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Potential Biomass Pools and Edaphic Properties of Plantation Forest in Tripura, India

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ABSTRACT

Plantation forest is a major land use land cover in India and have significant carbon sequestration capacity. Forestry plantation also influences edaphic properties like bulk density, soil pH, temperature and moisture content. We estimated the biomass carbon stock and Soil Organic Carbon stock in forestry plantations and establish relation between the plantations and some selected edaphic properties. Fifty transects (10 in each plantation) were laid in five (10x5) different forestry plantations. Tree biomass was estimated by using species specific regression equations available in the literature. SOC content of soil was estimated on unit area basis, for specific depth interval. We used Canonical Correspondence Analysis (CCA) to find correlations, between the plantation biomass carbon pool and the edaphic factors. The total AGB differed among the plantations (ANOVA, $F_{4, 49} = 29.47$, $P< 0.01$). Overall the soil carbon (%) significantly differed among the plantations and its value was highest and lowest for HB (1.18) and TG (0.65), respectively. The CCA output showed that the biomass C pool–edaphic correlations were low, of which eigenvalues were 0.017 for the first axis, 0.002 for second axis, 0.001 for third axis and 0.0001 for the fourth axis. Soil to plant carbon ration indicate that the plantation systems of the state are vulnerable in terms of sequestration and stocking of carbon from the disturbances. So, we should think of possibilities of increasing their carbon sequestration potential.

Key Words: Plantation Forest; Biomass; Soil Organic Carbon; Edaphic Properties; Carbon Sequestration.

INTRODUCTION

The latest Global Forest Resources Assessment 2015, reported that the global forest area fell by 129 million hectares (Mha) (3.1 percent) in the period 1990–2015. Forest losses during 2010–2015 were compensated partially by the establishment of plantation forests (3.1 Mha per year). Carle and Holmgren (2008) estimated that the area of plantation forests will increase from its current level (261 Mha) to about 303–345 Mha in 2030. Over the past 25 years the carbon stocks in forest biomass have decreased by almost 11.1 gigatonnes (Gt), equivalent to a reduction of 442 million tonnes (mt) per year or about 1.6 Gt of CO_2. Jindal et al. (2008) reported that cash incomes for households can be increased significantly with the use of plantation forests. In one project in Mozambique, local households received a cash payment of US $ 242 per hectare over seven years for carbon sequestered on their farms. Plantations are established to provide services like recreation, water quality control, run-off and erosion control and rehabilitation of degraded lands and many ecological services like sequestration of CO_2 (Lamb et al. 2005). Although, forestry plantations have small contribution to the total balance of terrestrial C (3.8% of the world's total forest area), but their potential to sequester and stock C has been recognized to play a crucial role in the future mitigation of climate change (Messier et al. 2009). It may provide about 30% of the total global efforts, needed in all sectors to meet climate mitigation strategies or to control emissions. The estimated sequestration potential of a range of forest management measures suggests that the temporal changes in forest C stocks could range from 0.15t C ha^{-1} $year^{-1}$ to 3.5t C ha-^{1} $year^{-1}$ (Nabuurs et al 2002).

In India, especially due the Forest Conservation Act 1980, and large afforestation programmes, the plantation forests are established. Approximately 275 million people are known to live in the forest fringes and earn bulk of their livelihood from forests. The total area of tree plantation in the year 1999-2000 was 31.2 Mha. The majority of plantations were done in non-forest lands. Out of 31.2 Mha , 10.26 Mha were planted by way of seedling distribution among farmers and the remaining 20.94 was done as block plantation. The Forest Department along with Forest Corporation also planting 70% of the fast growing species and 30% long rotation species (MoEF 2009). For meeting the growing needs of industries, degraded forests have been regenerated and planted with long-rotation tree species like Teak (*Tectona grandis*) and Garjan (*Dipterocarpus turbinatus*) and Sal (*Shorea robusta*) (MoEF 2009). The Sal and Teak has the maximum contribution in total volume, 12.06 and 5.30%, respectively. In 2000, plantations supplied one-third of the total demand for industrial roundwood. As per some estimates, approximately half of the global industrial roundwood supply will be provided by plantations and planted forests by the year 2040. Afforestation and reforestation of 6 Mha of degraded forest land covered under the national mission with participation of Joint Forest Management Committees would be able to add another 18 million Mg of C, equivalent to 66 million Mg of CO_2 by the year 2020. Forestry plantation also influences edaphic properties like bulk density (BD), soil pH, soil temperature (ST) and moisture content (MC) and vice-versa. It also has ameliorative effect and increase C level in the soil. Estimating SOC is important, as the soil contains the world's largest terrestrial active C pool, which plays a major role in the global C cycle.

However, studies attempting to estimate tree biomass and C stock in different plantation forests yield variable results. The inconsistency, generalization of the role of plantation forests in stocking C at global level has been barred (Liao et al. 2010). They argued against the replacement of natural forests by the plantations as a measure to enhance C sequestration. The tropical plantation forests have an edge over the natural forests in terms of C storage because of adoption of improved forestry practices. The contribution of forestry sector to overall GDP and employment generation is decreasing in the Asia-Pacific regions (FAO 2011). The consequence are tensions between government forest agencies and the poor populations that depended on forests for their livelihoods. The large scale, commercial forestry can also play a role in poverty reduction (Lamb et al. 2005). Recently some works on the C stocks have been done in the different land uses and natural forest patches of Tripura (Choudhary et al. 2016a, Majumdar et al. 2016). The C sequestration along the commercial plantation is also estimated (Choudhary et al. 2016a), but data base on the status of C stock's estimation in plantation forest and edaphic properties of the region are limited. In the background of the above information, the following objectives were taken for the study: (1) to determine the biomass C stock in the five major forestry plantations, (2) to estimate SOC stock and other edaphic properties and (3) to establish relation between the plantations, and some selected edaphic properties. As no previous study has been done in the region, the study will generate base line data for the region and also increase our understanding on the C stock of plantation system. While trying to increase the precision and reliability of carbon estimates of plantation system, we also expected that the availability of such information will increase the consideration of the mitigation potential of these activities into forest policy making.

MATERIALS AND METHODS

Study Area

Tripura is India's third smallest hill state, located in the northeast part of the country. The State lies between the latitudes 22° 56' and 24 ° 32' N and longitudes 91° 0' and

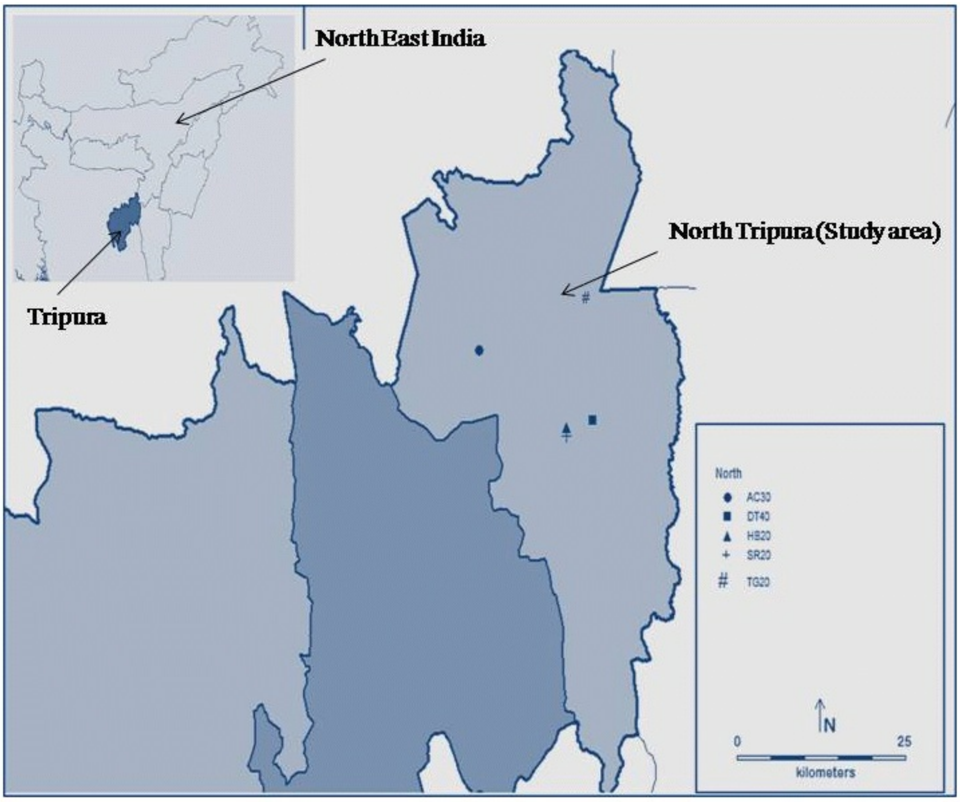

Figure 1. Map showing the location details of the sampling area in Tripura.

92° 22' E in the north east extension ranges of Himalaya. Due to maximum precipitation and high humidity, the region is floristically very rich and covered with largely evergreen and moist deciduous forests. According to the census report 2010-2011 the total population of the state was 36.71 lakhs. The indigenous tribal populations living in the hills have traditionally derived their livelihood from floral and faunal resources of the state. The forests in the state are mainly tropical evergreen, semi evergreen and moist deciduous and cover 77.18% of total geographical area.

The present study was conducted in North Districts of Tripura (Figure 1). The geographical position of every sampling point was taken using a GPS (GARMIN-Oregon-650) and recorded. At the time of sampling year (2014), five different plantation systems were viz. *Dipterocarpus turbunatus*- 40-yr old (DP40), *Artocarpus chaplasha*- 30-yr old (AC30), *Shorea robusta*- 20-yr old (SR20), *Tectona grandis*- 20-yr old (TG20) and *Hevea brasiliensis*- 20-yr old (HB20). The age of the plantations was recorded from the record of the forest department maintained by the forest range office. The initial age structure of the forest landscape is an important key of C dynamics in planted forests at the landscape level. These species were selected since they are the most promising native species and therefore the most commonly planted in the region. *Teak* and *Sal* are among the top 20 tree species planted all over the world. Teak in India shares about 8% of the main plantation species.

Aboveground Carbon Estimation

The total sampling area was 5 hectares. Fifty transects were laid in different plantations. Due to the distribution of these land uses on large area, we laid transects in each land use over diverse location to increase their representation. Transects were further divided into ten equal areas of 10×10 m, 5×5 m and 1x1 m quadrats. A nested plot design was used, to measure the various biomass components (trees, herbs, necromass) and soil in different sized subplots. For shrubs, herbs and grasses and litter, the complete harvest method was used. The material was separated, dried at 80°C to determine its dry weight. Thus, each transect represented an area of 0.1 ha (10 ×100 m) and encompassed 10 (10×10 m) contiguous subplots (MacDicken 1997). The circumference at breast height (CBH) and height of all tree (CBH ≥10 cm girth) over bark at 1.3 m height were measured. The basal area (BA) of the tree was calculated by using the formula:

$$BA = CBH^2 / 4\pi;$$

where, CBH = circumference at breast height and π = 3.1416.

The value of basal area was presented as sq. meter per hectare (m^2 ha^{-1}). Tree biomass was estimated using species specific regression equation available in the literature (Table 1). Species-specific allometric equations, developed on site provided better biomass estimation than generalized equations. The belowground tree biomass (BGB) was calculated as equal to 15% of the aboveground tree biomass (AGB) (MacDicken 1997). The value of trees and understorey biomass was converted into C equivalent by multiplying by 0.5 since, C content in plant tissue is approximately, half of the dry weight of the above ground live biomass (Malhi and Grace 2000). The rate of C sequestration (Mg C ha^{-1} y^{-1}) was calculated for each age class per year by dividing the C mass per ha by the age of trees (Prodan et al. 1997).

Soil Sampling, Analysis and Carbon Stock

The study of SOC contents of soil was done on unit area basis, for specific depth interval. Soil cores were divided into four depth profiles of 0–10 cm, 10–30 cm, 30–50 cm, 50-100 cm and 0-100 cm. The composite samples were prepared, air-dried, ground and passed through 2 mm sieve and for each depth five replicates of each composite were analyzed. The SOC was estimated by wet oxidation method (Walkley and Black 1934). The soil bulk density in grams per cubic centimeter (g cm^{-3}) was calculated as follows; $\rho b = Ms/Vt$; Where: ρb = bulk density of the soil in grams per cubic centimeter (g cm^{-3}), Ms = oven dry mass total sample in grams, Vt = core volume in cm^3. The total stock (Mg ha^{-1}) was calculated by following standard method (Guo and Gifford 2002):

$$SOC\ (Mg\ C\ ha^{-1}) = \%\ Carbon/100 * BD\ (Mg\ m^{-3}) \times D\ (m) \times 10{,}000$$

where, BD is the soil bulk density (g cm^{-3}), Cc (%) the soil C concentration and D is soil sampling depth (m).

Table 1. Allometric models used for biomass calculation for different plantations

Plantation code	Species	Allometric model	Reference
AC30	*Artocarpus chaplasha*	$AGB = 0.1245 \times D^{2.4163}$	Hung et al. 2012
DT40	*Dipterocarpus turbinatus*	$AGB = 0.03713 \times DBH^{2.73813}$	Huy et al. 2016
HB20	*Hevea brasileinsis*	$AGB = 2.278479\ X^{2.6823}$	Sone et al. 2014
SR20	*Shorea robusta*	$AGB = 0.0921 \times (DBH)^{2.5899}$	Mandal and Joshi 2014
TG20	*Tectona grandis*	$AGB = 0.045(D^2\ H)^{0.921}$	Ounban et al. 2016.

Where, AGB= Biomass (Kg $tree^{-1}$), D= Diameter at breast height, X = diameter at 15 cm height from the bud union.

Soil pH was measured in 1M potassium chloride (KCl) suspension of 1:5(soil: liquid) using a pen type digital pH meter (Hanna-Hi 96107). Soil MC (%) was calculated on dry weight basis (Allen 1989). ST was measured for each soil depth with digital soil temperature meter (Hanna-Model 6310). For each depth, ST value was noted in the field at the time of collection of soil samples. The stock and biomass values obtained, were presented on megagram per hectare (Mg ha^{-1}) basis. The total carbon stock in the forest ecosystem is then converted to tons of CO_2 equivalent by multiplying it by 44/12 or 3.67 of the molecular weight ratio of CO_2 to O_2 in order to understand the climate change mitigation potential of the study area. The significance of each property between land uses systems was tested through Analysis of Variance (ANOVA). All statistical analysis was performed by PAST version 1.89 (Hammer et al. 2001).

Soil and Vegetation Data Ordination

We used Canonical Correspondence Analysis (CCA) to find correlations between the plantation biomass C pool and the edaphic factors (Soares et al 2015). It was used to detect the pattern of variation within the plantation data that may be best explained by measure of sum soil properties. Environmental variables included in the CCA were soil edaphic properties. Data matrices were assembled based on the plantation species biomass C pool values with some soil edaphic variables (SOC, BD, MC, ST, pH). The output ordination plot will be able to express the variation among the different plantations and the relationship between edaphic properties and planted species. The significance level of the canonical ordination axes was analysed by the Monte Carlo test, which can be applied to determine the reliability of correlations between soil variables and plant species.

RESULTS

Stand Characteristics of Plantations

The details of the structural poperties of different tree plantations are given in Appendix 1 and Figure 2. The tree density (individuals ha^{-1}) was highest in SR(748), followed by TG (632), HB (504), AC (377) and DT (217). Mean value of number of species per hectare was highest in DT(7), whereas SR25 had the least number of species (2). BA (m^2 ha^{-1}) was highest in TG (44.27), followed by HB (40.29), SR (38.68), AC (27.20) and DT (17.30) and it did not vary significantly among the plantations (ANOVA, $F_{4, 49} = 1.59$, $P = 0.195$). The significant difference (ANOVA, $F_{4, 49} = 257$, $P < 0.001$) was found among the plantations in terms of mean CBH and value was highest for DT (145.39± 10.20), followed by AC (108.75 ±1.40), HB (96.73 ± 2.43), TG (91.37 ±3.27) and SR (72.82 ±3.24), respectively. Similarly, the significant difference (ANOVA, $F_{4,49} = 416.6$, $P < 0.001$) was found among the plantations. in terms of mean tree height and the value was highest for DT (20.29±0.33), followed by AC(17.32±0.40), SR (14.08±0.87), TG (14.08±0.36) and HB (12.24±0.25), respectively. In DT 7.95, 82.85 and 8.78 % individuals were counted in >200, >100 and <100 cm CBH groups, respectively. The tree height of 57.98 and 42.02 percent of individuals fell

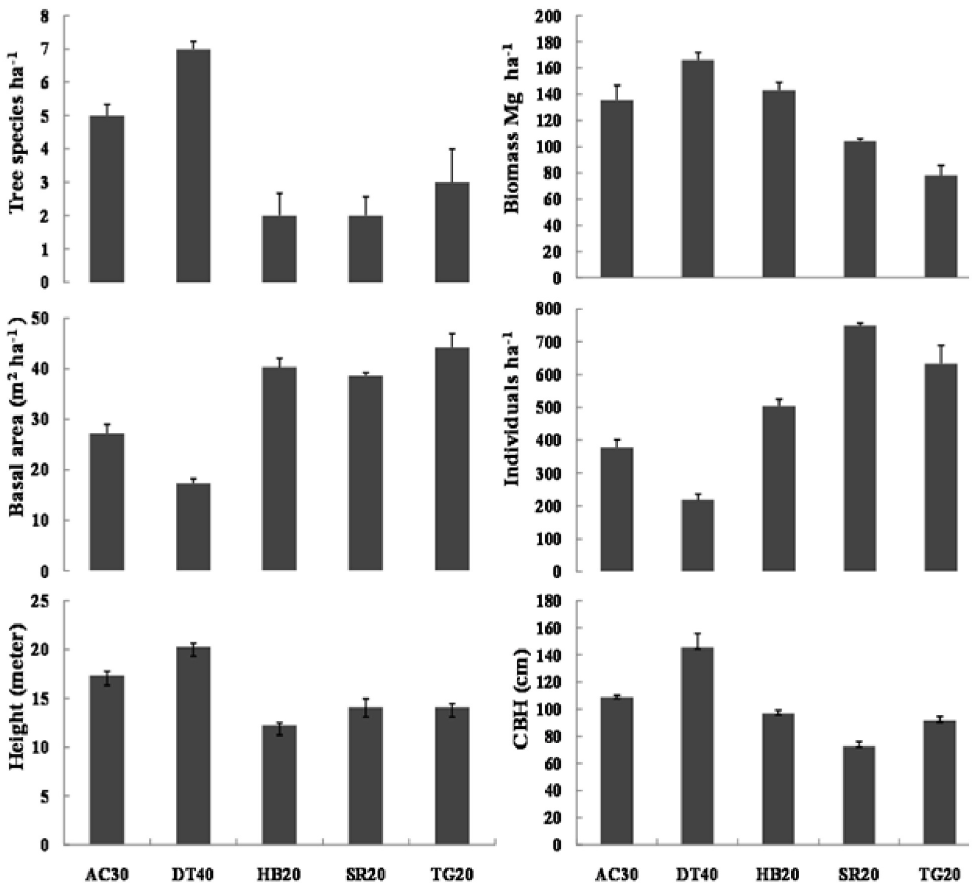

Figure 2. showing the structural properties of different plantations in Tripura.

under 20 and 16-19 m class. In AC, 66.21 and 33.79% stands fell under 160 to <100 and 40 to100 cm CBH classes, respectively, whereas height wise analysis revealed that 19.05, 71.43 and 9.29% of the total stand represented by 23-20, <20-15 and <15-11 m height classes. In HB, about 53.98% stands were present in 134-100 cm CBH class, whereas, 91.43 and 8.56% in 15-10 and <10 to 6 m height class. In SR plantation, 9.79, 62.85 and 27.35% of stems were found in 144-100, <100-60 and <60-36 cm CBH classes, respectively. Similarly, in 22-15, <15-10 and <10-8 m height class, 45.37, 51.42 and 3.11% stems were counted. In TG plantation, 28.41, 43.72 and 27.68% stems were recorded in 131-100, <100-80 and <80-43 cm CBH class, whereas, in 17-10 and <10-8 m height class, 99.27 and 0.73% stems were recorded. The inventorised tree species form the different plantations were *D. turbinatus*, *A. chaplasha, S. robusta, T. grandis, H. brasiliensis, Syzigium cumini, Microcos peniculata, Gmelina arbrea, Macaranga peltata, Lagestroemia speciosa, Ficus hispida* and *Bauhinia purpurea*.

Biomass Stocks in Tree Plantations

The different land uses under the study showed a wide variation in distribution of Above Ground Biomass (AGB) (Figure 2). The maximum value (Mg ha^{-1}) was found for TG (138.88), followed by HB (123.22), SR (116.28), AC (84.71) and DT (65.26 Mg ha^{-1}). The significant difference (ANOVA, $F_{4, 49} = 29.9$, $P< 0.001$) was found among the land uses in terms of stocking AGB. Maximum AGB to the total biomass was equally contributed by *S. robusta* and *H. brasiliensis (*86%). The maximum productivity (Mg ha^{-1} yr^{-1}) was recorded for TG(4.15 ± 0.45), followed by HB(3.57 ± 0.45), SR (3.39 ± 0.88), AC(1.73 ± 0.40) and DT (0.97 ± 0.28). The shrub pool had a considerable amount of share in total biomass and mostly contained the seedling of dominant tree species. Shrubs biomass significantly differed (ANOVA, $F_{4,49} = 47.3$, $P< 0.05$) and maximum contribution through shrub biomass was provided by TG(3.89 Mg ha^{-1}), followed by AC (3.34 Mg ha^{-1}), DT (1.63 Mg ha^{-1}) and SR (0.15 Mg ha^{-1}). HB had a negligible amount of shrub biomass. Herb biomass, mostly composed of grasses, runners and seedling. It also significantly differed (ANOVA, $F_{4, 49} = 24.8$, $P< 0.01$) and highest contribution (Mg ha^{-1}) was made by AC (2.08), followed by TG (1.67) SR (0.74), HB (0.65) and DT (0.41). In different plantations, the contribution of shrubs, herbs and litter, including dead wood to the total biomass content was 1.60, 0.92 and 0.74 percent, respectively. Overall the total AGB differed among the plantations (ANOVA, $F_{4, 49} = 29.47$, $P< 0.01$) and the highest value (Mg ha^{-1}) was found in TG (166.07), followed by HB (143.05), SR (135.64), AC (104.32), and DT (78.05). In AC, tree, belwoground, herbaceous and litter biomass shared 82.57, 12.39, 3.96 and 1.09 percent of the total biomass. Biomass and soil C pool shared 36.23 and 63.87 percent, respectively. In SR plantation, belowground, herbaceous layer and litter biomass contributed about 86.35, 12.95, 0.49 and 0.19 percent, respectively. Biomass and soil C pools were 43.33 and 56.58 percent, respectively. In TG, stand, belowground, herbaceous and litter biomass were 82.70%, 12.40%, 4.28% and 0.61% respectively. Biomass and soil shared 35.44% and 64.54% of the total C pool respectively. In 20 year rubber plantation, stand, belowground, herb and litter biomass were 86%, 12.90%, 0.52% and 0.56% respectively. Shrub biomass was not found in this plantation system. Biomass and soil C contributed 26.07% and 73.93% of the total C, respectively.

SOC and Edaphic Properties in Plantations

The details of the results are given in Appendix 2 and Figure 2. Overall the soil C (%) significantly differed (ANOVA, $F_{4,24}=57.95$, $p<0.001$) among the plantations and its value was highest and lowest for HB (1.18) and TG (0.65), respectively. The sudden decrease in SOC was observed from top to sub layers, irrespective of plantations. The value of % C in top layer (0-10 cm soil depth) among plantations ranged from 0.85(SR) to 1.41(HB). Total C stock (Mg C ha^{-1}) in AC, DT, HB, SR and TG were 170.28 ±16.10, 162.08 ±13.64, 238.54 ±15.90 205.83 ±4.38 and 172.31 ±14.54, respectively. The total C and C stocked in each pool was significantly differed (df = 6, 34) (Table 2) among the plantations. The details of the edaphic properties and soil C stocks are given in Table 3. The value of SOC stock was significantly higher (ANOVA; $F_{4, 24} = 65.02$, p=<0.001) in DT (178 Mg C ha^{-1}), followed by HB (176.99 Mg C ha^{-1}), AC (102.97 Mg C ha^{-1}), TG (97.89 Mg C ha^{-1}) and SR (85.34 Mg C ha^{-1}). All soil samples analysed in the present study were strongly acidic. The soil pH ranges from AC (4.28) to DT (4.44) and did not varied significantly among the plantations. The soil of HB was strongly acidic (pH 4.51±0.07) and sandy loam in texture. The MC (%) in the soils significantly varied (ANOVA, $F_{4,24}=12.81$, $p<0.001$) and value ranged from 16.99% (DT) to 13.08 % (SR). ST is the important attribute of soil and its value (degree celsius) was significantly (ANOVA, $F_{4,24}=8.08$, $p<0.001$) high in TG

Table 2. Ecosystem carbon stock (Mg C ha^{-1}) in different MPs

Plantation Forests	AGC	BGC	Shrub	Herbs	litter	SOC	Ecosystem Carbon
AC30	42.36±3.26	6.35±0.49	1.67±0.25	1.04±0.14	0.74±0.17	102.97±2.95	159.66±4.24
DT40	32.63±3.11	4.90±0.47	0.82±0.07	0.21±0.04	0.48±0.05	178.42±5.23	213.72±7.24
HB20	61.61±2.51	9.24±0.38	0.02±0.001	0.33±0.04	0.35±0.04	176.99±7.96	253.15±8.67
SR20	58.44±4.80	8.77±0.72	0.08±0.11	0.37±0.09	0.17±0.05	85.34±1.97	159.28±6.45
TG20	69.44±2.51	10.42±0.38	1.95±0.16	0.84±0.05	0.40±0.04	97.89±4.06	88.27±2.44
F value	29.9		29.9	29.06	47.93	20.98	65.02 29.47
P- value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

(20.8) and lowest value was recorded for HB (18.44). Soil BD also significantly varied (ANOVA, $F_{4,24}$=17.75, p<0.001) and its value (g cm^{-3})was highest and lowest was for TG (1.51) and DT (1.37), respectively.

Carbon Sequestration in Plantations

The total C (and equivalent CO_2) sequestration in the plantations, biomass and soil in the five forestry plantation was estimated (Table 2). The total C stock significantly varied (ANOVA, $F_{4, 24}$= 119.2, p<0.001) among the different plantations and its value was highest for the HB (253.15), followed by DT (213.72), AC (159.66), SR (159.28) and TG (88.27), respectively. The maximum amount of C sequestration rate was found in plant biomass (Mg C ha^{-1} yr^{-1}) and it significantly differed (ANOVA, $F_{4, 49}$ =81, p<0.001) among the plantations. It was highest for SR(3.39±0.88), followed by TG (4.15 ± 0.45), HB (3.57±0.45), AC (1.73±0.12) and DT (0.97 ±0.09), respectively. The C sequestration rate in soil also varied significantly (ANOVA, $F_{4, 24}$=85.23, p<0.001) and its value was highest for HB (8.85± 0.39), followed by TG (4.89 ± 0.20), SR (4.26 ± 0.09), AC (3.43±0.09) and DT (4.46±0.13). The CO_2 eq. sequestration rate (Mg CO_2 ha^{-1} yr^{-1}) in plant biomass significantly differed (ANOVA, $F_{4,49}$=81, p<0.001)was highest in TG (15.23 ± 0.53), followed by HB (13.12 ±0.53), SR (12.44±1.02), AC (6.38±0.46) and DT (3.58±0.32), respectively. CO_2 sequestered in soil (up to 1 m soil depth) of the different plantations also differed significantly (ANOVA, $F_{4, 24}$=85.23, p<0.001) and its value was recorded highest for HB (32.47 ± 1.47), followed by TG (17.96 ±0.74), DT (16.36 ± 0.47), SR (15.66±0.36) and AC (12.59± 0.35), respectively. Total ecosystem CO_2 sequestration also vary significantly (ANOVA, $F_{4, 24}$=119.2, p<0.001) and its value was highest for HB (46.45 ±1.58), followed by SR (29.35 ±1.17), DT (19.60 ±0.66), AC (19.53 ±0.87) and TG (16.19 ±0.44), respectively. Direct ordination of CCA examines the similarity or dissimilarity of plantation samples. The CCA output showed that the biomass C pool–edaphic correlations were low, of which eigenvalues were 0.017 for the first axis, 0.002 for second axis, 0.001 for third axis and 0.0001 for the fourth axis (Table 3) (Figure 3). It showed that the strength was only 28 and 24%. The Monte Carlo permutation test also showed that there was no significant differences between the eigenvalues of the three ordination axes (p > 0.05).

DISCUSSION

The mean TD (632 individual per hectare) and BA(46.06 m^2 ha^{-1}) recorded in the study for *Teak* plantation is comparable with the study by Negi et al. (1990). They reported TD (444 individuals ha^{-1}), mean CBH (66.31 cm), BA (34.9 m^2 ha^{-1}), tree height (20. 4 m) from a 20 yr old *T. grandis* plantations of Tripura. The productivity recorded for *T. grandis* plantations was about 4.15 ± 0.45 Mg ha^{-1} yr^{-1}, this value is lower than the earlier reported value by Negi et al. (1990), which was 6.9 and 8.2 Mg ha^{-1} yr^{-1} for Teak and *Gmelina arborea* plantations, respectively. The productivity of all plantations under study is lower than this value. Among five plantation forests, the maximum value of AGB was found for TG (138.88 Mg ha^{-1}). The value of total AGB is also comparable with the reported value as Giri et al. (2014) reported that the total biomass of *T. grandis* trees was estimated at 147.50 Mg ha^{-1}, of which the AGB comprised 121.88 Mg ha^{-1} and the BGB comprised 25.62 Mg ha^{-1} in a 28-yr old *T. grandis* plantation in Uttara-

Table 3. Canonical Correspondence analysis (CCA) of biomass carbon pools with edaphic properties in different plantations of Tripura, northeast India. Internal correlation between plantation biomass, carbon stock and edaphic variables with first four ordination axis. The weighted correlation between the edaphic variables were used in the analysis. Correlation for which the absolute value exceeds *<0.05; **<0.01 and ***<0.001.(TC= Tree carbon; RC= root carbon; SC= Shrub carbon; HC= Herb carbon; SOC= Soil organic carbon; BD= bulk density; MC= moisture content; ST= Soil temperature and PH= soil pH).

	Axis_1	Axis_2	Axis_3	Axis_4	TC	RC	SC	HC	LC	SOC	BD	MC	ST	PH
Axis_1		0.842	0.959	0.858	0.007	0.007	0.174	0.006	0.005	0.137	0.001	0.603	0.094	0.012
Axis_2	-0.042		0.132	0.930	0.586	0.587	0.043	0.558	0.070	0.539	0.445	0.909	0.969	0.944
Axis_3	0.011	0.310		0.339	0.644	0.644	0.177	0.975	0.114	0.043	0.136	0.721	0.196	0.123
Axis_4	0.038	0.018	-0.199		0.899	0.897	0.711	0.767	0.536	0.255	0.472	0.171	0.118	0.138
TC	0.526**	0.114	-0.097	-0.027		0.000	0.664	0.198	0.080	0.052	0.113	0.013	0.005	0.998
RC	0.525**	0.114	-0.097	-0.027	1.000		0.662	0.198	0.080	0.052	0.113	0.013	0.005	1.000
SC	-0.281	-0.407	0.279	-0.078	0.091	0.092		0.005	0.121	0.001	0.004	0.135	0.180	0.529
HC	-0.535**	-0.123	-0.007	0.062	0.267	0.267	0.546		0.030	0.000	0.013	0.230	0.567	0.009
LC	-0.544**	-0.369	-0.324	0.130	-0.356	-0.356	0.318	0.434		0.539	0.101	0.440	0.225	0.005
SOC	0.306	-0.129	-0.409	0.237	-0.392	-0.393	-0.611	-0.680	-0.129		0.056	0.012	0.007	0.353
BD	0.635	0.160	-0.307	0.151	0.325	0.325	-0.551	-0.491	-0.336	0.387		0.841	0.985	0.423
MC	-0.109	0.024	-0.075	0.283	-0.488	-0.488	-0.307	-0.249	0.162	0.497	-0.042		0.031	0.848
ST	0.343	0.008	0.268	-0.321	0.545	0.546	0.277	0.120	-0.252	-0.524	0.004	-0.432		0.029
PH	0.491***	-0.015	0.317	-0.305	-0.001	0.000	-0.132	-0.509	-0.542	0.194	0.168	0.040	0.436	

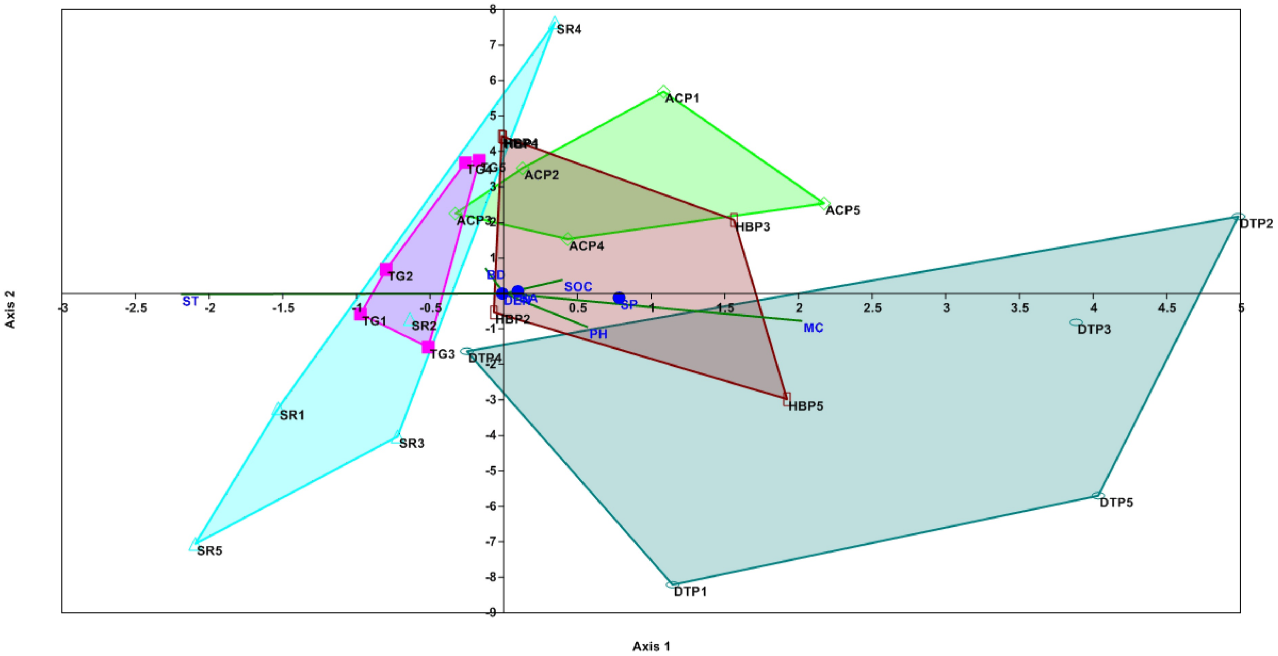

Figure 3. CCA ordination diagram of 25 plantation plots in Tripura, northeast India. The biomass carbon pools in plantations were:TC- Tree carbon, HC- Herbs carbon, SC- Shrub carbon, LC-Litter carbon, RC- Root carbon. The edaphic variables in the diagramme were: pH-Soil pH; ST- Soil Temperature, BD- Bulk density, MC- Moisture content, SOC- Soil Organic Carbon.

khand. This value is also comparable to that reported earlier by Negi et al. (1990) in Tripura (114 Mg ha^{-1} for 20 years *Teak* plantation). This means that the productivity of TG can be increased by using better management practices which could also lead to better goods and services. The biomass value for SR was 116.28 Mg ha^{-1}.

While studying the biomass stock in different forest patches of Tripura, Majumder et al. (2016) have reported that the value of AGB (Mg ha^{-1}) ranged from 20.86 (moist deciduous Sal forest) to 126.37 (Semi evergreen *Dipterocarpus* forest). The estimated value of biomass in *S. robusta* plantation is also less than the natural *S. robusta* forest as Pande and Patra (2010) reported the biomass value in the range of 154.9-345.6 Mg ha^{-1}.

The value of SOC was highest and lowest in HB (1.18) and TG (0.65), respectively. Thapa et al. (2011) in their study from Meghalaya reported that the percentage of SOC from top 0-20 cm was 0.88 and 1.05 percent in natural and plantation forests of *S. robusta.* The lower value of SOC in *T. grandis* may be attributed to the risk of soil erosion, caused by large raindrops falling from broad and large leaves. Another possible risk of preventing C accumulation in the soil of TG may be forest fires. Ground fire is the common management practice, used by forest department. Although teak resists fire, litter on the forest floor is lost if fires occur in the dry season, which is considered to be the main cause of low soil carbon accumulation in Myanmar teak plantations (Suzuki et al. 2007). The sudden decrease in SOC was observed from top to sub layers, irrespective of plantations. The value of % C in top layer (0-10 cm soil depth) among plantations ranged from 0.85(SR) to 1.41(HB). Total C stock (Mg C ha^{-1}), (up to 1 meter soil depth) in AC, DT, HB, SR and TG was 170.28, 162.08, 238.54, 205.83 and 172.31, respectively. However, this value is quite low compared with the another reported value, as the SOC stock in a 20 years-old Teak plantation was 225 Mg C ha^{-1} reported from Panama (Kraenzel et al. 2003). Choudhary et al. (2016a), have reported that from 0-10 cm to 10-30 cm soil depth, the C stock decrease by 60.5, 68.03 and 65,07 percent in natural forest, managed plantation and jhum fallow of the region. The conversion of natural forest into plantations led to 39% decrease in SOC in top layer. All the soil were acidic irrespective of plantations and soil depth, but did not showed any definite trend. The soil pH ranged from 4.28 (AC) to 4.44 (DC). This may also be possible reason for low SOC in plantations as acidic soils generally have less SOC i.e. inverse relationship between soil pH and organic C is being reported (Homann et al. 2005). Choudhuri et al. (2009) also reported that the soil of the mixed forest in the surrounding of HB plantation was highly acidic (pH 4.62). Continuous standing tree may lead to reduction in the soil pH as reported elsewhere (Hölscher et al. 1997). The MC (%) in the soils ranged from 16.99% (DT) to 13.08 % (SR). The highest value of MC in DT may be attributed to thick ground vegetation cover and large value of tree height. It is reported that the leaf litter forms humus after decomposition and improves various soil MC. Heavy positive correlation between soil MC and SOC has been reported (Zeidler et al 2002). ST is the important attribute of soil and its value (degree celsius) was highest in TG (20.8) and lowest value was recorded for HB (18.44). The highest value of ST in TG may be correlated with lowest value of percentage SOC (0.65 percent). As in general, SOC decreases with increasing temperature, but trend is uncertain (Homann 2007). On the other hand, increasing ST is thought to increase the rate of microbial decomposition and respiration by increasing the rate of enzymatic reactions in the soil. This would increase release of CO_2 from soil (Kirschbaum 1995). This observation can be supported by the higher proportion of soil C stock in temperate cooler climates compared to warmer tropical climates. In all plantations, the value of soil BD (g cm^{-3}) was high and maximum and minimum was for recorded for TG (1.51) and DT (1.37), respectively. High value of BD in TG may due to the fact that the soil had low percentage of organic C. This value is comparable with that of the neighbouring region. Ralte et al. (2005) in their study from Meghalaya, India have reported that BD varies from 0.9±0.03 g cm^{-3} in surface layer (0-10 cm depth) to 1.5± 0.1 g cm^{-3} in the sub-surface soil (10-20 cm soil depth) of primary forest. Many other studies have reported the inverse relationship between BD and soil C (Homann et al. 2005).

The maximum amount of C sequestration rate was found in plant biomass. The difference in the sequestration rate in different plantations may also be due to difference in the growth rate of tree species. Choudhary et al. (2016b) while studying the carbon sequestration potential of different aged HB plantation have reported that 5, 10,15 and 20 yr old HB plantations have capacity to sequester 3.17, 3.98, 3.42 and 1.64 Mg C ha^{-1} yr^{-1} , respectively. Derwisch et al. (2009) studied the estimation of aboveground C storage in TP plantations using 20 years rotation period in Western Panama. The CO_2 storage over this period amounted to 191.1 Mg CO_2 ha^{-1}. In DT plantation, tree, belowground, herb and litter biomass was 84.77, 12.71, 1.71 and

0.79%, respectively. The SOC and AGB ratio of the present study comes to be 0.51. It means that DT plantations are most and TG are least vulnerable in terms of of CO_2 flux into the environment compared to other four plantations system. Soil to plant C ration indicated the vulnerability of plantations from the disturbances. This ration varied from 4.57 (DT) to TG (1.17). Ravindranath et al. (1997) reported that the ratio of SOC and biomass C was 1.25. Kaul (2010) has given the range of this ratio between 0.7 to 2. She indicates that in the plantations, the C content in the soil was double the biomass carbon but not 2.5 to 3 times the biomass C as recorded earlier. Biomass C and SOC stock shared about 29% and 71% of the total C stock in DT. This result is contrary to the finding of Saner et al. (2012). They reported that in DT forest, major C stocks stocked as AGB (55% or 91.9 Mg C ha^{-1}). So we can say that the replacement of natural DT forest by plantation decrease its carbon sequestration capacity.

CONCLUSION

The results of this study indicate that managed plantations of Tripura have high potential of storing biomass and carbon. Since the magnitude of storage is comparatively low than the adjoining areas, we can add more with the help of proper management strategy. The SOC pool is relatively more stable than the biomass pool, but we have to preserve it as it gets input from the AGB. The interest in the stabilizing carbon stock in managed plantation is well acknowledged and increasing. Globally, climate negotiations have highlighted the importance of differential use of land in mitigating the climate the climate change. Soil carbon sequestration differs from other atmospheric carbon mitigation mechanisms in that it removes CO_2 from the atmosphere and also decreases soil erosion, improves surface water quality and improves soil physical properties. To rescue the world from global warming and climatic change, the sustainable management of forest with the objectives of carbon sequestration is mandatory. Stand age is the dominant factor influenced the total forest ecosystem carbon pool. Soil to plant carbon ratios indicate that the plantation systems of the state are vulnerable in terms of sequestration and stocking of carbon from the disturbances. So, we should think of possibilities of increasing their carbon sequestration potential. Higher soil: plant carbon ratio in DT, indicates that in the near future if any accident or conversion takes place then this plantation system can be the major source of CO_2 flux into the atmosphere compared to other four plantations system. With the help of this study. researchers and administrator can analyse the carbon storage potential of state and it will help in negotiating global carbon credit, which can further helpful in improve forest resources of the state. Carbon stocks and sequestration of plantation forest can be a source for livelihood and human development Carbon financing schemes like the Clean Development Mechanism (CDM) and Reduced Emissions from Deforestation and Degradation (REDD) could help to secure both the economic and ecological stability of the region. By managing the plantation densities and spatial structure, we can increase the level of plant and animal diversity. To understand the complete dynamics of carbon the emission patter, exact sequestration rate and other C pools like relation between organic and inorganic C in soil should also be analysed.

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Author contributions: B.K. Choudhary and K. Majumdar did the field work, data collection and developed the manuscript. B.K. Datta contributed to the experimental design and analysis of the results. We declare that there are no competing interests.

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Appendix 1.

Structural properties of five plantations (on per hectare basis) in the study area. SP-Species; DN-Density, BA-Basal area (m^2), BM-Biomass (Mega gram).

		AC				DT				HB				SR				TG			
S.N.	Species	SP	DN	BA	BM	SP	DN	BA	BM	SP	DN	BA	BM	SP	DN	BA	BM	SP	DN	BA	BM
1	*Artocarpus chaplasha*	1	371	39.9	82.12	1	1.15	0.12	64.68												
2	*Bauhinia purpurea*	1	0.5	0.02	0.34	1	0.91	0.23	0.013					1	1.02	0.23	0.22				
3	*Cedrela toona*	1	0.7	0.01	0.51																
4	*Dipterocarus turbinatus*	1	1.1	0.01	1.51	1	213	16.69	0.001												
5	*Ficus hispida*	1	2.3	0.06	0.02																
6	*Gmelina arborea*																	1	2.71	0.86	0.48
7	*Hevea brasiliensis*									1	503.64	38.63	122.79								
8	*Lagestroemia speciosa*																	1	1.26	0.27	0.21
9	*Macaranga peltata*					1	0.49	0.01	0.016												
10	*Microcos peniculata*					1	0.26	0.03	0.25	1	0.38	0.22	0.42	1	0.87	0.67	0.84				
11	*Shorea robusta*	1	1.4	0.01	0.22									1	744.2	40.02	115.3				
12	*Syzygium cuminii*					1	1.12	0.29	0.26					1	2.29	1.07	0.59				
13	*Tectona grandis*																	1	628.2	45.03	138.22
	Total	6	377	40.0	84.7	6	217	17.62	65.27	2	504	38.9	123.2	4	748	41.97	116.9	3	632	46.07	138.88

Appendix 2. The edaphic properties and result of ANOVA of different plantations .

Soil parameter	Soil depth (cm)	AC30	DT40	HB20	SR20	TG20	ANOVA F value	P- value
pH	0-10	4.40±0.24	4.66±0.07	4.33±0.16	4.35±0.08	4.44±0.12	1.64	<0.17
	10-30	4.19±0.05	4.42±0.09	4.31±0.13	4.35±0.04	4.36±0.19	1.77	<0.14
	30-50	4.23±0.14	4.45±0.04	4.31±0.11	4.24±0.07	4.24±0.14	0.53	<0.77
	50-100	4.12±0.08	4.44±0.09	4.29±0.08	4.29±0.06	4.32±0.11	4.33	<0.05
	0-100	4.28±0.22	4.44±0.04	4.40±0.18	4.29±0.08	4.32±0.22	1.79	<0.13
MC	0-10	18.56±1.43	15.49±0.56	16.10±0.88	12.34±0.37	13.47±0.65	5.64	<0.001
	10-30	18.89±0.75	17.65±0.5	15.99±0.66	13.75±0.83	15.57±0.79	3.04	<0.05
	30-50	12.09±0.83	16.26±0.82	15.82±1.15	15.49±0.39	12.51±0.86	8.10	<0.001
	50-100	13.47±0.34	17.75±0.68	17.28±0.65	12.95±0.49	14.17±0.34	12.81	<0.001
	0-100	15.75±1.74	16.99±0.62	16.30±0.33	13.08±0.81	13.76±0.65	3.25	<0.05
ST	0-10	18.58±0.44	18.90±0.17	17.50±1.23	20.28±0.37	20.76±0.77	20.41	<0.001
	10-30	19.54±1.32	19.48±0.24	18.72±0.95	21.08±0.35	20.64±0.55	10.02	<0.001
	30-50	19.12±0.8	18.84±0.23	18.88±0.7	19.26±0.6	21.08±0.8	11.97	<0.001
	50-100	19.26±0.7	19.80±0.39	18.48±0.6	20.8±0.7	19.44±0.9	2.20	<0.069
	0-100	19.22±1.23	19.20±0.11	18.44±1.23	20.20±0.05	20.80±1.1	8.08	<0.001
SOC	0-10	0.98±0.4	1.11±0.04	1.41±0.19	0.85±0.06	0.89±0.3	39.06	<0.001
	10-30	0.74±0.6	0.92±0.04	1.29±0.09	0.69±0.02	0.70±0.2	36.02	<0.001
	30-50	0.62±0.04	0.79±0.01	1.10±0.5	0.60±0.03	0.56±0.11	18.57	<0.001
	50-100	0.47±0.02	0.69±0.02	0.92±0.3	0.56±0.02	0.52±0.13	9.53	<0.001
	0-100	0.69±0.3	0.83±0.03	1.18±0.81	0.77±0.02	0.65±0.09	57.95	<0.001
BD	0-10	1.56±0.22	1.37±0.01	1.45±0.4	1.45±0.01	1.48±1.04	7.14	<0.001
	10-30	1.48±0.34	1.33±0.01	1.56±0.34	1.45±0.05	1.56±0.2	6.26	<0.001
	30-50	1.55±0.02	1.43±0.02	1.59±0.27	1.42±0.08	1.55±0.3	3.68	<0.05
	50-100	1.46±0.04	1.36±0.04	1.50±0.19	1.43±0.01	1.55±0.12	1.48	<0.225
	0-100	1.50±0.07	1.37±0.02	1.50±0.11	1.41±0.02	1.51±0.16	17.75	<0.001
SOC Stock	0-10	15.21±1.34	15.19±0.6	20.36±1.23	12.29±0.82	13.23±0.17	33.18	<0.001
	10-30	10.93±1.12	12.47±0.53	20.02±3.11	9.86±0.27	10.85±1.1	34.83	<0.001
	30-50	9.59±0.88	11.37±0.21	17.47±2.39	8.18±0.35	8.75±0.88	17.53	<0.001
	50-100	6.79±0.6	9.5±0.28	13.79±1.62	8.69±0.42	8.14±0.31	8.79	<0.001
	0-100	10.30±1.12	11.66±0.39	17.70±2.18	11.01±2.7	9.79±1.21	65.06	<0.001
Total SOC Stock	0-10	15.21±1.34	15.19±0.6	20.36±1.23	12.29±0.82	13.23±0.17	33.18	<0.001
	10-30	21.9±1.87	40.6±2.15	40.0±1.66	16.7±1.96	21.7±2.18	28.53	<0.001
	30-50	19.2±1.25	27.8±2.82	34.9±1.30	15.2±1.24	17.5±1.67	17.53	<0.001
	50-100	33.9±2.70	55.6±7.82	68.9±3.32	34.5±3.49	40.7±2.56	8.74	<0.001
	0-100	103.0±2.94	178.4±5.23	177.0±7.95	85.3±1.97	97.9±4.05	65.06	<0.001