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Biomass and Carbon Stock of Trees in a Tropical Moist Deciduous Forest of Kamrup Metropolitan District, Assam, India

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ABSTRACT

The present investigation deals with the estimation of biomass and Carbon stock potential of tree species in a tropical moist deciduous forest of Kamrup Metropolitan district of Assam, India. For vegetation sampling of trees, the stratified random method was employed and biomass and Carbon stock of trees were estimated by using an allometric equation. Altogether 39 tree species representing 34 genera and 20 families were reported. A high total density and total basal cover (TBC) were reported during the investigation (1008 stem ha^{-1} and 71.74 m^2 ha^{-1} respectively). Total biomass (TB), total Carbon stock (TCS), and CO_2 equivalent were estimated to be 985.56 Mg ha^{-1}, 492.78 Mg C ha^{-1}, and 1808.50 Mg C ha^{-1} respectively. Among the trees, *Cassia fistula* exhibited the highest amount of TB, TCS, and CO_2 equivalent (131.33 Mg ha^{-1}, 65.66 Mg C ha^{-1}, and 240.99 Mg C ha^{-1} respectively). TCS displayed a positive correlation with density, TBC, and diameter of tree species. The study provides valuable information on biomass and Carbon sequestration potential of trees in the tropical moist deciduous forest, which could be of help to forest policymakers to ensure sustainable management of Carbon stock and hence promotes mitigation of global climate change.

Keywords CO_2 equivalent, Total basal cover, Total biomass, Total Carbon stock, Total density.

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INTRODUCTION

Global warming due to emission of greenhouse gases (GHGs) and its consequence on climate change is a serious environmental issue worldwide (Kumar and Sharma 2015). To limit the problem of emission of GHGs into the atmosphere, many international agreements such as United Nations Framework Convention on Climate Change (UNFCCC) were introduced over time (Nonini and Fiala 2021). The main implementing instrument of UNFCCC is the Kyoto Protocol, adopted in 1997 and entered into force in 2005. The Protocol proposed that reduction of atmospheric Carbon dioxide (CO_2) would be possible by decreasing fossil fuel emissions, or by accumulating Carbon in the vegetation of terrestrial ecosystems (Joshi and Singh 2020).

To accomplish the sustainable management of forests and mitigate global climate change issues, Carbon stock assessment is necessary which can predict and reduce GHGs emissions from forest degradation as well as conserve and enhance the existing forest Carbon stocks (Kumar and Sharma 2015, Salunkhe *et al.* 2023). A key variable for ecologists and foresters to access forest Carbon stocks is the above-ground biomass (AGB) (Chave *et al.* 2004). The chief predictors of AGB of a forest are girth size, wood specific gravity, and height of tree species as well as forest type (moist, dry, or wet) (Chave *et al.* 2005). Measuring the tree height is often challenging as the tree tops are hidden by the tree canopy. However, it is possible to infer AGB in the absence of height measurements (Chave *et al.* 2014).

The total forest cover of India is 7,13,789 sq km of which about 23.28% was occupied by Northeast India (ISFR 2021). The Northeastern states of the country hold the highest percentage (65.15%) of forest cover with respect to the total geographical area of the region. Numerous studies have been conducted on the estimation of biomass and Carbon stocks in the forests of India (Bahuguna *et al.* 2018, Raha *et al.* 2020, Pragasan 2022, Salunkhe *et al.* 2023) and particularly in Northeast India (Malunguja *et al.* 2021, Yumnam and Ronald 2022, Buragohain *et al.* 2023). However, such studies in tropical moist deciduous forests of Northeast India are limited (Banik *et al.* 2018, Joshi 2020). With this background, the present investigation was conducted with the main objective to estimate the biomass and Carbon sequestration potential of trees in a tropical moist deciduous forest of Kamrup Metropolitan district of Assam, India.

MATERIALS AND METHODS

For the present investigation, a tropical moist deciduous forest (Gotanagar Reserve Forest) located in Kamrup Metropolitan district of Assam, India (Fig. 1) was selected that covers a geographical area of 171 ha and lies between 26°07'58.93″ N latitude and 91°41'14.74″ E longitude. As per Champion and Seth (1968), the main vegetation of the study site falls under tropical moist deciduous forest, with an average annual temperature varying from 8.5 °C (minimum) to 38.6 °C (maximum), average annual precipitation of 1751 mm and relative humidity between 55.5–85.5%. The climate of the region is dividable into four seasons: Pre-monsoon (March–April), monsoon (May–August), post-monsoon (September–October), and winter (November–February).

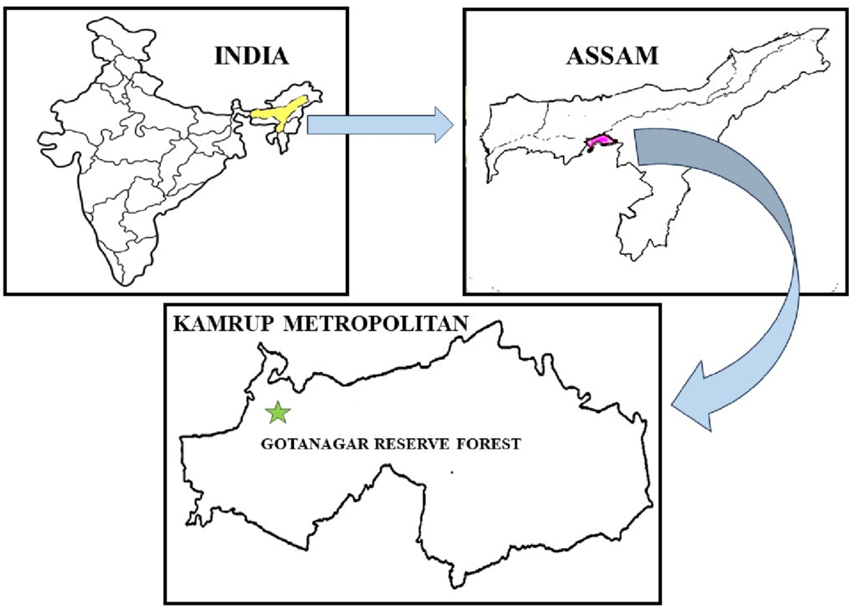

Fig. 1. Map showing the study site.

An extensive field survey was undertaken in the selected study site in the year between 2020 and 2022. The stratified random sampling method was employed and 25 quadrats (based on species-area curve) of 10×10 m^2 size were laid down for trees. Tree species in all the quadrats were identified by referring to authentic websites (http://www.plantsoftheworldonline.org/, https://indiabiodiversity.org, and https://www.cabi.org). The number of individuals of each tree species occurring in all the quadrats and circumference at breast height (CBH) of trees (≥15 cm CBH) were recorded using measuring tape. Trees having CBH<15 cm had been excluded because such trees hold a negligible amount of AGB in forests (Chidumayo 2002). Density and basal cover were calculated following formulae given by Misra (1968). AGB of tree species was estimated by using the allometric formula developed by Chave *et al.* (2005) i.e., AGB (Mg ha^{-1}) = ρExp [-1.499 + 2.148 ln (D) + 0.207 (ln (D))^2 - 0.0281 (ln (D))^3], where, ρ is the wood-specific gravity and D is the diameter at breast height (DBH) of the tree species. The wood-specific gravity of each tree species had been taken from the World Agroforestry Database. Furthermore, for the species that are lacking wood-specific gravity value, an average standard value (0.62 g cm^{-3}) was used (IPCC 2006). The below-ground biomass (BGB) was determined by multiplying the AGB with a factor of 0.26 based on the root: Shoot ratio (Zanne *et al.* 2010). Total biomass (TB) was estimated by summing the AGB and BGB. The total Carbon stock (TCS) of each species was estimated by multiplying the respective TB with a conversion factor of 0.5 which depicts that Carbon content is 50% of TB (IPCC 2003). The amount of CO_2 equivalent was determined by multiplying TCS by 3.67 (the ratio of CO_2 to C is 3.67).

RESULTS AND DISCUSSION

In the present investigation, a total of 39 tree species representing 34 genera and 20 families was reported (Table 1) with Fabaceae having the highest number of species (8 species) followed by Anacardiaceae, Combretaceae, Meliaceae, and Moraceae (3 species

Table 1. Family, DBH, TBC, density, AGB, BGB, TB, TCS, and CO_2 equivalent of different tree species.

Name of species	Family	DBH (cm)	TBC (m^2 ha^{-1})	Density (stem ha^{-1})	AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	TB (Mg ha^{-1})	TCS (Mg C ha^{-1})	CO_2 equivalent (Mg C ha^{-1})
Aegle marmelos (L.) Correa	Rutaceae	28.98 ± 0.56	3.16	48	41.32	10.74	52.07	26.03	95.55
Albizia lebbeck (L.) Benth.	Fabaceae	28.66 ± 1.64	2.58	40	25.59	6.65	32.24	16.12	59.16
Albizia procera (Roxb.) Benth.	Fabaceae	16.88 ± 1.22	0.54	24	4.41	1.15	5.55	2.78	10.19
Alstonia scholaris (L.) R.Br.	Apocynaceae	16.88 ± 0.96	0.27	12	1.28	0.33	1.61	0.80	2.95
Artocarpus heterophyllus Lam.	Moraceae	40.45 ± 0.82	3.08	24	33.55	8.72	42.28	21.14	77.58
Averrhoa carambola L.	Oxalidaceae	19.11 ± 3.18	0.34	12	2.67	0.69	3.37	1.68	6.18
Azadirachta indica A.Juss.	Meliaceae	23.89 ± 0.69	1.25	28	13.65	3.55	17.19	8.60	31.55
Bixa orellana L.	Bixaceae	15.92 ± 1.59	0.24	12	1.02	0.27	1.28	0.64	2.36
Bombax ceiba L.	Malvaceae	26.11 ± 1.48	1.07	20	5.39	1.40	6.79	3.40	12.47
Cassia fistula L.	Fabaceae	45.54 ± 0.93	5.86	36	104.23	27.10	131.33	65.66	240.99
Delonix regia (Bojer ex Hook.) Raf	Fabaceae	47.77 ± 1.59	1.43	8	23.26	6.05	29.31	14.66	53.79
Erythrina stricta Roxb.	Fabaceae	25.16 ± 3.39	1.39	28	4.71	1.22	5.93	2.97	10.89
Ficus hispida Blanco	Moraceae	30.57 ± 1.79	2.94	40	20.28	5.27	25.55	12.77	46.88
Ficus religiosa L.	Moraceae	54.14 ± 1.77	6.44	28	65.98	17.16	83.14	41.57	152.56
Gmelina arborea Roxb. ex Sm.	Lamiaceae	32.80 ± 0.80	6.76	80	53.46	13.90	67.36	33.68	123.60
Litsea glutinosa (Lour.) . C.B. Rob.	Lauraceae	28.66	0.26	4	2.40	0.62	3.03	1.51	5.56
Magnolia champaca (L.) Baill. ex Pierre	Magnoliaceae	25.16 ± 1.54	0.99	20	8.26	2.15	10.40	5.20	19.09
Mangifera indica L.	Anacardiaceae	18.15 ± 0.82	0.83	32	6.21	1.61	7.82	3.91	14.36
Melia azedarach L.	Meliaceae	18.79 ± 0.60	0.55	20	3.27	0.85	4.12	2.06	7.56
Phoenix dactylifera L.	Arecaceae	23.89	0.18	4	1.66	0.43	2.09	1.04	3.83

Table 1. Continued.

Name of species	Family	DBH (cm)	TBC (m^2 ha^{-1})	Density (stem ha^{-1})	AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	TB (Mg ha^{-1})	TCS (Mg C ha^{-1})	CO_2 equivalent (Mg C ha^{-1})
Phyllanthus emblica L.	Phyllanthaceae	20.38 ± 1.61	0.78	24	7.72	2.01	9.72	4.86	17.84
Pongamia pinnata (L.) Pierre	Fabaceae	20.70 ± 1.20	1.48	44	12.52	3.25	15.77	7.89	28.94
Psidium guajava L.	Myrtaceae	19.11 ± 0.50	0.57	20	4.98	1.29	6.27	3.14	11.51
Samanea saman (Jacq.) Merr.	Fabaceae	50.96 ± 0.92	2.45	12	28.78	7.48	36.26	18.13	66.54
Schima wallichii (DC.) Korth.	Theaceae	47.77 ± 1.32	7.88	44	102.02	26.52	128.54	64.27	235.88
Semecarpus anacardium L.f.	Anacardiaceae	23.89 ± 2.06	0.72	16	5.02	1.31	6.33	3.16	11.61
Shorea robusta C.F.Gaertn.	Dipterocarpaceae	32.48±0.66	6.30	76	87.35	22.71	110.06	55.03	201.97
Spondias pinnata (L.f.) Kurz	Anacardiaceae	24.20 ± 1.27	0.55	12	2.57	0.67	3.24	1.62	5.94
Sterculia villosa Roxb. ex Sm.	Malvaceae	17.52 ± 1.22	0.87	36	2.76	0.72	3.48	1.74	6.39
Stereospermum chelonoides (L.f.) DC.	Bignoniaceae	23.89 ± 1.59	0.36	8	3.52	0.92	4.44	2.22	8.15
Syzygium cumini (L.) Skeels.	Myrtaceae	28.66 ± 0.91	2.84	44	33.04	8.59	41.63	20.81	76.39
Tamarindus indica L.	Fabaceae	23.89 ± 1.59	0.36	8	5.29	1.37	6.66	3.33	12.22
Tectona grandis L.f.	Lamiaceae	24.52 ± 1.09	3.02	64	27.92	7.26	35.18	17.59	64.55
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	24.52 ± 1.56	0.94	20	11.51	2.99	14.51	7.25	26.62
Terminalia bellirica (Gaertn.) Roxb.	Combretaceae	27.07 ± 3.18	0.46	8	5.16	1.34	6.50	3.25	11.93
Terminalia chebula Retz.	Combretaceae	23.89 ± 2.06	0.72	16	8.87	2.31	11.17	5.59	20.50
Toona ciliata M. Roem.	Meliaceae	32.48 ± 2.23	0.66	8	4.98	1.29	6.27	3.14	11.51
Ziziphus mauritiana Lam.	Rhamnaceae	16.56 ± 1.52	0.34	16	2.89	0.75	3.65	1.82	6.69
Ziziphus rugosa Lam.	Rhamnaceae	16.88 ± 1.39	0.27	12	2.70	0.70	3.40	1.70	6.24
Total			**71.74**	**1008**	**782.19**	**203.37**	**985.56**	**492.78**	**1808.50**

*DBH= Diameter at Breast Height, TBC= Total Basal Cover, AGB= Above Ground Biomass, BGB= Below Ground Biomass, TB= Total Biomass, TCS= Total Carbon Stock.

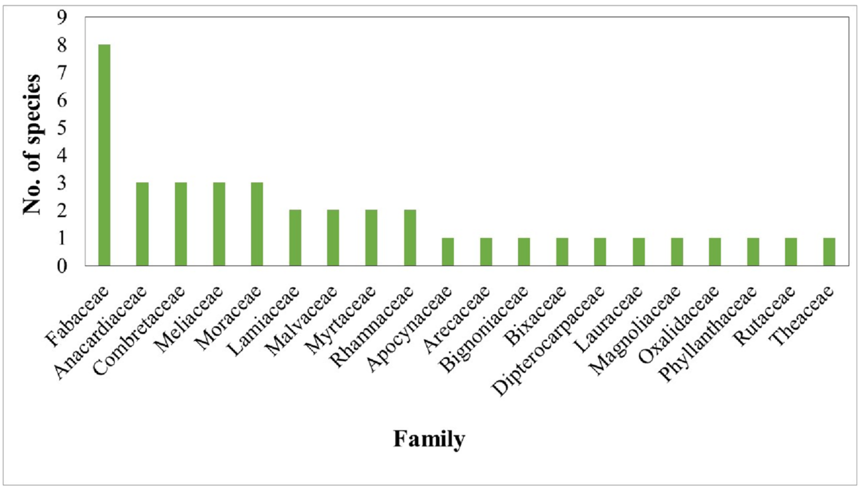

Fig. 2. Graph showing number of species belonging to different families.

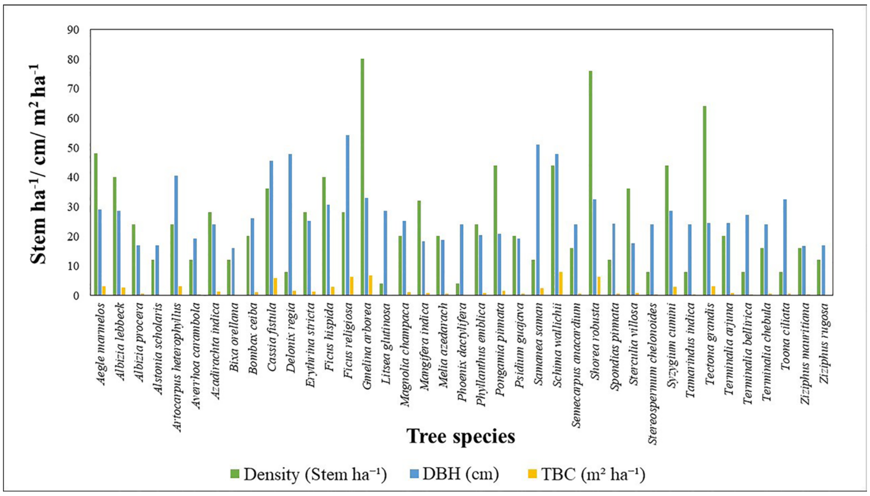

Fig. 3. Graph showing density, DBH, and TBC of different tree species.

each); Lamiaceae, Malvaceae, Myrtaceae, and Rhamnaceae (2 species each); Apocynaceae, Arecaceae, Bignoniaceae, Bixaceae, Dipterocarpaceae, Lauraceae, Magnoliaceae, Oxalidaceae, Phyllanthaceae, Rutaceae, and Theaceae (1 species each) (Fig. 2). The finding of the present study was comparatively higher than that of a tropical moist deciduous forest of Tripura (Banik *et al.* 2018). The higher species composition in the selected reserve forest might be due to the fact that the reserve forest is well managed and anthropogenic activities such as grazing, forest encroachment, exploitation of forest resources, are less in the reserve forest (Malunguja *et al.* 2021, Yumnam and Deori 2023).

The total density of trees was reported to be 1008 stem ha^{-1} (Table 1). Among the tree species, *Gmelina arborea* contributed the highest density of 80 stem ha^{-1} followed by *Shorea robusta* (76 stem ha^{-1}), *Tectona grandis (*64 stem ha^{-1}), and *Aegle marmelos* (48 stem ha^{-1}) (Table 1) (Fig. 3). While the lowest density was reported by *Litsea glutinosa* and *Phoenix dactylifera* (4 stem ha^{-1} each). The total density of trees was comparable with those of forests of Northeast India reported by Banik *et al*. (2018) and Mir *et al.* (2021). The selected reserve forest may be under formal protection owing to stringent management regimes by the government and because of that, it is facing fewer anthropogenic disturbances and hence harboring higher tree density (Malunguja *et al.* 2021, Chaudhary *et al.* 2022, Yumnam and Deori 2023).

Diameter is one of the important predictors for estimating the AGB of tree species (Chave *et al.* 2005). In the present investigation, *Ficus religiosa* was having the highest DBH (54.14 ± 1.77 cm) which was followed by *Samanea saman* (50.96 ± 0.92 cm), *Delonix regia* (47.77 ± 1.59 cm), *Schima wallichii* (47.77 ± 1.32 cm) and *Cassia fistula* (45.54 ± 0.93 cm) (Table 1) (Fig. 3). Similarly, *Ficus religiosa* was having higher DBH in a sub-tropical deciduous forest of West Bengal (Kumar and Gupta 2021). While the lowest DBH was reported by *Bixa orellana* (15.92 ± 1.59 cm) followed by *Ziziphus mauritiana* (16.56 ± 1.52 cm) in the present study. The DBH of most tree species in the study site was higher because the trees growing there are very old and fast-growing since the reserve forest is well-managed and not easily reachable by the locals (Malunguja *et al.* 2021, Chaudhury *et al.* 2022, Yumnam and Deori 2023).

The total basal cover (TBC) of trees was recorded to be 71.74 m^2 ha^{-1} (Table 1), the maximum of which was contributed by *Schima wallichii* (7.88 m^2 ha^{-1}) followed by *Gmelina arborea* (6.76 m^2 ha^{-1}), *Ficus religiosa* (6.44 m^2 ha^{-1}), *Shorea robusta* (6.30 m^2 ha^{-1}) and *Cassia fistula* (5.86 m^2 ha^{-1}) (Fig. 3). While *Phoenix dactylifera* occupied the lowest TBC (0.18

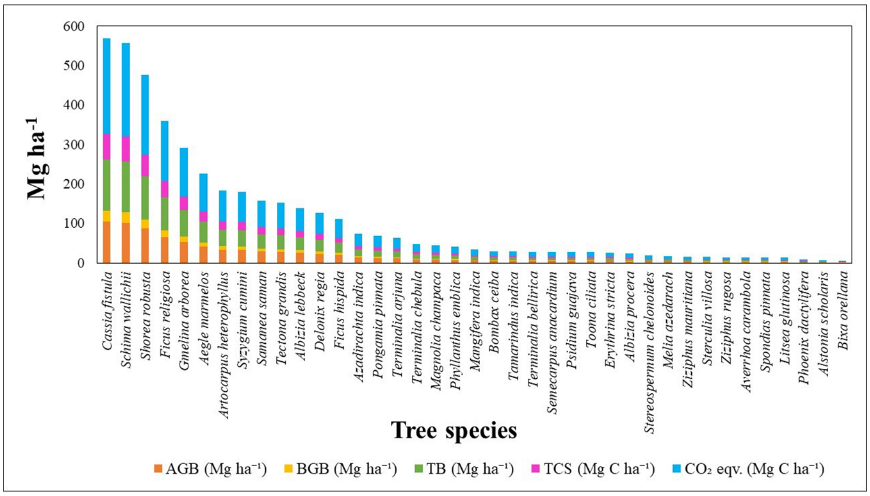

Fig. 4. Graph showing AGB, BGB, TB, TCS, and CO_2 equivalent of different tree species.

m² ha⁻¹) followed by *Bixa orellana* (0.24 m² ha⁻¹). Species composition, age structure, and successional stage of the reserve forest resulted in variation in TBC (Mir *et al.* 2021). The TBC of trees in the present study was found to be higher than those reported in tropical deciduous forests of India (Banik *et al.* 2018, Raha *et al.* 2020). While the finding was similar to that of a forest of Tehri Garhwal, Uttarakhand, India (Bahuguna *et al.* 2018).

The total AGB, BGB, and TB of trees were found to be 782.19 Mg ha^{-1}, 203.37 Mg ha^{-1}, and 985.56 Mg ha^{-1} respectively (Table 1). The total AGB of trees was comparatively higher than those reported in tropical forests of India (Buragohain *et al*. 2023, Salunkhe *et al*. 2023). Tree species with higher density, DBH, and TBC were the chief contributors to high TB storage in the present study. Among the 39 tree species, *Cassia fistula* had the highest storage capacity of AGB, BGB, and TB (104.23 Mg ha^{-1}, 27.10 Mg ha^{-1}, and 131.33 Mg ha^{-1} respectively) followed by *Schima wallichii* (102.02 Mg ha^{-1}, 26.52 Mg ha^{-1}, and 128.54 Mg ha^{-1}

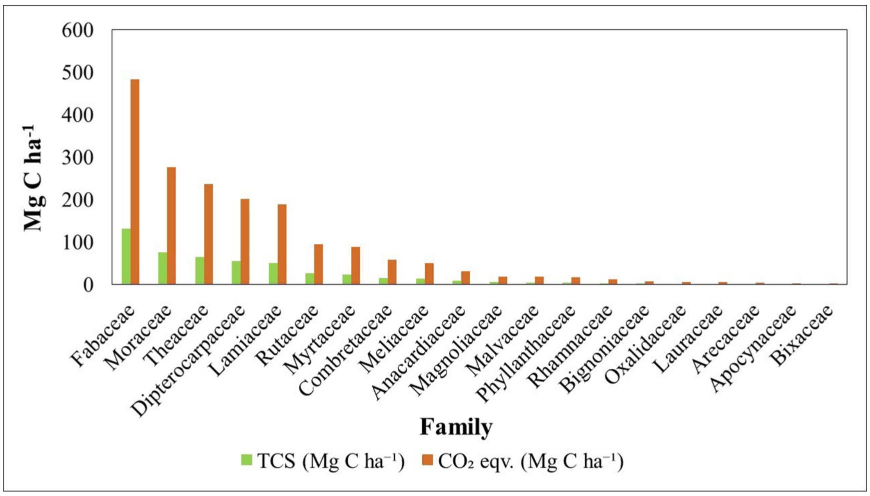

Fig. 5. Graph showing the contribution of TCS and CO_2 equivalent by different families.

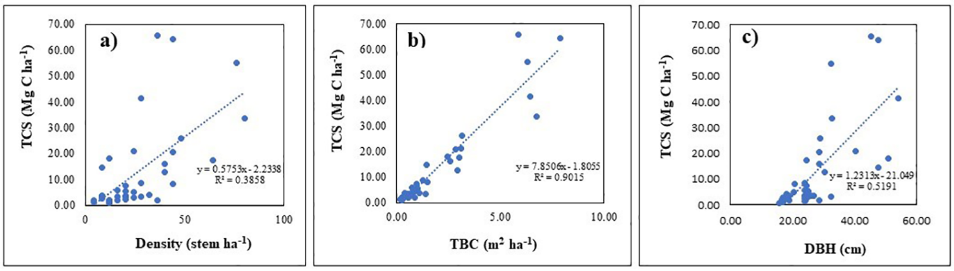

Fig. 6. Regression analysis between TCS and a) density, b) TBC, and c) DBH of tree species.

respectively) and *Shorea robusta* (87.35 Mg ha^{-1}, 22.71 Mg ha^{-1}, and 110.06 Mg ha^{-1} respectively) (Fig. 4). Similarly, *Shorea robusta* was reported to have the highest biomass storage capacity in a tropical moist deciduous forest of Tripura (Banik *et al*. 2018). While the lowest AGB, BGB, and TB were reported by *Bixa orellana* (1.02 Mg ha^{-1}, 0.27 Mg ha^{-1}, and 1.28 Mg ha^{-1} respectively) during the present study.

TCS of trees in the study site was found to be 492.78 Mg C ha^{-1} (Table 1) which was quite similar to that of Hmuifang forest of Mizoram (Sharma *et al.* 2018). However, the finding was comparatively higher than the tropical forests of India (Malunguja *et al*. 2021, Pragasan 2022, Salunkhe *et al*. 2023). During the present investigation, the higher value of TCS could be due to the high density of trees having higher girth size and wood-specific gravity (Yumnam and Ronald 2022). During the present study, *Cassia fistula* contributed the highest TCS of 65.66 Mg C ha^{-1} among the tree species, which was followed by *Schima wallichii* (64.27 Mg C ha^{-1}) and *Shorea robusta* (55.03 Mg C ha^{-1}), while the lowest TCS was contributed by *Bixa orellana* (0.64 Mg C ha^{-1}) (Fig. 4). Among the families, Fabaceae was dominant in terms of TCS (131.53 Mg C ha^{-1}) followed by *Moraceae* (75.48 Mg C ha^{-1}) and Theaceae (64.27 Mg C ha^{-1}), while Bixaceae contributed the least TCS (0.64 Mg C ha^{-1}) (Fig. 5). Likewise, in a dry tropical forest of Mexico, Fabaceae contributed a larger portion to the TCS (Mesa-Sierra *et al.* 2022).

During the present investigation, the total CO_2 equivalent was reported to be 1808.50 Mg C ha^{-1} (Table 1), of which the highest was reported by *Cassia fistula* (240.99 Mg C ha^{-1}) followed by *Schima wallichii* (235.88 Mg C ha^{-1}) and *Shorea robusta* (201.97 Mg C ha^{-1}), while the lowest was stored by *Bixa orellana* (2.36 Mg C ha^{-1}) (Fig. 4). The finding was comparable with that of Hmuifang forest of Mizoram (Sharma *et al.* 2018). Forest stands having mixed species can sequester more CO_2 due to different photosynthetic rates (Banik *et al.* 2018). Among the families, the highest CO_2 equivalent was found in *Fabaceae* (482.73 Mg C ha^{-1}) which was followed by *Moraceae* (277.01 Mg C ha^{-1}) and Theaceae (235.88 Mg C ha^{-1}), while the lowest was reported by Bixaceae (2.36 Mg C ha^{-1}) (Fig. 5). The highest Carbon storage capacity of tree species of the reported families has resulted in highest CO_2 equivalent in them. A similar finding was also observed in the tropical deciduous forests of Tripura with Moraceae storing the highest CO_2 equivalent (Majumdar *et al.* 2016).

The regression analysis showed that the TCS of tree species exhibited a weak positive correlation ($r^2 = 0.38$) with the density of tree species (Fig. 6a). Such a result was also reported from a tropical hill forest of Tamil Nadu, India (Pragasan 2022). However, the TCS of tree species showed a very strong positive correlation ($r^2 = 0.90$) with the TBC of trees in the present study (Fig. 6b). Similar result was observed in the forests of Northeast India (Mir *et al.* 2021, Chaudhury *et al.* 2022). Nevertheless, during the present study, TCS displayed a moderate positive correlation ($r^2 = 0.51$) with DBH of tree species (Fig. 6c). Similar result was also observed in forests of Kashmir Himalaya (Dar and Parthasarathy 2022). The findings of the regression analysis in the present study ascertain the reliance of TCS on density, TBC, and DBH of tree species.

CONCLUSION

The study reported a significant amount of TB and TCS of trees from the selected tropical moist deciduous forest of Kamrup Metropolitan district of Assam. The total density and TBC of trees were found to be very high (1008 stem ha^{-1} and 71.74 m^2 ha^{-1}). TB, TCS, and CO_2 equivalent were recorded to be 985.56 Mg ha^{-1}, 492.78 Mg C ha^{-1}, and 1808.50 Mg C ha^{-1} respectively with *Cassia fistula* exhibiting the highest amount of TB, TCS, and CO_2 equivalent. TCS displayed a positive correlation with community characteristics of tree species. The results of the current study indicate that tropical moist deciduous forests are important for Carbon sequestration as trees growing there can store a significant amount of Carbon as their biomass. The study provides valuable information on biomass and Carbon sequestration potential of trees in a tropical moist deciduous forest, which could be of help to forest policymakers to ensure sustainable management of Carbon stock and hence promotes mitigation of global climate change.

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