table 1. Coefficient of determination and significance of the allometric model relating to biomass organic carbon and growth parameters for 20 dominant trees**

| Sl. No. | Species name | A | B | $r^2$ | $P$ | DBH range (cm) |
|---|---|---|---|---|---|---|
| 01 | *Albizia lebbeck* | -0.197329 | 22.166233 | 0.95586 | 0.000 | ≥15 |
| 02 | *Albizia procera* | -0.421075 | 24.809910 | 0.88799 | 0.000 | ≥15 |
| 03 | *Albizia saman* | -0.148089 | 13.267731 | 0.94415 | 0.000 | ≥15 |
| 04 | *Alstonia scholaris* | -0.371891 | 17.020147 | 0.94579 | 0.000 | ≥17 |
| 05 | *Aphanamixis polystachya* | -0.355382 | 23.712272 | 0.96536 | 0.000 | ≥15 |
| 06 | *Artocarpus chaplasha* | -0.581639 | 28.192082 | 0.98229 | 0.000 | ≥17 |
| 07 | *Artocarpus heterophyllus* | -0.125404 | 15.474200 | 0.98756 | 0.000 | ≥15 |
| 08 | *Artocarpus lacucha* | -0.453032 | 23.313679 | 0.97622 | 0.000 | ≥16 |
| 09 | *Bombax ceiba* | -0.255484 | 15.542905 | 0.98137 | 0.000 | ≥15 |
| 10 | *Dipterocarpus turbinatus* | -0.516093 | 31.986985 | 0.97443 | 0.000 | ≥15 |
| 11 | *Dubanga grandifolia* | -0.353313 | 20.954494 | 0.94276 | 0.000 | ≥15 |
| 12 | *Gmelina arborea* | -0.117007 | 14.377647 | 0.96669 | 0.000 | ≥15 |
| 13 | *Hopea odorata* | -0.103491 | 20.372012 | 0.98925 | 0.000 | ≥15 |
| 14 | *Lagerstroemia speciosa* | -0.074635 | 15.326061 | 0.98784 | 0.000 | ≥15 |
| 15 | *Shorea robusta* | -0.152190 | 23.543551 | 0.98599 | 0.000 | ≥15 |
| 16 | *Swetenia mahagoni* | -0.079143 | 15.535524 | 0.99599 | 0.000 | ≥15 |
| 17 | *Swintonia floribanda* | -0.236538 | 20.314057 | 0.96907 | 0.000 | ≥15 |
| 18 | *Syzygium grande* | -0.221170 | 23.537777 | 0.95675 | 0.000 | ≥15 |
| 19 | *Tectona grandis* | -0.243989 | 21.267652 | 0.91041 | 0.000 | ≥15 |
| 20 | *Terminalia bellirica* | -0.221347 | 21.446552 | 0.98442 | 0.000 | ≥15 |
| 21 | All species except above species | -0.118030 | 17.749190 | 0.89041 | 0.000 | ≥15 |

**Notes**: The allometric model is as follows: $Y$ = A + B (BA), where, $Y$ is the organic carbon content in tree biomass (tonne); B, A is Basal area ($m^2$), respectively.

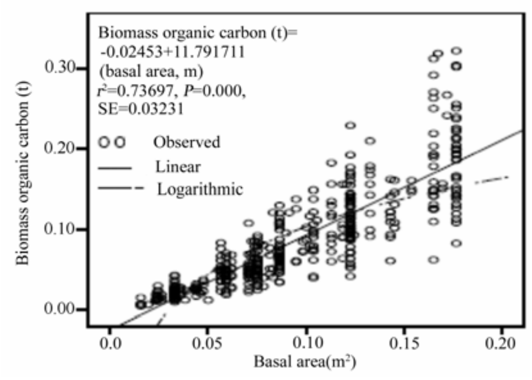


**Fig. 1 Allometric model of biomass organic carbon (t) versus basal area ($m^2$) developed for estimating biomass organic carbon in trees of >5cm to <15cm DBH rang**

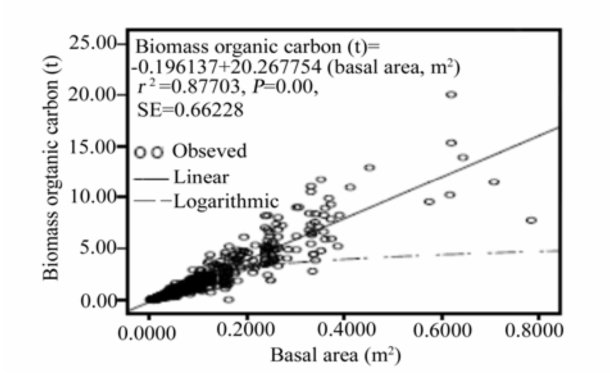


**Fig. 2 Allometric model of biomass organic carbon (t) versus basal area ($m^2$) developed for estimating biomass organic carbon in trees of ≥15cm**

Allometric models to estimate organic carbon in shrubs, herbs and grasses

Two allometric models were developed separately for above ground biomass of shrubs (g) and herbs and grasses (g) relating to the biomass organic carbon (g). For each model, linear and log–log relation were tested and the linear relation produced higher value of coefficient of determination ($r^2$) than log-log relations. For shrub, model relating to above ground biomass (g) as dependent variable and biomass organic carbon (g) as independent variable produced $r^2$ value 0.87201 and was highly significant ($P$ = 0.000) for linear relation. Model relating to above ground biomass (g) and above ground organic carbon (g) also produced $r^2$ value (0.89708) and was highly significant ($P$ = 0.000) for linear relation (Table 2).

In herbs and grasses, model relating to above ground biomass (g) and biomass organic carbon (g) produced coefficient of determination ($r^2$) value of 0.79007 for normal linear equation, which was higher than log-log relation, and the model relating above ground biomass (g) and above biomass organic carbon (g) produced $r^2$ value (0.88751) for normal liner equation, which was also higher than log-log relation (Table 2).

**Table 2. Model parameters, coefficient of determination and significance of the allometric model relating to biomass organic carbon and above ground biomass in the shrubs and herbs and grasses**

| Category | Models | A | B | $r^2$ | $P$ | SE | Sb |
|---|---|---|---|---|---|---|---|
| Shrubs | $Y = A + B (A_{GB})$ | 0.696735 | 0.536662 | 0.87201 | 0.000 | 1.63317 | 0.019877 |
| | $Y_1 = A + B (A_{GB})$ | -0.379625 | 0.500132 | 0.89708 | 0.000 | 1.34561 | 0.016377 |
| Herbs and grasses | $Y = A + B (A_{GB})$ | 0.467592 | 0.459782 | 0.79007 | 0.000 | 1.17911 | 0.018975 |
| | $Y_1 = A + B (A_{GB})$ | -0.004515 | 0.400509 | 0.88751 | 0.000 | 0.70937 | 0.011416 |

**Notes:** A & B---- regression coefficient, respectively, $r^2$ ---- Coefficient of determination; SE----standard error; Sb ---- error of regression coefficient 'b'; $Y$---- Biomass organic carbon (g); $Y_1$---- above ground organic carbon (g); $A_{GB}$ ----Above ground biomass (g).

In the present study, allometric models were also developed to estimate the biomass organic carbon by total biomass of shrubs, herbs and grasses (Fig. 3, 4).

Linear and log-log relations for total biomass and biomass organic carbon were tested. For each model, linear relations produced higher value of coefficient of determination ($r^2$) than log-log relations. The $r^2$ value for total biomass (g) relating to biomass organic carbon (g) is 0.87948 in shrubs and 0.87325 in herbs, and in all models, biomass organic carbon is highly significant ($P$ = 0.000) with total biomass of shrubs, herbs and grasses (Fig. 3, 4).

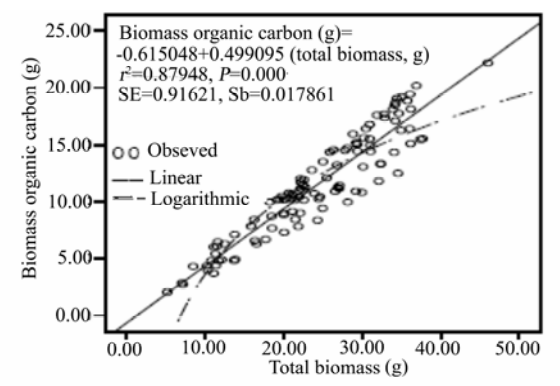


**Fig. 3 Allometric model of biomass organic carbon (g) versus total biomass (g) developed for estimating biomass organic carbon in shrubs**

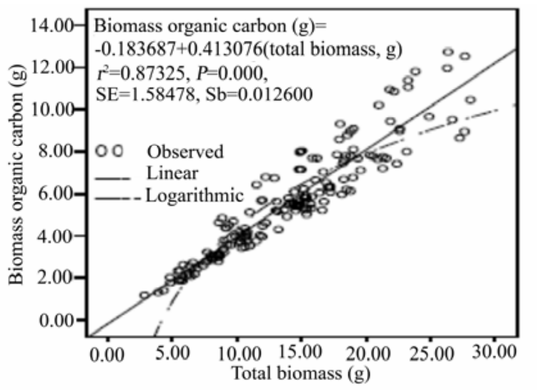


**Fig. 4 Allometric model of biomass organic carbon (g) versus total biomass (g) was developed to estimate biomass organic carbon in herbs and grasses**

Climate change is the most important present concern of the world. It is believed to be a function of concentration of green house gases particularly carbon dioxide (Rotter and Danish 2002). Forest has the capacity to sequester carbon from the atmosphere and same to store in organic form. Kyoto Protocol recognizes that forest may be the best land used as a sink and sources of atmospheric carbon (Ross 2000).

The Protocol's proposed "Clean Development Mechanism" is intended to provide credit for the projects in developing countries that both promote sustainable development and mitigate climate change. It also demonstrates the Bank's commitment to catalyze the market mechanisms in order to help developing countries benefit from carbon finance (PCF 2001). Environmental degradation in terms of greenhouse gases, carbon dioxide emission, thinning of ozone layer, land degradation, water scarcity, deforestation and other calamities like food and cyclone, etc. caused by anthropogenic and natural reasons have been a threat to the well being of people (Anon 2001). Forest has three major roles in climate change as: a source of $CO_2$ when destroyed or degraded; react sensitively to changing climate; and sustainably managed forests to provide a unique environmental service by removing $CO_2$ from the atmosphere and by offering an alternative to fissile fuels (Schoene 2002).

## Conclusion

From different models, it is found that $Y = A + B\,X$ , where $Y$ is the biomass organic carbon in tonne and $X$ is the basal area in m$^2$, for both DBH range of trees (> 5 cm to ≤ 15 cm and > 15 cm) is the most suitable equation to estimate tree biomass organic carbon stock. Allometric model $Y = A + B\,X$ , where $Y$ is the biomass organic carbon and $X$ is the total biomass, is the most accepted equation to estimate biomass organic carbon stock in shrubs, herbs and grasses.

To rescue the world from global warming and climate change, the sustainable management of forest with the objectives of carbon sequestration is mandatory. Before applying the approach of forest management, quantification of organic carbon in the different strata of forest is necessary. And to quantify organic carbon sequestration potential of a forest accurate, easy and fast scientific method is required. The present study will unbolt a new arena in this aspect of forest management for Bangladesh and other tropical countries with similar environment.

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