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Soil Organic Carbon and Tree Density in Homegardens of Rangpur District, Bangladesh

M. S. Jaman[1*], Md. Shariful Islam[1], Mahbuba Jamil[2] and M. F. Hossain[1]

[1]Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka 1207, Bangladesh.
[2]Department of Agriculture Extension, Dhaka 1207, Bangladesh.

Authors' contributions

This work was carried out in collaboration with all authors. Author MSJ designed the study, analyzed the data, wrote the protocol, wrote the first and final draft. Author MFH helped in design of study, checked the first and final draft. Author MSI directly helped in field experiment where author MJ helped in analyzed the data. All authors read and approved the final manuscript.

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ABSTRACT

Tropical agroforestry systems are considered to have a huge potential to sequester and store carbon (C) both in the aboveground biomass and the belowground biomass, as well as in soil. Compared to many other types of agroforestry systems homegardens are popular in the tropics and the sub tropics because they tend to sequester more C in soil than monoculture plantations and they can also serve as an important ecological tool in terms of species composition and storage of soil organic carbon (SOC). Tree species density is reported to be a important factor that influences SOC content in many of tropical agroforestry systems. This research was carried out to determine the SOC and tree density characteristics in homegardens in four selected villages in Rangpur district, Bangladesh. For determination of SOC, 128 number of soil samples were collected and combined to make a composite sample for each sampling depths (0–10 cm and

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**Corresponding author: E-mail: shmishu.sau@gmail.com, shmishu2287@sau.edu.bd;*

15–25 cm) in each of the two different sampling sites of homegardens. Average estimated SOC was 49.24 Mg ha^{-1}, where the size of the homegarden in related to tree density (1630 trees ha^{-1}) resulted in the highest amount of SOC (63.62 Mg ha^{-1}). This study demonstrates that homegardens with high tree density sequester more SOC.

Keywords: Tropical agroforestry; carbon sequestration; above and below ground biomass.

1. INTRODUCTION

Soil contains the most important long-term soil organic carbon (SOC) reservoir in terrestrial ecosystems. It can able to contain more (C) than plant biomass and the atmosphere [1,2]. The large soil reservoir of SOC is not permanent but results from a dynamic equilibrium between organic and inorganic material cycling through soil-plant-air and water interactions [3]. The C stored in soils is affected by changes in vegetation and plant growth, removal of biomass by harvest, mechanical soil disturbances such as plowing and some other agricultural operations [3]. Soil C is sensitive to environmental changes such as global warming or nitrogen deposition [4,5]. Minor changes in SOC storage impact atmospheric carbon dioxide concentrations [6,7], thus estimating SOC stored is required to assess the role of soil in the global C cycle [8].

Agroforestry systems have higher SOC sequestration rates than conventional agricultural systems as the trees these systems tend to have higher litter fall inputs, and deeper rooting systems, and therefore are capable of sequestaring C in the surface soil layer (0-30 cm) as well as in deep layers (>30 cm) [9,10]. Species rich homegardens and specific management practices tend to enhance nutrient cycling and increase soil organic matter as well as soil C [11]. Increases in the number of trees (i.e., tree density) in a system, increases the overall biomass production per unit area of land which influence the C storage in the soils [10,12]. Rapid deforestration and heavy urbanization increases the change in land use patterns in the tropics and these land-use changes are responsible for approximately 10% of the human-induced greenhouse gas emissions and are expected to remain the second largest source of carbon (C) emissions in the near future [13]. Conversion of tropical forests to agriculture causes release of stored SOC, often in the form of carbon dioxide, but it causes decline in soil productivity also [14]. To reduce greenhouse gas emissions from agricultural system while simultaneously maintaining agricultural productivity it is necessary to identify and implement simple and cost effective measures to store and capture C [14]. In this context homegarden agroforestry practices, which integrate trees into agricultural systems, offer a unique opportunity to store soil C while also growing food, diversifying incomes, and simultaneously providing numerous environmental benefits. These include mitigating soil erosion [10], improving soil structure [15], pumping up nutrients from the subsoil [16] and sequestering atmospheric carbon [15,17]. It is also likely that the amount of C stored in the soil will depend on homegarden characteristics such as size and age of the holding. Tree species density in homegardens is inversely proportional to the land-holding size [18,19]; therefore, smaller-sized homegardens are likely to sequester more soil C per unit area of land compared to larger-sized homegardens. Older homegardens can be expected to store more quantities of soil C than younger ones [20]. However, there is still lack of quantitative data available on these topics in the study area. Therefore, this study focused on assessing the SOC content and examining the relationship between tree species density and SOC in the 64 homegardens of four villages in Rangpur district, Bangladesh.

2. MATERIALS AND METHODS

2.1 Location of the Study Area

The study was conducted at four villages of two upazila (administrative unites) in Rangpur district. Rangpur district is located in the northern part of Bangladesh. The total area of the district is 2370.45 sq km, located in between 25°18' to 25°57' N latitudes and 88°56' to 89°32' E longitudes.The name of four studied villages are Manoharpur, Radhakrishnopur, Basantopur and Nandanpur. Among these the villages, Manoharpur and Radhakrishnopur are situated in Rangpur sadar upazila where as Basantopur and Nandanpur are situated in Badarganj upazila. Rangpur sadar upazila occupies an area of 330.33 km^2 and is located between 25°39' to 25°50' N latitudes and 89°05' to 89°20' E longitudes where as Badarganj upazila occupies an area of 301.29 km^2 and located between 25°32' to 25°46' N latitudes and 88°56' to 89°10' E longitudes (Fig. 2).

2.2 Climate and Soil

Tropical wet and dry climates are the major climatic characteristics of Rangpur district. The climate is generally marked by monsoons, high temperature and considerable humidity and rainfall. The hot season starts from early April and continues until mid to late July. The maximum mean temperature observed is 32 to 36°C during the months of May, June, July and August and the minimum temperature recorded in January is about 7 to 16°C [21]. During the months of monsoon, the highest rainfall observed is approximately 1378.6 mm. The average annual rainfall is about 1587 mm [22]. Soil composition in the study area mainly consists of alluvial soils (80%) and the remaining 20% is barind soils [23].

2.3 Sampling Procedure

Four selected villages (1. Manoharpur, 2. Radhakrishnopur, 3. Basantapur and 4. Nandanpur) of Rangpur district which are randomely selected from three unions (lowest unit of local self government) namely 1. Satgara 2. Rajendrapur and 3. Gopalpur. Satgara and Rajendrapur union comes from Rangpur Sadar and Gopalpur union from Badarganj Upazila. There are total 1244 of different homegardens in these selected villages. Out of 1244 homegardens, a sample of 15%, i.e., 186 homegardens were selected by stratified random sampling method. Then finally 64 representative homegardens were selected for soil organic carbon measurement and tree density assessment (Fig. 1).

2.4 Soil Sampling and Analysis

Soil samples were collected in November–December 2015 from 64 homegardens in each of the four study villages. In each homegarden (plot), two sampling sites were selected randomly and from the two sites soil sample were collected at two depths 0–10 and 15–25 cm (Fig. 3). A composite sample for each depth interval was prepared by mixing soil from two sampling sites resulting one sample per depth level from each study plots. There were total 128 soil samples (4 villages ×16 replication × 2 depths) from 4 villages. Soil samples were oven-dried at 105°C for 48 h until a constant weight was obtained and bulk density of sampled soil was measured Eq-[1]. The SOC content in the soil was analyzed using the Walkley-Black (1934) method as it is popular method for determining organic carbon Eq (2) [24]. Inorganic carbon was not calculate or analyze hare because significant soil carbon pool derived mostly from organic carbon fixed by photosynthesis [3]. Inorganic carbon does not possess the water-holding and soil-enhancing properties of organic carbon, but a significant sink for atmospheric carbon, though it changes at a slower rate.

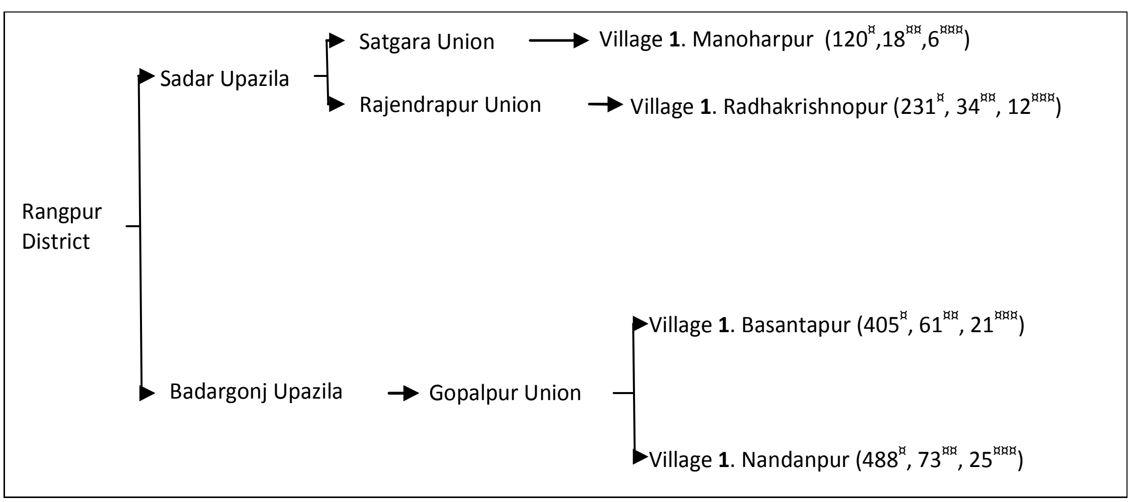

Fig. 1. Distribution of homegarden in four selected villages where ¤ indicate the total number of homegarden, ¤¤ indicate the primary selected homegarden and ¤¤¤ indicate the finally selected homegarden

$$BD\ [g\ cm^{-3}] = \frac{\text{Mass of dry soil sample [g]}}{\text{Sample volume [cm}^3]} \quad (1)$$

Where, BD= Bulk density

Organic carbon content percentages were calculated by using following formula:

$$SOC\ (\%) = \frac{(B-T) \times N \times 0.003 \times 1.3 \times 100}{ODW} \quad (2)$$

Where,

B = $FeSO_4 .7H_2O$ Solution required for blank titration.
T = Volume of $FeSO_4 .7H_2O$ solution required for actual titration.
N = Strength of $FeSO_4 .7H_2O$ or Normality.
1.3 = Convention recovery fraction.
ODW = Oven dry weight.

Soil organic carbon (SOC) was calculated by the formula of:

SOC = Depth (cm) **×** Bulk density (g/cm^{-3}) **×** Organic carbon (%)

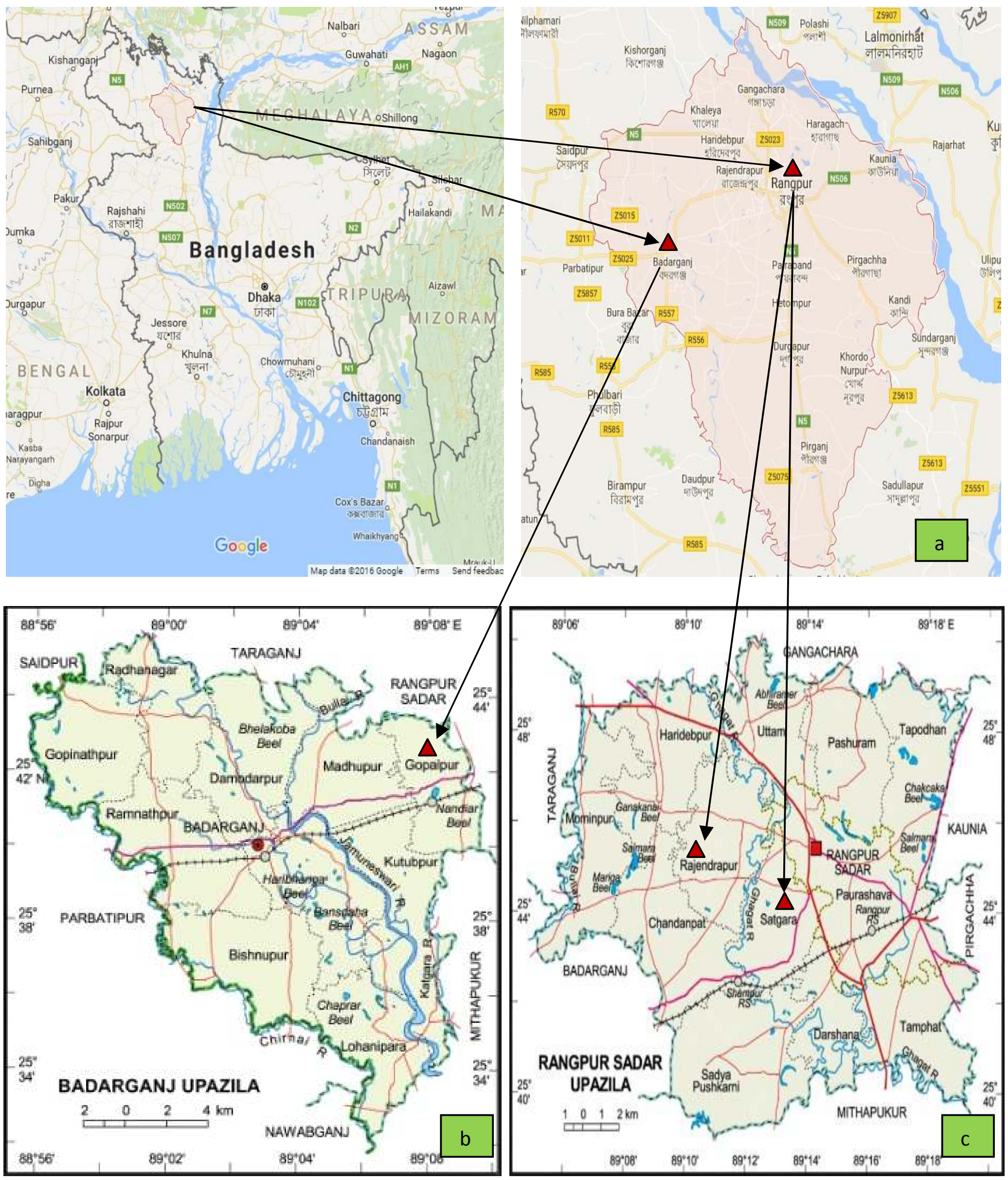

Fig. 2. Study area in Bangladesh (a) Rangpur district (b) Badarganj Upazila (c) Rangpur Sadar Upazila

Fig. 3. Three different sized homegardens (a) Large (b) Medium and (c) Small with showing the soil sampling procedures below

2.5 Data Analysis

Collected field data were processed and analysed using SPSS-11.5 version software and MS excel 2007. One-way ANOVA and t-test has been done to find out the significant differences among soil carbon and tree density at *P=0.05% level of significance. Regression analyses were used to test the relationship among different variables.

3. RESULTS AND DISCUSSION

3.1 Tree Density Characteristics

The tree density varied from 280.61 to 2319.28 trees ha^{-1} in small, medium and large homegardens, where the highest relative difference between the lower and the higher tree density value was found in the medium sized homegardens (7.26) compared to the small-sized homegardens (1.4) and the large-sized homegardens (1.25) respectively (Table 1).

Tree density is an important factor for SOC storage in homegardens as it directly relates to the C sequestration [25]. A study was conducted in central kerala, India that showed the relative difference in SOC (Mg ha^{-1}) stored in low and high tree densities homegardens are 0.2561, 0.2948, 0.2334, and 0.1242 at four different soil depth (i.e.,0–20, 20–50, 50–80, 80–100) cm in three different categories homegardens [26]. Tree density in an old-aged forest in Costarica and Central America found 462–504 trees ha^{-1} [27] that are comparatively lower than the present study result (280.61–2319.28) trees ha^{-1}. Another study was conducted in the homegardens of Sumatra, Indonesia to identify the tree density value and found the density value 13–59 trees per ha^{-1} that also comparatively lower than the present study result [28].

3.2 Soil Organic Carbon (SOC)

Among the other land use systems or agroforestry systems homegardens sequester more SOC. In the subtropical and tropical regions of Rangpur district, Bangladesh, SOC value vary from 2.95 Mg ha^{-1} to 70.19 Mg ha^{-1}. The mean SOC value ranges from 10.42 to 44.15 in small, medium and large homegardens within the 0–10 cm and 15–25 cm soil depth (Table 2). Considering the total SOC (Mg ha^{-1}) medium and large homegarden were found 33% and 39% less SOC than small homegardens.

Homegarden are comprised of trees, shrubs, and herbs and these plant classes have different belowground growth patterns. The SOC stock in homegarden was found higher in the upper, than in the lower soil layer. In the selected study area average soil organic carbon in two different depth (0–10 and 15–25 cm) was found 49.24 Mg ha^{-1} with the range from 2.95 to 70.19 Mg ha^{-1} is lower than the homegarden of Kerala, India where SOC ranged 101.5 to 127.4 Mg ha^{-1} in four different soil depth [26], coastal land area of Ireland (383 Mg ha^{-1}) in (0–10 cm) soil depth [7] but higher than the homegarden of Golestan province, Iran (0.49 to 16.64 Mg ha^{-1}) [29] and Brazilian savanna soils (22.98 Mg ha^{-1}) [30]. On the other hand soil organic carbon content within 1 m soil depth under moist deciduous forests in the district of Kerala were 176.6 Mg ha^{-1} that is much higher than the present homegarden SOC because forests characterized by high rates of litter fall, very low soil disturbance and high plant species diversity [31]. A positive relationship was found between tree density and SOC as well as between homegarden size and SOC with significant R value.

3.3 Soil Organic Carbon and Homegarden Size

The size of the homegarden is one of the major factor affecting SOC content per unit area of land and it is decrease in the order of small > medium > large. In small size homegardens, the average soil organic carbon was found higher (63.62 Mg ha^{-1}) compared to medium (42.48 Mg ha^{-1}) and large (38.57 Mg ha^{-1}) size homegardens (Fig. 4).

3.4 Soil Organic Carbon in Relation to Tree Density

The relationship between the tree density and SOC stocks in small, medium, and large homegardens is shown in (Fig. 5). The figure shows that among three different categories homegardens there was positive and highly significant relationship between tree density and SOC (R^2=0.94). Fig. 5 also indicates that homegardens with high tree density (1630 trees ha^{-1}) contained higher amount of SOC (63.62 Mg ha^{-1}) per unit area compared to medium (878 trees ha^{-1}, 42.48 Mg ha^{-1}) and large (385 trees ha^{-1}, 38.57 Mg ha^{-1}) size homegardens.

Table 1. Tree density of various homegardens in Rangpur district

Homegarden categories (HG no.)	Lower tree density value (LTDV)/ha	Higher tree density value (HTDV)/ ha	Relative difference (HTDV-LTDV)/LTDV	Relative difference (%)
Small (24)	555.55	1333.33	1.40	140
Medium (21)	280.61	2319.28	7.26	726
Large (19)	317.46	714.29	1.25	125

Table 2. Soil organic carbon at two depth in homegardens of Rangpur district

Homegardens (HG no.)	Depth (cm)	Range soc (Mg ha^{-1})		Mean ± CI
		Highest	Lowest	
Small	0–10	70.19	11.26	44.15 ± 5.22
(24)	15–25	35.92	10.10	19.46 ± 2.94
Medium	0–10	60.83	12.90	32.37 ± 6.26
(21)	15–25	20.12	2.95	10.42 ± 2.96
Large	0–10	60.38	8.90	26.28 ± 7.02
(19)	15–25	32.01	3.32	12.29 ± 2.96

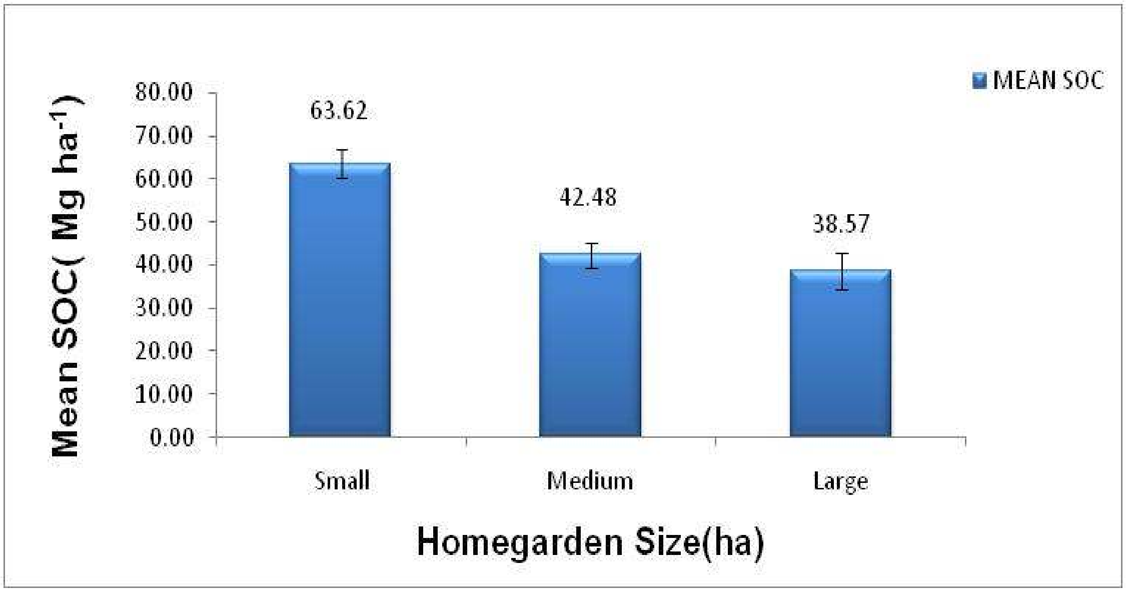

Fig. 4. Soil organic carbon (SOC) and homegardens size in homegardens in Rangpur district, Bangladesh. Error bar shows the standard error

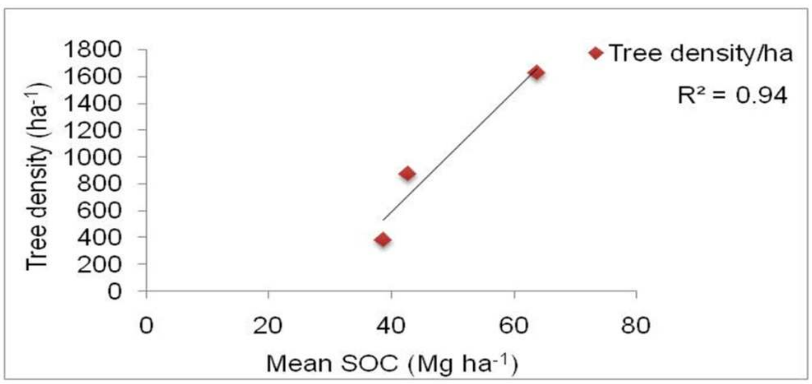

Fig. 5. The relationship between tree density (number of trees ha^{-1}) and soil organic carbon (SOC Mg ha^{-1}) in various homegardens in Rangpur district, Bangladesh

The SOC content increased with the increase in tree density. A study was conducted in homegardens of north eastern Bangladesh where homegarden with highest tree density (26 trees/100 m^2) had the highest SOC (averaging 1.65 %) and homegardens with the lowest tree density (3 trees /100 m^{-2}) had the lowest SOC (averaging 0.12 %) [32]. A similar result was obtained in both tropical [26] and temperate zone agroforestry systems [33], clearly indicated that trees have an influence on SOC content in homegarden agroforestry systems. Tree density affects the dynamics of the tree litter inputs into the soil [34]. In general, litter biomass is higher in high density agroforestry system. Soil management activities including ploughing and fertilization may also affect SOC content in agroforestry systems.

3.5 Average SOC Content in Two Different Soil Depth

Soil organic carbon decreased with soil depth across all treatments of the present study area. Due to accumulation of higher quantity of litters and other organic materials on the surface and their rapid decomposition, homegarden act as a

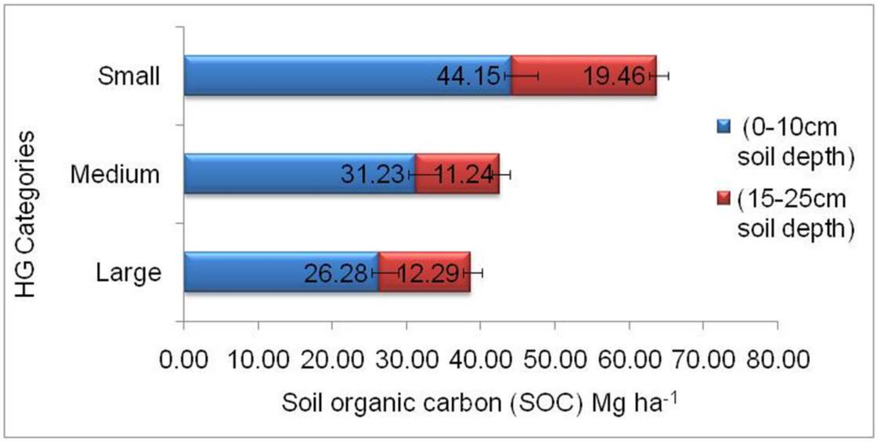

Fig. 6. Soil organic carbon (SOC) (Mg ha^{-1}) in various homegardens (HG) in Rangpur District, Bangladesh. Error bar shows the standard error

vital source of storing organic carbon in the soil. In the present study soil organic carbon (SOC) has found always higher within 0–10 cm depth in small (44.15 Mg ha^{-1}), medium (31.23 Mg ha^{-1}) and large (26.28 Mg ha^{-1}) homegardens rather than 15–25 cm soil depth (Fig. 6).

In general, the SOC stock decreased with increased in soil depth and this is common in almost all cultivated mineral soils. One of the reason is accumulation of higher quantities of litter and other organic materials in the upper soil surface layers and litter decomposition rates where microbial activity is higher in the rooting zones of species with shorter rooting depth [26]. The majority of root growth and activity of shrubs and herbs are expected to be restricted within the upper soil layers (~0–30 cm or more depending on the species and soil conditions) [35]. In general increasing the number of trees, herbs, and shrubs promotes higher SOC accumulation in the upper soil layers [26]. However Poirier et al. [36] have also reported that there is a high SOC content in 15−30 cm layer of tilled soil.

4. CONCLUSION

In conclusion, the study revealed that the SOC stock increased with the increase in tree density. There were differences between small, medium, and large homegardens in terms of their tree-stand characteristics such as tree and tree-species density, and overall tree species diversity. Perhaps because of the differences in tree-stand characteristics, SOC content also varied with the size of homegarden. Smaller-sized homegardens had more SOC per unit volume of soil than the larger homegardens. The species influence on SOC in homegarden agroforestry system was prominent at the top 10 cm of soil and decreased with increasing depth. The SOC stocks estimates were considered as proxies for Carbon Sequestration Potential (CSP). Therefore, it is inferred that the increase in tree density increases the CSP in homegardens in the tropical and subtropical regions of Rangpur District, Bangladesh. Further studies are needed that include a larger number of homegardens and at various study locations with varying soil, agro-climatic conditions, soil management practices, and species composition to explore the relationship among different parameters some of which are not addressed in this study. Overall, this work and future work should be used to develop SOC sequestration-friendly species-composition models for different situations as well as for different agro-climatic regions of Rangpur District, Bangladesh.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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