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Carbon Stock and Sequestration Potential in Biomass of Tea Agroforestry System in Barak Valley, Assam, North East India

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ABSTRACT

The study assessed the potential of carbon stock and sequestration in the biomass of three tea plantations of 6, 14 and 22 years age in the Cachar district in Barak valley (24° 39' 27.7" N, 92° 41' 46.8" E and 24° 40' 49.3" N, 92° 39' 49.9" E). Allometric equation was developed for biomass estimation in tea bushes. Shade tree biomass was estimated using species specific volume equation along with incorporation of wood specific gravity and biomass expansion factor (BEF). Carbon stock in 6, 14 and 22 yr old plantations were 44.8 ± 1.3 , 50.2 ± 4.6 and 56.7 ± 4.9 Mg C ha⁻¹ with a share of 78.76 % and 21.24 % in above- and belowground compartment. Carbon sequestration was estimated 5.5 ± 0.55 , 2.1 ± 1.34 and 0.7 ± 0.32 Mg C ha⁻¹ yr⁻¹ respectively, for the three sites during the study period. Shade trees and tea bushes share 70.66 % and 29.34 % of total carbon stock. The medium girth (at 5 cm height) sized (>15-25 cm) tea bushes exhibit dominant cover (62.2 %) followed by smaller (≤ 15 cm) and larger sized (>25 cm) tea bushes. Medium GBH (50-90 cm) sized shade trees store maximum (73.5 %) carbon followed by larger (> 90 cm) trees (17.7 %) and smaller sized (10-50 cm) trees (8.8 %). Among the shade tree species encountered, *Albizia odoratissima* (63.9 %) is the major contributor to carbon storage followed by *A. lebbbeck* (24.3 %) and *Derris robusta* (8.7 %).

Key Words: Allometric Equation; Barak Valley; Biomass; Carbon Sequestration; Shade Tree; Tea Agroforestry System.

INTRODUCTION

The retained increase in atmospheric carbon dioxide (CO₂) concentration is considered to be hastened by human activities such as burning of fossil fuels and deforestation (IPCC 2007). Reduction in CO₂ emission or sequestration through different carbon (C) sinks is the probable option to mitigate climate change. The post-Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) era drew substantial attention in bracing the CO₂ level in the atmosphere encouraging varied land use systems as C sink. The woody perennial-based land use systems have relatively high capacity for capturing and storing atmospheric CO₂ in vegetation, soils, and biomass products (Kumar and Nair 2011). Agroforestry systems (AFS) offer important opportunities of creating synergies between both adaptation and mitigation actions with a

technical mitigation potential of 1.1–2.2 Pg C in terrestrial ecosystems over the next 50 years (IPCC 2007). The accent of AFS have higher carbon content and can help attain net gains in carbon than conventional lower biomass land uses like grasslands, crop fallows etc. Agroforestry provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation (Murthy et al. 2013). Although agroforestry systems are not primarily designed for carbon sequestration, they can play a major role in storing carbon in the above- and belowground biomass and in soil (Sathaye et al. 2001, Montagnini and Nair 2004, Nair et al. 2009).

In different AFS, C stock and sequestration occurs in both above- and belowground compartments, in the form of standing biomass, root biomass and enhancement of soil organic carbon (SOC). Some studies on C storage in AFS and alternative land use systems for India

had estimated a sequestration potential of 68-228 Mg C ha⁻¹ (Dixon et al 1994), 25 Mg C ha⁻¹ over 96 M ha of land (Sathaye and Ravindranath 1998). But this value varies in different regions depending on the biomass production (Pandey 2007). Agrisilvicultural systems sequester C in tree biomass. Annual carbon sequestration potential of planted tree species on abandoned agricultural land (3.9 Mg ha⁻¹yr⁻¹) and degraded forest land (1.79 Mg ha⁻¹ yr⁻¹) have been estimated. Leading carbon sequestering species was *Alnus nepaliensis* (0.256 Mg C ha⁻¹ yr⁻¹) and *Dalbergia sissoo* (0.141 Mg C ha⁻¹ yr⁻¹) intercropped with wheat and paddy (Maikhuri et al. 2000). Swamy et al. (2003) estimated C sequestration in a 6 year old *Gmelina arborea* based agri-silvicultural system (31.37 Mg C ha⁻¹). C sequestration in monoculture of trees and food crops is 40% and 84% less than in agri-silviculture indicating that agroforestry systems have more potential to sequester carbon (Dhyani et al. 2009) compared to 18.74 Mg C ha⁻¹ in sole wheat cultivation (Chauhan et al. 2010). In a system comprising *Albizia* and mixed tree species like *Mandarin* biomass stock and sequestration was reported as 6.94 Mg ha⁻¹ and 1.3 Mg ha⁻¹yr⁻¹ (Sharma et al. 1995).

Agroforestry has the potential of restoration and maintenance of soil fertility, and increase in productivity. Some of the agroforestry systems followed in northeast India are Agri-horticulture, Silvopastoral, Agri-silviculture, Silvi-horticulture, Pastoral-silviculture and home gardens (Murthy et al. 2013).

Tea (*Camellia sinensis* (L.) O. Kuntze) is grown under a canopy of trees which provide partial shade. It is grown widely in countries of Asia, Africa and the Near East and plays a vital role for earnings and food security for a large fraction of population in these countries. The Barak valley of northeast India is well known for the high density of tea gardens. In the valley tea agroforestry covers 32,312 hectare area of its total geographical area of 6922 km². (Tea Board of India 2007). The tea gardens are human-managed AFS of eminent productivity. While much is known about the productivity and management of tea, little attention has been paid to the plants' overall biomass production and C sequestration. There is limited information on C and nutrient study in tea AFS. The few published studies are limited to where tea has been commonly studied in association with shade tree species (Wijerante 1996, Dutta 2006, Kamau 2008). Assessment of soil organic carbon stock under an age sequence of tea AFS in Barak Valley has also been reported (Kalita et al. 2016). The objectives of this study were, therefore, to (1) provide a useful snapshot of the carbon stock and

sequestration in tea, shade tree biomass and plantation floor litter in three plantations of different age and (2) estimate the proportionate contribution towards biomass carbon storage by different compartments and (3) give a glimpse of the potential of tea agroforestry system to offset carbon emissions.

METHODS

Study site

Barak Valley region of Assam covers an area of 6922 km². The study was conducted in Rosekandy tea estate of Cachar district (24° 39' 25.9"- 24° 42' 10.7" N; 92° 39' 45.7"- 92° 42' 24.2" E). The climate of the study area is sub-tropical, warm and humid with average annual rainfall of 2390 mm, received mostly during the southwest monsoon season (May–September). The average maximum and minimum temperature ranges from 25.4 °C (January) to 33.5 °C (August) and 11.2 °C (January) to 25.3 °C (August). The soil of the region is a mixture of alluvial, sandy loam, silt clay loam.

Sampling

For sampling the vegetation (shade trees and tea bushes), homogeneous patches of 6, 14 and 22 years old tea plantations were selected. The ages of the tea plantations are defined based on 2010 as a reference year. A super plot of 250 m × 250 m area was surveyed to ensure the homogeneity of the site. For sampling the shade trees, four cluster sample plots (quadrat) of 0.1 ha (31.62 m × 31.62 m) were placed at the site. Total 12 quadrats were demarcated and treated as permanent plot for further study. For tea bushes 5 m × 5 m quadrats were placed within every 0.1 ha quadrat (Singh and Dadhwal 2009). GPS readings regarding latitude, longitude and elevation were collected for each plot.

Biomass Determination

Allometric equation was used for biomass estimation in tea bushes. Data from 31 destructively sampled tea bushes were pooled to develop biomass equations. For measuring the diameter, girth measured at 5 cm height was converted to diameter (girth/π). After harvesting, samples were divided into leaf, branch and stem components (aboveground) and their respective fresh weights were determined on-site by weighing on a

balance (20 kg) to the nearest 0.002 kg. For belowground compartment roots from individual tea bushes were completely excavated to a depth of 1m in square plots keeping the selected bush at the center. Soil embedded in the stump joints and on root surfaces was removed and their fresh weight determined. Five sub-samples were collected from each component and transported in ziploc bags to the laboratory for biomass estimation. Labeled samples were oven-dried for at 70 °C till constant weight and their dry weight determined on a 1200 g (0.01g) scale. The biomass of each component was obtained by multiplying component fresh weight by their respective dry weight-to fresh weight ratio. Aboveground biomass (AGB) of individual trees was attained by adding up dry weights from the stems, branches and leaves. Above- and below-ground (root biomass) biomass was aggregated to yield total biomass (TB).

Circumference of the shade tree stem was measured at 1.37 m from the base using metal tape. AGB in shade trees were estimated using species specific volume equation and regional volume equations published by Forest Survey of India (FSI 1996) multiplying wood density (WD) and biomass expansion factor (BEF). We used WD values from World Agroforestry Center database (Orwa et al. 2009) and BEF value used was 1.74 (Brown 1997). Belowground biomass (BGB) has been calculated by multiplying the AGB by 0.26 factors as the root-to-shoot ratio (Ravindranath and Ostwald 2008). Sub-samples were collected and oven dried at 70 °C to a constant weight. Oven-dried samples of tea components were powdered for further analysis.

Carbon Estimation

A total of 58% of the ash-free mass was calculated as the C content in all the samples of tea. The ash content was determined by igniting 1 g of powdered sample at 550 °C for 6 hours in a muffle furnace (Allen et al. 1989). The carbon storage in tea was determined by multiplying the biomass with the carbon concentration. The IPCC default value of 0.5 has been used for the carbon fraction of shade tree biomass. Carbon sequestration was estimated by deducting carbon stock values of previous year from proceeding year.

Statistical analysis

All data were entered and arranged for analysis using Microsoft Excel 2010 version. Data were subjected to statistical analysis of variance (ANOVA) for comparing the carbon stocks in plantation of different age over time following LSD using SPSS 15.0 for windows. Paired t-test was performed to analyze the growth, carbon stock and sequestration difference during study period.

RESULTS

Stand Characteristics

Tea is grown under a canopy of trees which provide partial shade. In the agroforestry system, tea bush density varies from 11400± 1100 stem ha⁻¹ to 19000 ± 1025 stem

Table 1. Distribution of density (stem ha⁻¹) and basal area (m² ha⁻¹) of shade tree and tea bush in three different aged Tea agroforestry system in Barak Valley during the years 2011 to 2013. All values are Mean ± standard error .

Plantation age	Compartment	Parameter	2011	2012	2013
6 years	Shade tree	Density	237.5 ± 7.40	230 ± 7.91	227.5 ± 7.40
		Basal are	6.44 ± 0.23	7.09 ± 0.26	7.96 ± 0.25
	Tea bush	Density	19000 ± 1024.70	18400 ± 836.66	17000 ± 300
		Basal area	38.74 ± 2.20	42.06 ± 2.51	42.72 ± 1.60
14 years	Shade tree	Density	210 ± 14.58	205 ± 13.46	205 ± 13.46
		Basal area	7.01 ± 0.33	6.98 ± 0.49	7.25 ± 0.54
	Tea bush	Density	17200 ± 1392.84	17000 ± 1337.91	16700 ± 1243.99
		Basal area	44.57 ± 2.29	47.48 ± 2.32	50.59 ± 2.50
22 years	Shade tree	Density	192.5 ± 17.46	182.5 ± 19.80	170 ± 20.62
		Basal area	7.39 ± 0.57	7.29 ± 0.62	7.20 ± 0.60
	Tea bush	Density	12000 ± 1240.97	11400 ± 1034.41	11400 ± 1100
		Basal area	47.20 ± 4.53	51.08 ± 5.06	52.91 ± 4.44

ha⁻¹. Shade tree density values lies between 170 ± 20.6 stem ha⁻¹ and 237.5 ± 7.4 stem ha⁻¹ (Table 1). The basal cover observed in the 6, 14 and 22 yr old plantations were 45.2 ± 4.1, 51.6 ± 5.1 and 54.6 ± 8.7 m² ha⁻¹ respectively. Tea bushes and shade trees share 86.6 % and 13.4 % of total basal cover. In the study site, medium girth (at 5 cm height) sized (>15-25 cm) tea bushes were dominant by their cover (62.2 %) followed by smaller (≤15 cm) and larger sized (>25 cm) tea bushes (Figure 1). Five different shade tree species namely *Albizia odoratissima* (L.F.) Benth., *Albizia lebeck* (L.) Benth., *Derris robusta* (Roxb.ex DC.) Benth., *Albizia chinensis* (Osbeck) Merrill and *Dalbergia sissoo* (Roxb. ex. DC.) were encountered at the study site. *Albizia odoratissima* was the dominant shade tree species followed by *Albizia lebeck* and *Derris robusta* registering 48.8 %, 37.5 % and 11.7 % occurrence and 53.5 %, 29.5 % and 9.1 % basal cover, respectively (Figure 2). Medium GBH (50-90 cm) sized shade trees were dominant in the stand followed by smaller sized (10-50 cm) trees and larger (> 90 cm) trees contributing 66.4%, 26.6% and 7% occurrence respectively; however, the basal cover contribution was 66 %, 23 % and 11% respectively for the three size classes (Figure 3). Shade tree density and basal area among girth classes exhibited significant difference during 1st year (ANOVA, F₂ = 5.89, P = 0.009 and F₂ = 6.43, P = 0.006) 2nd year (ANOVA, F₂ = 6.81, P = 0.005 and F₂ = 7.52, P = 0.003) and 3rd year (ANOVA, F₂ = 11.69, P = 0.000 and F₂ = 10.5, P = 0.001) of study. ANOVA showed significant difference in basal cover (F₂ = 5.45, P = 0.045) among the concerned girth classes of tea.

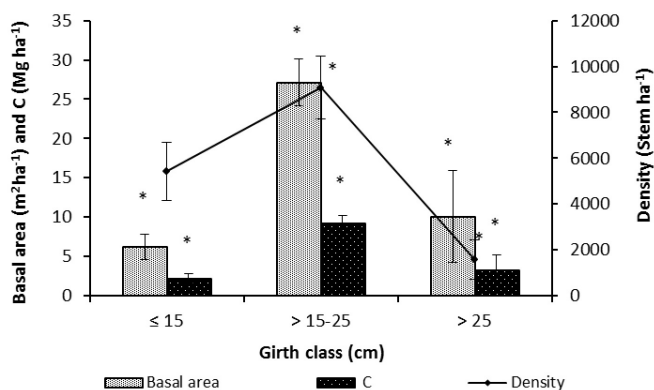


Figure 1. Density, basal cover and C stock allocation in different girth size classes of tea in tea agroforestry system in Barak Valley. Bars indicate ± S.E.; * indicates significant differences of mean between specific girth classes at 0.05 level.

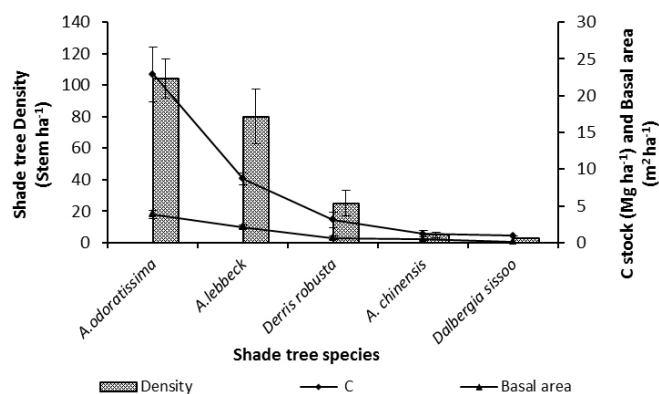


Figure 2. Species wise distribution of density, basal area and C stock allocation of shade trees in tea agroforestry system in Barak Valley.

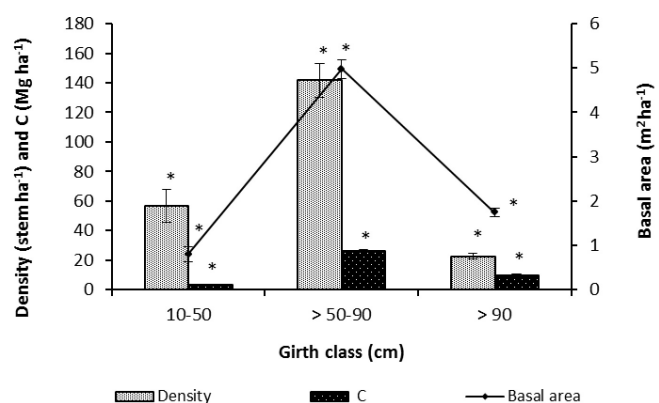


Figure 3. Density, basal cover and C stock allocation in different girth size classes of shade trees in tea agroforestry system in Barak Valley. Bars indicate ± S.E.; * indicates significant differences of mean between specific girth classes at 0.05 level.

Biomass Estimation and Carbon Sequestration

The data obtained from harvested tea (*Camellia sinensis*) were checked for errors prior to analysis and tested for outliers using scatter plots; the plots also revealed the relationship between biomass and predictor variables. Biomass values of different components and compartments were regressed on diameter to obtain allometric coefficients for biomass equations. Simple power function equation ($Y = aX^b$) was developed to estimate biomass of tea, where Y represents the biomass components (kg stem⁻¹), X denotes stem diameter (cm) at 5 cm height. In the equation, a and b stands for coefficient and the allometric constant respectively (Table 2). Diameter alone was the best independent variable for describing different biomass components, estimating stem, above-ground and total tree biomass with about 95 % accuracy

Table 2. Allometric power function equations ($y = ax^b$) for estimation of aboveground biomass (AGB) and biomass of roots (BGB). Allometric coefficients (a, b), coefficient of determination (R^2) are displayed (N = 31).

Component	A (\pm SE)	B (\pm SE)	R^2	Adj. R^2	SEE	P
AGB	0.047 (\pm 0.007)	1.878 (\pm 0.064)	0.967	0.966	0.238	< 0.001
BGB	0.014 (\pm 0.003)	1.870 (\pm 0.078)	0.952	0.951	0.289	< 0.001

(Figure 4). AGB accounted for most of the total tree biomass (77.2 %), with the stems, branches and leaves contributing 25.5, 64.1, and 10.4 % to AGB. Carbon concentration in the above- and belowground biomass components was 55.23 % and 55.13 %, respectively.

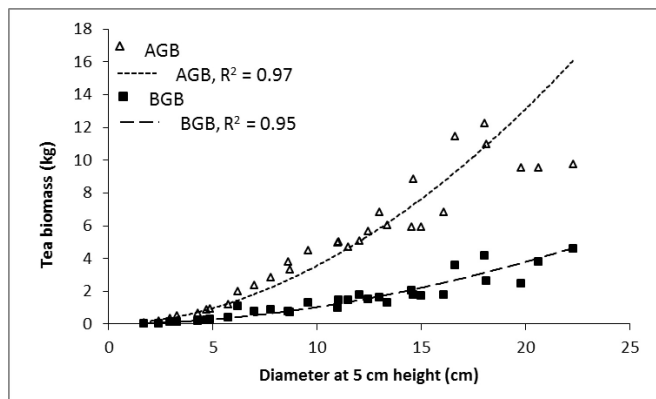


Figure 4. The relationship between diameter and the aboveground biomass (AGB), and belowground biomass (BGB) in Tea.

Carbon stocks in 6, 14 and 22 yr old plantations were 44.8 ± 1.3 , 50.2 ± 4.6 and 56.7 ± 4.9 Mg C ha⁻¹ with a share of 78.76 % and 21.24 % in above- and belowground compartment (Figure 5). Significant difference was observed in basal cover (t-test, $t = 22.11$, $df = 11$, $P < 0.01$) and C stock (t-test, $t = 26.10$, $df = 11$, $P < 0.01$) in the sites. Carbon sequestration was estimated 5.5 ± 0.55 , 2.1 ± 1.34 and 0.7 ± 0.32 Mg C ha⁻¹ yr⁻¹ respectively for the three sites during the study period (Figure 6). Paired samples t- test evinced significant mean difference of basal cover in the 1st and 2nd year ($t = -12.49$, $df = 11$, $P < 0.01$) and 2nd and 3rd year ($t = -3.11$, $df = 11$, $P < 0.05$) and of C stock in the 1st and 2nd year ($t = -3.68$, $df = 11$, $P < 0.01$) and ($t = -3.99$, $df = 11$, $P < 0.01$). Shade trees and tea bushes share 70.66 % and 29.34 % contributions towards carbon stock (Fig 7). Tea C stock varies significantly among the concerned size categories (ANOVA, $F_2 = 5.74$, $P = 0.04$). Shade tree C

stock varied significantly among the respective girth classes during 1st year (ANOVA, $F_2 = 5.21$, $P = 0.014$), 2nd year (ANOVA, $F_2 = 6.01$, $P = 0.008$) and 3rd year (ANOVA, $F_2 = 7.71$, $P = 0.003$) of the study.

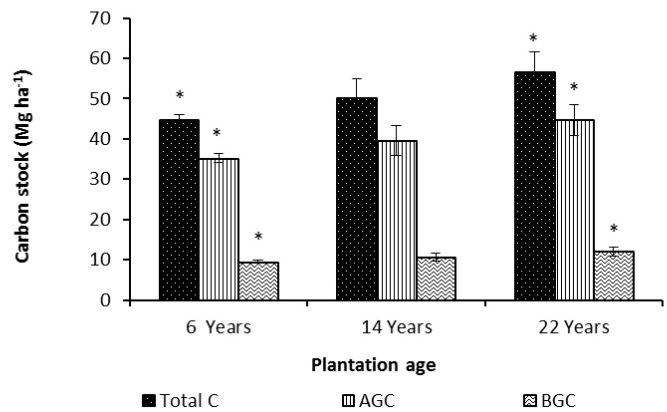


Figure 5. Biomass carbon stocks in three different ages of tea agroforestry system. Bars indicate \pm S.E.; * indicates significant differences of mean between specific girth classes at 0.05 level.

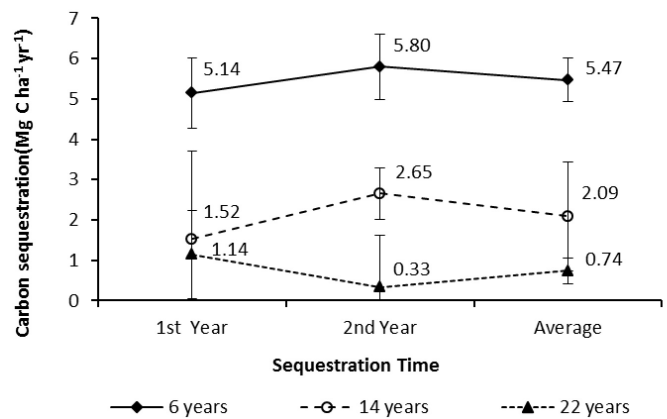


Figure 6. Carbon sequestration for two successive years in three plantations of different age of plantation in tea agroforestry system. Bars indicate \pm S.E.; * indicates significant differences of mean between specific girth classes at 0.05 level.



Figure 7. Carbon storage share of tea bushes and shade trees in different age of plantation in tea agroforestry system.

Among the shade tree species, *A. odoratissima* exhibited significant variation in C stock distribution in different girth classes during the 1st, 2nd and 3rd year of the study (ANOVA, $F_2 = 25.18$, $P = 0.002$, $F_2 = 32.19$, $P = 0.001$ and $F_2 = 22.44$, $P = 0.002$). ANOVA revealed similar trend in *A. lebbeck* with significantly different C allocation in different girth classes ($F_2 = 20.15$, $P = 0.004$, $F_2 = 10.26$, $P = 0.017$ and $F_2 = 7.89$, $P = 0.028$). Medium sized (GBH 50-90 cm) shade trees store most of the carbon (73.5 %) followed by larger (GBH > 90 cm) trees (17.7 %) and smaller sized (GBH 10-50 cm) trees (8.8 %). LSD indicates the effective dominance of the medium sized trees, which reflects significant difference with the smaller as well as larger sized trees. Among the shade tree species, *A. odoratissima* (63.9 %) is the major contributor to carbon storage followed by *A. lebbeck* (24.3 %) and *Derris robusta* (8.7 %) (Figure 2). In the present study, C sequestration in shade trees declined with increased age of the plantation from 4.86 Mg C ha⁻¹ yr⁻¹ (in 6 yr old plantation) to 1.14 Mg C ha⁻¹ yr⁻¹ (14 yr old plantation) and -0.15 Mg C ha⁻¹ yr⁻¹ (22 yr old plantation).

DISCUSSION

Dominance of medium sized shade trees in the plantations provides scope for impressive growth and increment in C stock in the compartment. Increasing trend was observed in C stock in the plantations along with age of the plantation. C sequestration was observed to be maximum in younger (6 yr old) plantation site and minimum in older (22 yr old) plantation. C sequestration

increased in 2nd increment year compared to the previous sequestration value in 6 and 14 yr old plantations, whereas reverse trend was observed in 22 yr old plantation (Table 3). Although the basal cover of the tea is much higher in comparison to shade trees, the latter emerged as dominating entity in terms of C stock and sequestration. *A. odoratissima* and *A. lebbeck* exhibits similar growth pattern. Although *A. lebbeck* is superior to *A. odoratissima* in terms of girth increment (Kalita et al. 2014) species wise C stock in the respective years did not differ significantly. Above-ground C stocks of 15 and 30-year old cocoa has been reported as 16.8 and 15.9 Mg C ha⁻¹ for in Ghana (Isaac et al. 2005). In Guatemala, the combined aboveground woody biomass of coffee and shade trees was determined to be 27.3 Mg C ha⁻¹ (Powell and Delaney 1998). C stocks in tea agroforestry in this study is comparable to the C estimation in cacao agroforestry (70 Mg C ha⁻¹) in Cameroon (Saj et al. 2013) and presents higher value than the farmed *Eucalyptus* species (11.7 Mg C ha⁻¹) in Kenya (Kuyah et al. 2013). The C storage in tea agroforestry (50.57 Mg C ha⁻¹) is remarkably higher than C storage in silvipastoral systems system involving *Acacia tortilis* with *Cenchrus ciliaris* (6.82 Mg C ha⁻¹) or with *Cenchrus setigerus* (6.15 Mg C ha⁻¹) in arid northwestern India (Mangalassery et al. 2014). Albrecht and Kandji (2003) indicated C storage potential between 39 and 102 Mg ha⁻¹ for agroforestry in the humid tropics of South America. Along with age of the plantation, the density of the shade tree and tea bushes decreased but basal cover showed increasing trend. To maintain proper shade for tea bushes under shade tree canopy, felling of shade trees in older plantations is a common practice. Decline in shade tree density in 22 years old plantation may be attributed as a result of shade management strategy which was clearly reflected in net C accumulation in the system.

CONCLUSIONS

Tea agroforestry system store and sequester considerable amount of C in biomass components. Shade trees are the major contributor for C stock and sequestration in the system. Shade tree species composition and distribution of biomass C highlighted the key role of every component for C stock and sequestration in the system. The study attempted to report and analyze the potentiality of tea agroforestry system to store and sequester C contributing towards climate change mitigation in Barak Valley, Assam, northeast India.

Table 3. Distribution of AGC (Mg ha⁻¹), BGC (Mg ha⁻¹) and TC (Mg ha⁻¹) in different compartments in three different aged plantation sites during the study period.

Plantation age	Compartment	Parameter	2011	2012	2013
6 years	Shade tree	AGC	24.85 ± 0.72	28.08 ± 0.98	32.57 ± 0.78
		BGC	6.46 ± 0.19	7.30 ± 0.25	8.47 ± 0.20
		TC	31.31 ± 0.91	35.39 ± 1.23	41.03 ± 0.98
	Tea bush	AGC	10.39 ± 0.58	11.21 ± 0.65	11.33 ± 0.39
		BGC	3.05 ± 0.17	3.29 ± 0.19	3.33 ± 0.12
		TC	13.44 ± 0.75	14.51 ± 0.85	14.66 ± 0.51
14 years	Shade tree	AGC	27.82 ± 1.33	28.29 ± 1.97	29.62 ± 2.21
		BGC	7.23 ± 0.35	7.36 ± 0.51	7.70 ± 0.57
		TC	35.05 ± 1.68	35.65 ± 2.48	37.32 ± 2.58
	Tea bush	AGC	11.75 ± 0.59	12.46 ± 0.60	13.22 ± 0.64
		BGC	3.45 ± 0.17	3.66 ± 0.18	3.88 ± 0.19
		TC	15.19 ± 0.77	16.12 ± 0.78	17.10 ± 0.83
22 years	Shade tree	AGC	32.60 ± 2.13	32.56 ± 2.33	32.37 ± 2.10
		BGC	8.48 ± 0.55	8.47 ± 0.61	8.42 ± 0.55
		TC	41.08 ± 2.69	41.02 ± 2.93	40.78 ± 2.64
	Tea bush	AGC	12.10 ± 1.12	13.03 ± 1.25	13.47 ± 1.12
		BGC	3.55 ± 0.33	3.82 ± 0.37	3.95 ± 0.33
		TC	15.65 ± 1.45	16.85 ± 1.62	17.42 ± 1.44

All values are Mean ± standard error ; AGC = Aboveground biomass carbon; BGC = Belowground biomass carbon; TC = Total biomass carbon.

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