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Estimation of Ecosystem Carbon Stock and Tree Species Diversity at National Botanical Garden, Dhaka, Bangladesh

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MFH and MSI planned the experiment and lead the research. Authors MFH, MSI and MDH designed and carried out the research. Author MEH performed the statistical analysis. Authors MDH, MNIS and MS carried out the research on the field. Authors MDH, SA, MS and MNIS collected the data. Authors MEH and MDH wrote the manuscript. Authors MDH and SA managed the literature searches. All authors provided critical feedback and helped shape the research, analysis and final manuscript.

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ABSTRACT

The study was conducted from January to April 2018 to estimate ecosystem carbon stock and tree species diversity at National Botanical Garden, Bangladesh. Transects line method square plots with a size of 20 m × 20 m were used. So altogether there were total eighty-three sample plots in National Botanical Garden. Above ground carbon (AGC) and below ground carbon (BGC) biomass

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stock was 192.67 and 31.34, respectively and soil organic carbon mean value of 27.52 Mg ha^{-1}, 21.45 Mg ha^{-1} and 16.23 Mg ha^{-1}, respectively for 0-10 cm depth, 10-20 cm and 20-30 cm depth. The average number of tree species per hectare was 128 with a mean value of each plot 3.00 to 9.00 species. The average number of trees in National Botanical Garden (233 tree ha^{-1}), basal area (21.45 m^2 ha^{-1}) and mean DBH (39.86 cm). Tree diversity range from 0.25 to 1.86 and the mean value of (0.93 ± 0.14) in National Botanical Garden. A relationship such as biomass carbon with the basal area, mean DBH, stem density and tree diversity were estimated. Among these, the relationship between basal area and biomass carbon showed positive significant correlation. Therefore, the results of the study confirmed that the selected botanical garden can serve as a valuable ecological tool in terms of carbon sequestration, diverse tree species and storage of soil organic carbon.

Keywords: Biomass; carbon stock; diversity; ecosystem and tree species.

1. INTRODUCTION

Climate change, the outcome of anthropogenic global warming is the single biggest environmental crisis facing Earth, which may lead to unfathomable humanitarian disasters [1,2]. In the fifth assessment (AR5) of 2014, the Intergovernmental Panel on Climate Change (IPCC) asserted increasing concentrations of greenhouse gases (GHG) mainly from anthropogenic activities as the cause of global warming [3]. AR5 climate model projected a rise of average global surface temperature by 0.3-1.7ºC and 2.6-4.8ºC, respectively, under the lowest and the highest emission scenarios [4]. AR6 expected to limit the global warming within 1.5ºC (IPCC, 2018) by keeping GHG emission under check through internationally binding instruments [5] including carbon quota, Clean Development Mechanism (CDM). The Government of Bangladesh is taking initiatives to meet up nation-wide carbon stock data and prepared the REDD+ Readiness Roadmap [6]. As a signatory of the Kyoto protocol, Bangladesh needs accurate estimations of existing carbon stocks throughout the country to implement carbon trading CDM projects [7]. The reliable quantification of carbon sequestration by vegetation will help the policymakers, researchers, and entrepreneurs of Bangladesh to sell Certified Emission Reduction to developed countries [8,9] in global carbon markets under REDD+ and CDM as they need to offset their higher per capita carbon emission. Carbon estimation is also necessary for Bangladesh to implement climate change mitigation policies [7]. As forests, trees, or vegetation acts as the carbon sink, these can be used in devising mechanisms to cope with the adverse impact of global climate change. Achievement of full carbon mitigation potential requires estimation of country-level carbon stocks through statistically validated methods [10].

Estimation of above-ground biomass (AGB) is an essential aspect for the estimation of carbon stocks and effects of deforestations and carbon sequestration on global carbon balance [11]. It is also a useful measure for comparing structural and functional attributes of forest ecosystems across a wide range of environmental condition [12]. Carbon stock estimation includes quantification of soil organic carbon, the carbon in living trees, understory vegetation, woody debris, and litters of forest floor in form of above-ground carbon and below-ground carbon [13]. In Bangladesh, researchers have estimated carbon stocks in different forms at different parts of the country and have developed allometric models. However, most of the available estimation is limited to the application of a few variables that miss the vast pools of ecosystem carbon [14]. Again, most of the works reflect allometric equation of some common tree species, palm, and shrub species. Globally, about 60% of the carbon is stored in forests, with about 12-20% of anthropogenic greenhouse gas (GHG) emissions being attributable to forest degradation and loss [15]. Tree species are known to affect soil through the absorption of nutrients and water from and the addition of litter to different soil layers [16]. Some studies have demonstrated that tree species diversity can lead to higher mineral soil carbon stocks and pH [17] or increase soil carbon stocks and the C/N ratio [18].

Other studies have demonstrated that tree species diversity has no effect on plant-available nitrogen in the soil compared to each mono-species with mixed-species stands [19]. However, it is still unknown whether species diversity provides a positive effect on soil nutrient status in a certain forest ecosystem, although previous studies have shown that species diversity promotes productivity and the aboveground carbon stock [20,21]. Species identity is an important driver of soil properties, especially in the forest topsoil layer [18].

Soil contains about three times more organic carbon than vegetation and about twice as much carbon than is present in the atmosphere [22]. Terrestrial vegetation and soil currently absorb 40% of global CO_2 emission from human activities. So, soil in the urban park can also play in climate change mitigation. Worldwide, the forests and species biodiversity and number of trees are being degraded. So, in this aspect urban green space can play an important role in conserving tree diversity. Diversity of tree species also increases the efficiency of trees to play their roles in an urban environment [23]. Species-level tree biomass carbon estimation using diameter at breast height (DBH) with a tree density-based allometric model is becoming popular [24]. Studies have made significant contributions in estimating ecosystem-level aboveground carbon stocks using basal biomass. In spite of having these benefits, there is still a lack of quantitative data and available information on urban park concerning their ecosystem carbon stock and tree species diversity, especially in Dhaka city. So, this study focused on estimating the amount of above and below ground carbon stock, soil organic carbon (SOC) and pattern of tree species diversity at National Botanical Garden, Dhaka, Bangladesh.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was conducted from January to April 2018. The study was located at 23º50$^{/}$N latitude and 90º40/E longitude with an elevation of 8.6 meters above sea level. It is situated in Chiriakhana Road, Mirpur-1, Dhaka, Bangladesh.

2.2 Sampling Procedure

In the sampling procedure for this study to measure the sample, plot transects line method was used.

2.3 Selection and Description of the Study Area

Using transects line method square plots with a size of 20 m × 20 m were taken. So altogether there was a total eighty-three plot in National Botanical Garden. In case of soil, auger was used to collect soil sample from 0-10 cm, 10-20 cm and 20-30 cm and then collected soil sample were tested in Soil Resource Development Institute. Among each plot, the 50-meter interval from the plot to the plot was maintained for the feasibility of determining the sample plot. Plot No. 4, 9, 17, 21, 25, 29, 30, 34, 38, 43, 49 and 62 were avoided due to presence of pond, residence, very low land, office and lake and there were 12 plots accordingly.

2.4 Soil Sampling and Analysis

There were a total of 83 sample plots in the National Botanical Garden. But Soil samples were collected from 71 sample plots. Twelve sample plots were avoided due to the presence of pond, residence, very low land, office and lake. In each sample plot, three sampling sites were selected randomly and soil samples were collected at three depths measuring 0-10 cm, 10-20 cm and 20-30 cm from each sites using Auger. A composite sample for each depth interval was prepared by mixing soil from three sampling sites resulting in one sample per depth level from National Botanical Garden. There were in total of 213 (71 × 3) soil samples. Bulk density of sampled soil was measured using the formula stated below. Carbon content in the sample soil was analyzed by Wondimu [25] method. Soil analysis was done in Soil Resource Development Institute (SRDI), Bangladesh.

2.5 Allometric Equation for Above and Below-Ground Biomass

2.5.1 Tree biomass

Biomass equations relate to the diameter at breast height (DBH) of tree biomass and biomass may differ among species. It is because trees in a similar functional group can differ greatly in their growth forms between different geographical areas [26]. Considering these factors Chave, et al. [27] developed allometric equations for tropical trees that can be used for wide geographical and diameter range.

2.5.2 Above ground biomass

To measure the above ground plant biomass of the study plot, following equation was used [27]:

$$AGB = \rho \times \exp\,(-1.499+2.148 \times \mathrm{Ln}\,(DBH) + 0.207 \times (\mathrm{Ln}\,(DBH))^2 - 0.0281\,\{\mathrm{Ln}(DBH)\}^3$$

Where, ρ = Wood density (g cm^{-3}): - 1.499, 2.148…………0.207 and 0.0281= Constant.

2.5.3 Below ground biomass

To determine the below-ground biomass and carbon, the model equation developed by Cairns, et al. [28] was employed. It was the most cost-effective and practical methods of determining root biomass.

BGB = exp (-1.0587 + 0.8836 x Ln AGB)

Where,BGB = Belowground biomass, Ln = Natural logarithm, AGB = Aboveground biomass, -1.0587 and 0.8836 are constant.

2.5.4 Palm species biomass

The following equation that was developed by Brown, et al. 2001 for palms was used for AGB calculation:

AGB = 6.666 + 12.826×ht0.5 × Ln (ht), Where, AGB = Above Ground Biomass, Ln = Natural logarithm, ht = Height

2.6 Conversion of Biomass to Carbon

After estimating the biomass from the allometric relationship, it was multiplied by wood carbon content (50%). Almost all carbon measurement projects in the tropical forest assume all tissues (i.e. wood, leaves and roots) consist of 50% carbon on a dry mass basis [27].

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

2.7 Data Analysis

After the collection of field data, the information was processed and compiled by MS Excel 2007 and SPSS-16 software. Aboveground C pools were computed using international standard common tree allometries combined with local tables of wood density by tree species. Regression analyses were used to test the relationship between different variables.

3. RESULTS AND DISCUSSION

3.1 Ecosystem Carbon Stock

The present study was conducted at National Botanical Garden, Dhaka, Bangladesh. There were a total of 83 sample plots in this garden but 12 sample plots were avoided from due to the presence of pond, residence, very low land, office and lake. So, data were collected from 71 sample plots from this garden. The ecosystem carbon stocks i.e., above-ground carbon, below ground carbon and soil organic carbon, were estimated from this garden.

3.2 Above and Belowground Biomass Carbon (AGC and BGC)

For the estimation of above and below-ground biomass carbon stock of the plantation sites of the selected experimental site was measured based on diameter at breast height (DBH) and height and also calculated by using the desired equations. For measuring biomass carbon stock total plantation of 71 plots of National Botanical garden were used. So the total number of sample plot was n = 71.

The data revealed that the biomass carbon stock of National botanical garden ranged from 3.08 to 265.74 Mg C ha^{-1}. The average value of the biomass carbon stock was 144.46 Mg C ha^{-1} (Table 1). In the earlier study, Averti, et al. (2014) [29] found that the AGC in humid tropical wetland forests of the Republic of Congo was 223 Mg ha^{-1}. Gibbs, et al. [30] found that the mean biomass carbon in Bangladesh was 65-158 Mg ha^{-1}. Borah, et al. (2013) [31] reported that AGB was ranged from 32.47 Mg ha^{-1} to 261.64 Mg ha^{-1} and C-stocks ranged from 16.24 Mg ha^{-1} to 130.82 Mg ha^{-1}in ten tropical forests of Cachar district.

Data also revealed that the above-ground carbon (AGC) and below ground carbon (BGC) biomass stock was 192.67 and 31.34, respectively (Fig. 1). Jaman, et al. (2016) [32] recorded mean above and below-ground biomass carbon stocks (AGB+BGB) 53.53 Mg ha^{-1} in the home garden around four villages of two Upazilas of Rangpur district. Liu, et al. (2014) [33] also recorded that the AGC and BGC of Lesio-louna tropical rainforest of Congo were 168.60 Mg ha^{-1} and 39.55 Mg ha^{-1}, respectively.

3.3 Soil Organic Carbon

Soil organic carbon (SOC) was comparatively higher in the study area. Soil organic carbon ranged from 10.20 to 18.24 Mg ha^{-1} at 0-10 cm depth, 19.00 to 32.56 Mg ha^{-1} at 10-20 cm depth and 17.64 to 26.32 Mg ha^{-1} at 20-30 cm depth with a mean value of 16.23 Mg ha^{-1}, 27.52 Mg ha^{-1} and 21.45 Mg ha^{-1}, respectively in National Botanical garden (Table 2).

Table 1. Carbon stock in national botanical garden

Number of sample plot	Carbon stock range (mg ha^{-1})		Average ± CI*
	Lowest	Highest	
71	3.08	265.74	144.46±26.38

** CI: 95% confidence interval*

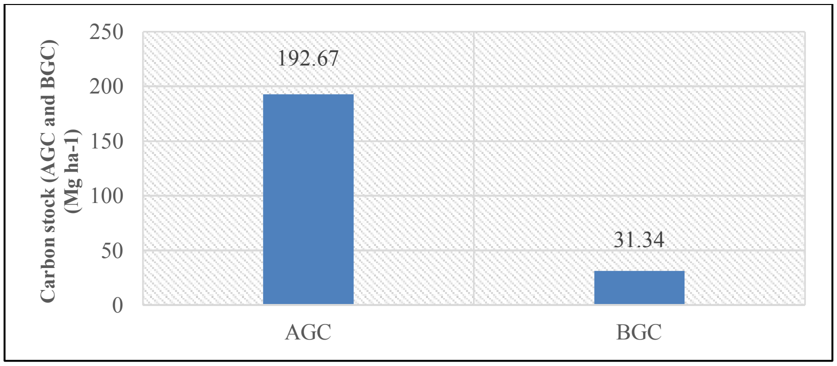

Fig. 1. Above and below ground carbon stocks in national botanical garden

Table 2. Soil organic carbon in National Botanical Garden

Depth (cm)	Range SOC (Mg ha^{-1})		Average ± CI*
	Maximum	Minimum	
0-10	18.24	10.20	16.23 ± 1.68
10-20	32.56	19.00	27.52 ± 1.98
20-30	26.32	17.64	21.45 ± 1.74

** CI: 95% confidence interval*

It was observed that soil organic carbon was always higher at 10-20 cm depth in comparison to 20-30 cm and 0-10 cm depth (Fig. 2). The soil carbon stock measured in the forest was 43.73 Mg ha^{-1} were found the soil carbon stock for a *Pinus densiflora* forest at Gwangneung, central Korea was estimated using the soil carbon model. The average soil organic carbon of the National Botanical Garden (65.20 Mg ha^{-1}) is lower than in Hanang forest, Tanzania where soil organic carbon was 64.2, 41.93 and 31.0 Mg ha^{-1} in the upper (0-15 cm), mid (> 15-30 cm) and lower (>30-45 cm) layer [34].

3.4 Amount of Different Carbon Pool

Ecosystem carbon stock e.g. Above ground carbon (AGC), Below ground carbon (BGC) and Soil organic carbon (SOC) were 192.67 Mg ha^{-1}, 31.34 Mg ha^{-1} and 65.2 Mg ha^{-1}, respectively in National Botanical Garden (Fig. 3).

3.5 Tree Diversity

Tree diversity of National Botanical Garden was measured by using the Shannon Wiener Index (SWI). SWI showed that the mean value of (0.93 ±0.14) in the National Botanical Garden (Table 3). The average number of tree species per hectare was 233 (Table 3). The number of species recorded 128 with a mean value of each plot 3.00 to 9.00 species (Table 3).

3.6 Vegetation Characteristics

Vegetation characteristics such as the average number of trees per hectare, basal area and mean DBH of a total of 71 plots were estimated including their standard error (Table 4). From this table, it was revealed that the average number of trees in National Botanical Garden (233 tree ha^{-1}), basal area (21.45 m^2 ha^{-1}) and mean DBH (39.86 cm).

3.7 Tree Density Characteristics

Tree density ranged from 48 to 662 trees ha^{-1} with a mean value of 213 trees ha^{-1} in National Botanical Garden (Table 5).

3.8 Occurrence of Major Tree Species

From the experimental area it was found that the occurrence of major trees in National Botanical

Garden were *Terminalia chebula* and *Mahua Longifolia* (6.04%) in same percentage which was followed by *Mangifera indica* (4.83%), *Artocarpus heterophyllus and Tamarix gallica* (4.08%), *Terminalia bellirica* (3.78%), *Acacia auriculiformis* (3.63%) and *Eucalyptus camaldulensis* (2.87%) and *Swietenia macrophylla* (2.72%) (Fig. 4). Data revealed that the occurrences of the major tree species were more or less evenly distributed. There were no specific tree species with a major number.

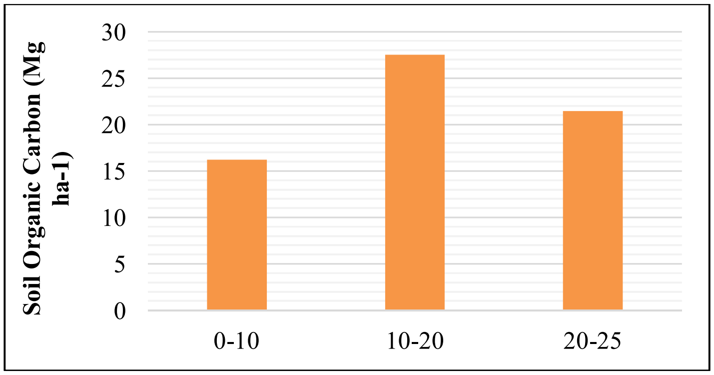

Fig. 2. Soil organic carbon (Mg ha^{-1}) in national botanical garden

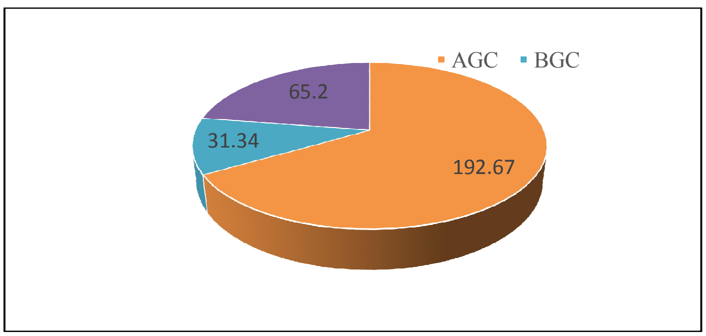

Fig. 3. Total mean ecosystem carbon stock (Mg ha^{-1}) (AGC, BGC, SOC) in national botanical garden

Table 3. Tree diversity in national botanical garden

Mean number of trees/ha	Species recorded		Shannon wiener Index (SWI)
	Maximum	Minimum	
233	9.00	3.00	0.93 ± 0.14

Table 4. The average number of trees (ha^{-1}), basal area (ha^{-1}) and mean DBH (cm) in national botanical garden

Parameters	Value
Average trees (ha)	233 (3.67)
Basal area (ha)	21.45 (1.98)
Mean DBH	39.86 (5.03)

Table 5. Tree density in national botanical garden

The lower tree density value	Higher tree density value (ha^{-1})	Total tree density (ha^{-1})	Mean ± SE
8	662	5296	213 ± 54.17

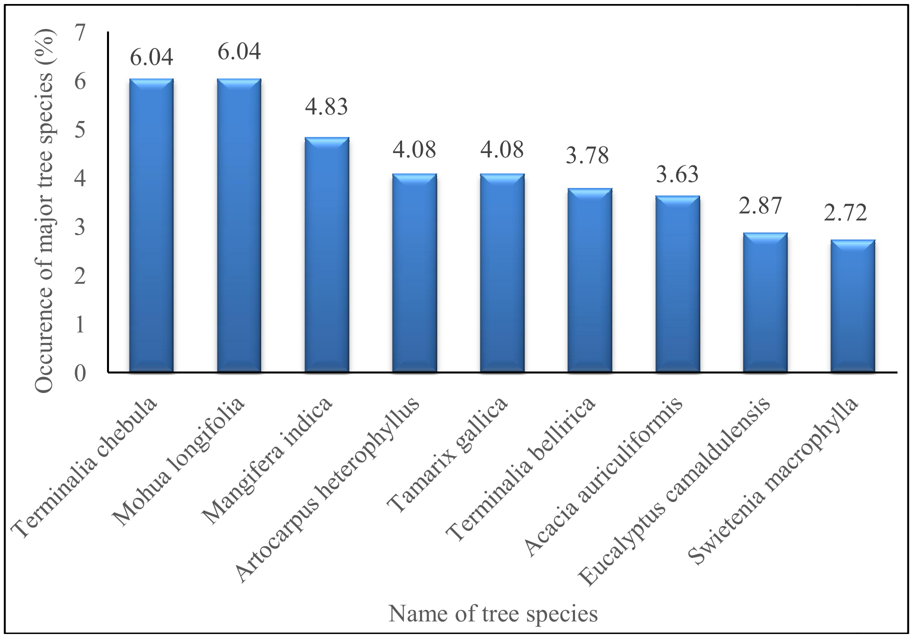

Fig. 4. The occurrence of major tree species (%) among the recorded tree species in national botanical garden

3.9 Major Carbon-containing Tree Species

Estimated data revealed that the major carbon-containing trees were *Mangiferaindica* (52.12 Mg) followed by *Artocarpus heterophyllus* (34.67 Mg), *Tamarix gallica* (27.55 Mg), *Mohualongifolia* (15.32 Mg), *Tamarix gallica* (12.89 Mg), *Acacia auriculiformis* (11.45 mg), *Terminalia chebula* (9.33), whereas the lowest was observed from *Eucalyptus camaldulensis* (9.01 mg) (Fig. 5) in National botanical garden.

3.10 Relationship between Different Stand Structure of Tree Species and its Carbon Stock

Correlation and Regression analysis were computed to determine the relationship among the different mean value of DBH, basal area and stem density with biomass carbon stock of tree species.

3.11 Basal Area

The relationship between the mean basal area and biomass carbon stock of the National Botanical Garden was measured and presented in shown Fig. 6. The linear equation as: Y = 10.728 x + 4.7823 (R^2 = 0.862), where R^2 value was positive, r = 0.928 and $p < 0.01$. So the estimated value indicated that there was a significant and strong positive correlation between basal area and biomass carbon stock and with the increase of basal area the biomass carbon stock also increases.

3.12 Mean DBH

The relationship between the mean basal area and biomass carbon stock of the National Botanical Garden was measured and presented in shown Fig. 7. The linear equation as: Y = 4.779 x + 121.67 (R^2 = 0.042), where R^2 value was positive, r = 0.205 and $p > 0.05$. So the estimated value indicated that there was a non-significant and positive correlation between mean DBH and biomass carbon stock and with the increase of mean DBH the biomass carbon stock also increases. In this present study, there was no significant correlation was found between mean DBH and biomass carbon stock of the National Botanical Garden.

3.13 Stem Density

The relationship between stem density and biomass carbon stock of the National Botanical Garden was measured and presented in shown Fig. 8. The linear equation as: y = 0.9063x +3.982 (R^2 = 0.798), where R^2 value was positive, r = 0.893 and $p < 0.01$. So the estimated value indicated that there was a significant and strong positive correlation between stem density and biomass carbon stock and with the increase of stem density the biomass carbon stock also increases.

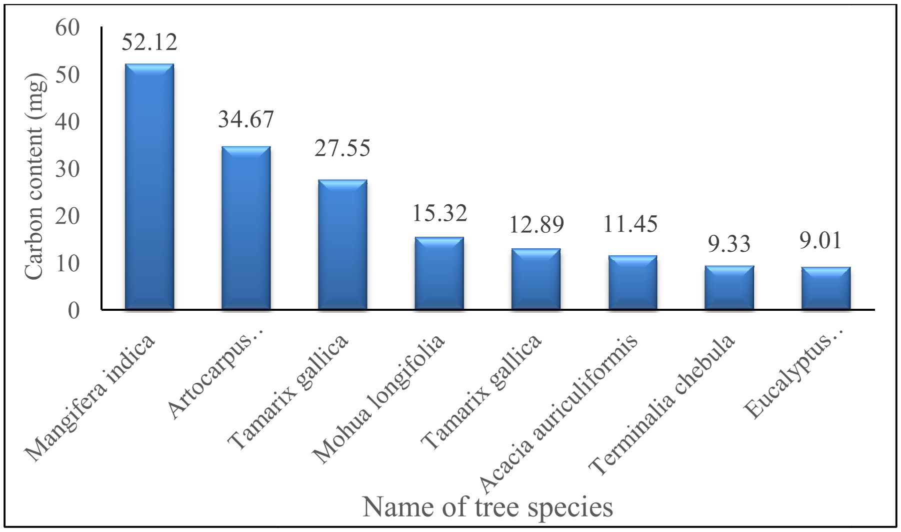

Fig. 5. Major carbon-containing tree species in national botanical garden

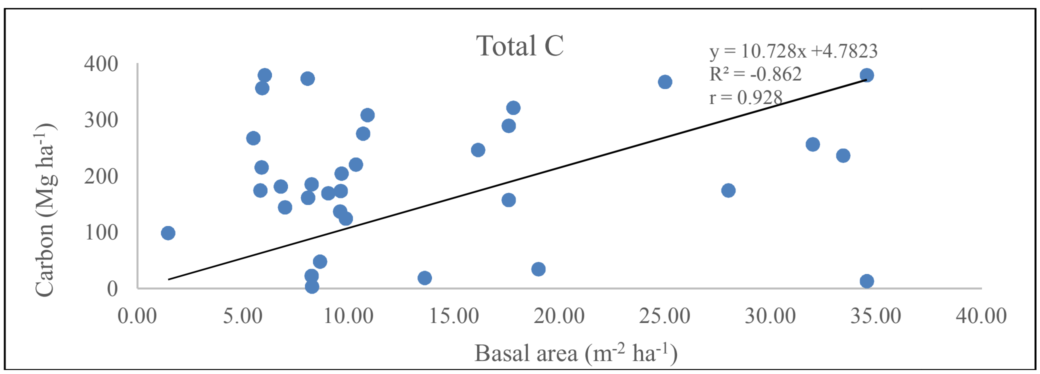

Fig. 6. Relationship between basal area (m^2 ha^{-1}) and carbon stock (Mg ha^{-1}) in national botanical garden

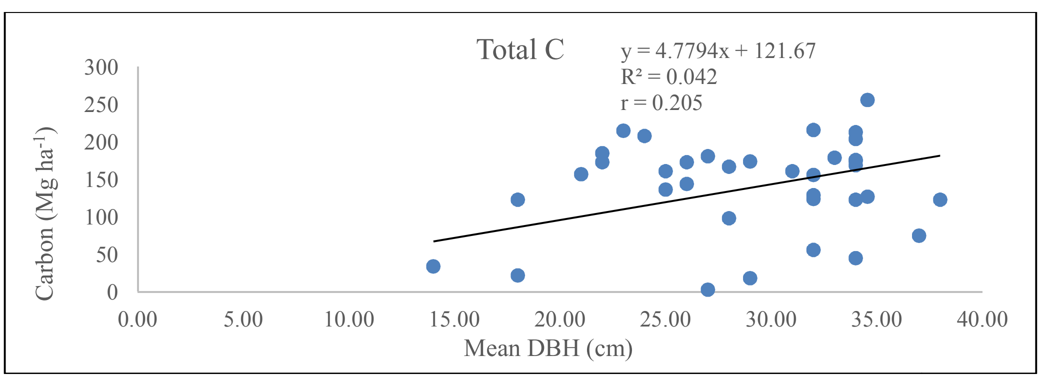

Fig. 7. Relationship between mean DBH (cm) and carbon stock (Mg ha^{-1}) in national botanical garden

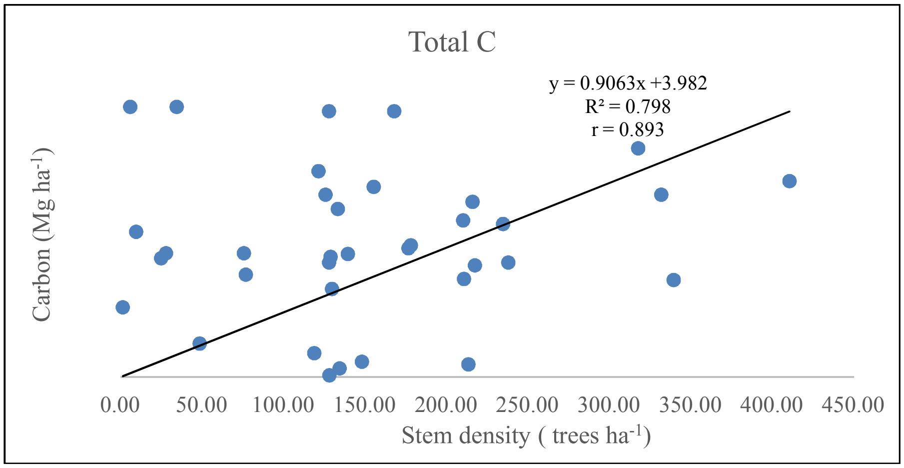

Fig. 8. Relationship between mean DBH (cm) and carbon stock (Mg ha^{-1}) in National Botanical Garden

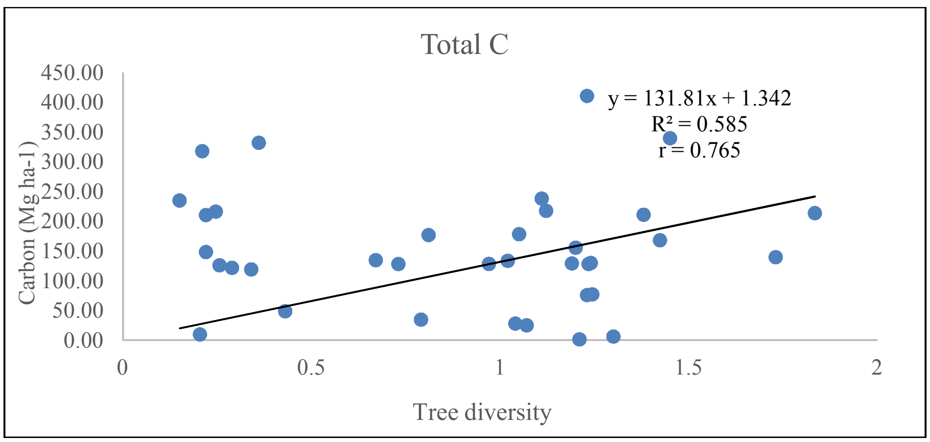

Fig. 9. Relationship between tree diversity and carbon stock (Mg ha^{-1}) in National Botanical Garden

3.14 Tree Diversity

The relationship between tree diversity and biomass carbon stock of the National Botanical Garden was measured and presented in shown Fig. 9. The linear equation as: y = 131.81x + 1.342 (R^2 = 0.585), where R^2 value was positive, r = 0.765 and $p < 0.01$. So the estimated value indicated that there was a significant and strong positive correlation between tree diversity and biomass carbon stock and with the increase of tree diversity the biomass carbon stock also increases.

4. CONCLUSION

The experiment was conducted to estimate the amount of carbon (both above and below ground) stock which is found 144.46 (Mg ha-1) and also to determine the number of species occurrence in 71 plots. In consideration of aboveground carbon (AGC) and below ground carbon (BGC) biomass and the stock were 192.67 and 31.34, respectively. On the other hand, in case of soil organic carbon mean value of 27.52 Mg ha^{-1}, 21.45 Mg ha^{-1} and 16.23 Mg ha^{-1}, respectively for 0-10 cm depth in comparison to 10-20 cm and 20-30 cm depth. Shannon Wiener Index (SWI) showed that the mean value of Tree diversity of (0.93±0.14) in National Botanical Garden. Tree density ranged from 48 to 662 trees ha^{-1} with a mean value of 233 trees ha^{-1} in National Botanical Garden. Relationship between basal area and biomass carbon showed positive significant correlation. The relationship among different parameters varied from place to place due to the structure and composition of tree species as well as soil structure and management of gardens.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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