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Estimation of Soil Organic Carbon and Storage Under *Aquilaria malaccensis* Based Homestead Plantation System of Assam

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ABSTRACT
Soil is one of earth's most complicated environments for life. The single most important property determining the soil i.e., soil organic carbon has gained prominence in assessment of soil quality and also as a strategy for climate change mitigation. However, different forestry practices have different potential to store carbon and depend on the species composition and environmental variables. Hence, the present study has been carried out to investigate the status of soil organic carbon storage in the *Aquilaria malaccensis* based homestead plantation systems in three districts of Assam viz., Golaghat, Jorhat and Hojai. Soil samples from three depths (0-10, 10-20 and 20-30 cm) were collected seasonally and analyzed. Results indicated that average SOC ranges between 1.51-1.65%. Similarly, SOC stock ranged from 38.8 to 39.7 Mg C ha^{-1} among the three study sites. Both SOC (%) and stock does not show any significant variation among different depths and sites. Seasonally SOC (%) and stock were high in the post-monsoon season and lowest in the winter season. In the present study SMC, pH, EC, SOM and TKN showed positive relationship with SOC, whereas BD have negative relationship. The present study also reported a marginally higher content of SOC than other plantation systems. Higher content of carbon in *Aquilaria* based homestead plantations was attributed to the soil characteristics, elevated litter inputs and higher biological activity. Seasonal variation in SOC was attributed to factors such as local climate, rainfall and temperature pattern.

Key words: Carbon storage, Seasonal variation, Homestead plantation

INTRODUCTION

Soil is one of the most complex habitats for life on earth and represents a highly compact form of three-dimensionally structure featuring fine-scale gradients in physico-chemical characteristics, resource availability, and gas concentrations (Young and Crawford 2004). However, it has become one of the world's most vulnerable resources in the face of land degradation, biodiversity loss and climate change. The quality and health of the soil determines its capacity to support biological activity. Soils are the largest active reservoirs of terrestrial organic carbon and are thought to offer a feasible climate change mitigation approach (Lehmann et al. 2020). Soil organic carbon (SOC) acquired relevance in soil quality assessment because of its significant impacts on physical, chemical and biological characteristics of soil (Ramady et al. 2014, Sainepo et al. 2018, Ngatia et al. 2021). Understanding the dynamics of SOC is vital for managing carbon stocks, in order to sustain a balance in productive systems.

Depending on the species compositions and other ecological and environmental variables, different forestry operations have varying carbon storage capacity (Bajigo et al. 2015). The SOC stocks in agroforestry systems are noticeably high compared to those of other productive ecosystems and soils (Agevi et al. 2017). However, the amount of SOC in such practices differs with region, systems and soil depths (Negash and Kanninen 2015). Further it also depends on climatic and edaphic factors, stand characteristics and management practices. Stand characteristics including tree density, species richness, species diversity and soil properties can directly or indirectly influence SOC content. Studies showing improvements of SOC in forestry systems have mostly concentrated on changes in the topsoil layer (0-30 cm) where the largest carbon pools are detected (Makumba et al. 2007, Oelbermann and Voroney 2007).

While most carbon assimilation studies have mainly focused on natural forests, understanding the spatial distribution of carbon in commercial forests is central to determining their role in the global carbon cycle. A systematic review on tropical forest conversion to diverse land-uses, indicates that SOC stores dropped by 18.9% on average as forests were transformed to plantations (Mishra et al. 2021). However, plantation forests can restore soil organic matter (SOM) and nutrients that were depleted under intensive cultivation (Parrotta 1992). Despite of the fact that soil is the store house of a vast quantity of carbon, agreement on the magnitude of global SOC stocks, their geographical and temporal distribution, and emission owing to alterations in land cover is still absent.

In India, smallholder homestead plantation system is one of the popular land-use practices, providing both financial and ecological benefits. Since centuries, these homestead systems have been followed in India's north eastern part, notably in Assam where almost every household in rural areas and many small towns have homestead plantation in the available spaces of either backyard or in front of house or both sides to fulfill their daily basic needs. Though many studies have shed light on various aspects of homestead plantations, only few studies have focused on the relationship between SOC content and the stand characteristics of these homestead plantations viz., bamboo (Nath et al. 2015), tea (Kalita et al. 2016) and rubber (Nath et al. 2018). The present study intended to investigate the status of SOC storage in the *Aquilaria malaccensis* based homestead plantation systems in three districts of Assam viz., Golaghat, Jorhat and Hojai.

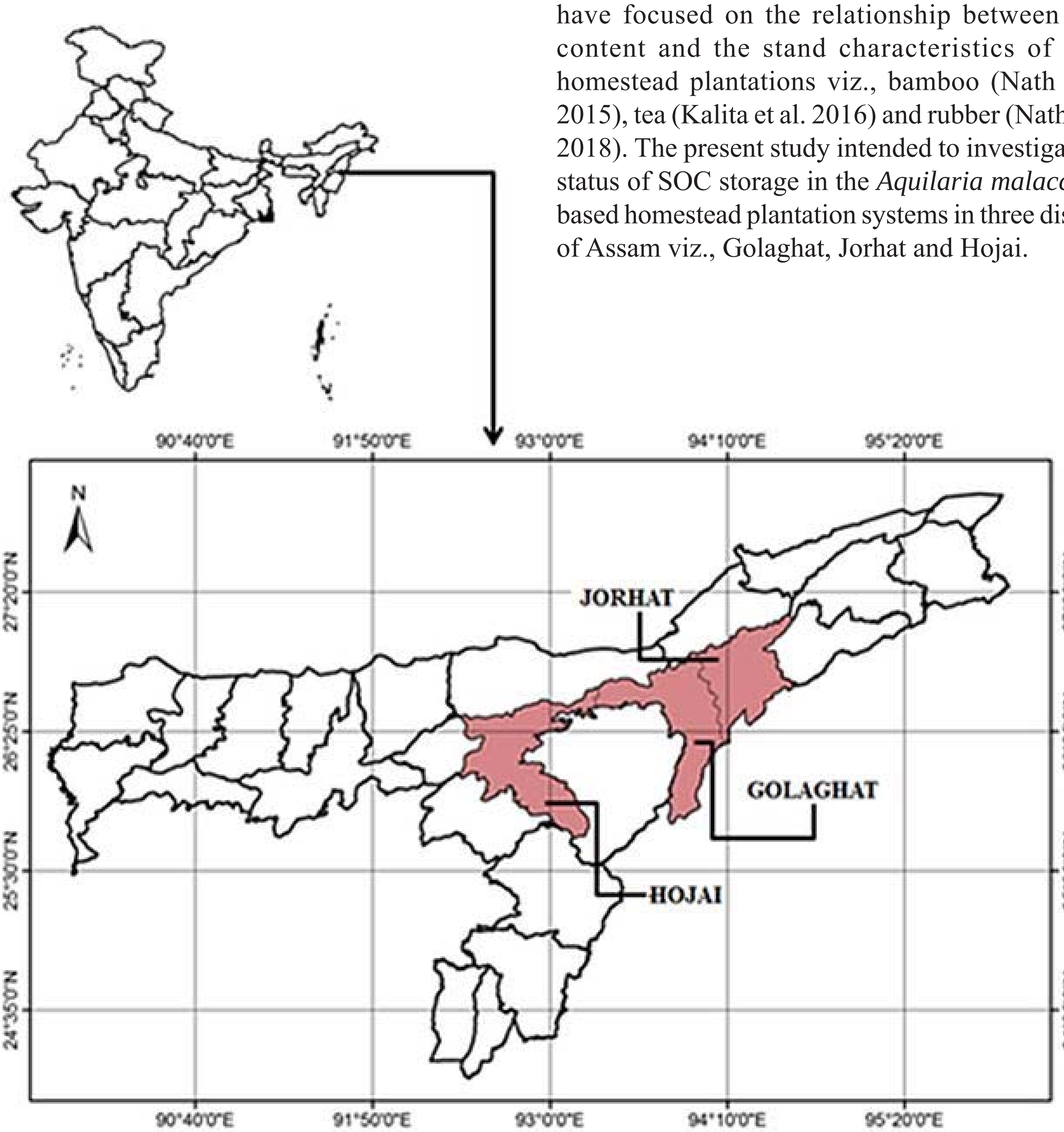

Figure 1. Map of the study area showing Golaghat, Jorhat and Hojai District of Assam

MATERIAL AND METHODS

Study site

The study areas are from three districts, namely Golaghat (Site I), Jorhat (Site II) and Hojai (Site III), of Assam state situated in the Brahmaputra valley in Northeast India (91°55294°152E longitude and 25°302 and 27°202N latitude) (Fig. 1). The entire region is alluvial plain terrain having tropical climate with an average elevation of 95 m asl. The climate is tropical, having distinct hot and humid summers (34°C during June-July) and cool winters (10°C during December-January). The region experiences 1200 to 1900 mm of mean yearly rainfall and the relative humidity remains very high throughout the year. A total of nine different *Aquilaria malaccensis* based homestead plantation systems within the age between 10 to 13 years were selected for the study (3 each in each district). Considering the sizes of these agarwood cultivated systems, two randomly selected quadrats of 0.01 ha (i.e., 10 × 10 m) were laid in each site. All individual trees (GBH > 10 cm) within each quadrat were counted, to measure the tree density within each system.

Soil sample collection

To estimate the SOC stock at different soil depths and the seasonal variation, sampling was done during four seasons, i.e., pre-monsoon (March-May), monsoon (June to September), post monsoon (from October to November) and Winter (December to February). In each of the selected homestead plantation, three sampling points are randomly selected and soils were collected from three depths i.e., 0-10, 10-20 and 20-30 cm. A composite sample for each depth per plot was prepared by mixing soils, resulting in one sample per depth from each studied cultivation system (27 soil samples from 9 plantations X 3 depths). The samples were marked as PS1, PS2 and PS3 for plantation systems 1, plantation systems 2 and plantation systems 3, respectively.

Soil analysis

Soil texture and porosity was estimated following Allen et al. (1974). Soil moisture content (SMC), bulk density (BD), soil electric conductivity (EC) and soil pH were assessed following methods suggested by Anderson and Ingram (1993). Walkley and Black's (1934) rapid titration method was used to quantify the amount of soil organic carbon (SOC). Soil organic matter (SOM) was estimated using the conversion factor of Waxman and Stevens (1930). Total Soil Nitrogen (TKN) content was determined using Kjeldahl method (Allen et al. 1974). SOC stock was calculated based on the formula proposed by Marin Spiotta and Sharma (2012).

SOC stock = (% SOC/100 x Db x soil depth x 100)

where SOC stock is soil organic carbon stock (Mg C ha^{-1}), % SOC = Percentage of soil organic carbon, Db = Bulk density of soil samples (g cm^{-3}) and soil depth is the depth at which soil sample is taken (cm).

RESULTS

Site characteristics

Aquillaria malaccensis based homestead systems are widely maintained as a single species crop in the extended area of the home garden or rarely as intercropping with other trees. Tree density of *A. malaccensis* varied among different hemestead systems, and ranged from 570 to 1243 individuals ha^{-1}, the average value being 832 individuals ha^{-1}. Highest tree density was observed in the homesteads of Golaghat (site I) followed by Jorhat (site II) and Hojai (site III) (Table 1).

Physico-chemical properties of soil

The textural class of soil was sandy clay loam in Site I, whereas it was clayey in Site II and Site III (Table 1). Soil pH was found to be acidic for all the three sites ranging between 5.13-5.27. Soil pH shows a slight increase with the increase in depth in site III, whereas it showed a decreasing trend with increase in depth for site I and site II.

Bulk density also increased with increasing soil depth at all the sites (Table 1). The lowest bulk density was observed at site II compared to site I and site III. Soil EC was found to be lowest in site I (70.33 mS/m) followed by site III (83.78 mS/m) and site II (86.73 mS/m). Reduction in EC was observed with increasing soil depth at all sites. SOM values varied between 2.71 to 2.96%, and found to decrease with increasing soil depth at all the sites. Highest SOM was found in site II (2.96%) followed by site I (2.72%) and site III (2.71%).

Table 1. Characteristics of the studied sites

Site and soil characteristics	Site I	Site II	Site III
Age of the homestead plantation (years)			
Plantation System I	11	11	12
Plantation System II	10	13	10
Plantation System III	10	12	10
Density (individuals ha^{-1}) (Trees>10 cm)			
Plantation System I	1125	812	570
Plantation System II	1243	675	633
Plantation System III	1023	767	640
Soil texture	Clay loam	Clay	Clay
Soil bulk density (BD) (g cm^{-3})			
(0-10 cm)	0.84 ±0.024	0.77 ±0.037	0.86 ±0.014
(10-20 cm)	0.84 ±0.023	0.78 ±0.036	0.88 ±0.012
(20-30 cm)	0.85 ±0.022	0.80 ±0.026	0.88 ±0.030
Soil pH			
(0-10 cm)	5.27 ±0.105	5.19 ±0.145	5.13 ±0.066
(10-20 cm)	5.25 ±0.125	5.19 ±0.090	5.19 ±0.068
(20-30 cm)	5.24 ±0.132	5.18 ±0.078	5.20 ±0.060
Soil moisture content (SMC) (%)	18.4 ±2.707	19.9 ±3.249	18.9 ±3.022
Soil EC (mS/m)	70.33 ±4.44	86.73 ±5.25	83.78 ±1.95
Soil organic carbon (SOC) %	1.57 ±0.014	1.65 ±0.012	1.51 ±0.015
Soil organic Matter (SOM) %	2.72 ±0.144	2.96 ±0.161	2.71 ±0.172
Total Kjeldahl Nitrogen (TKN) (%)	0.28 ±0.046	0.27 ±0.046	0.28 ±0.031

Soil organic carbon and stock

SOC among all the three sites shows a significant difference ($F = 7.103$, $P < 0.05$) and annual mean for all the depths together (0-30 cm) was found to be 1.57% for site I, 1.65% for site II and 1.51% for site III. However, within a site SOC did not show any significant variation among different depths ($F = 0.096$, $P > 0.05$ for site I, $F = 0.068$, $P > 0.05$ for site II and $F = 0.079$, $P > 0.05$ for site III). Annual average SOC at the depth of 0-10 cm was found to be 1.58, 1.64 and 1.50% for site I, site II and site III, respectively. At the depth of 10-20 cm the average annual SOC was found to be 1.58, 1.66 and 1.50% and at the depth of 20-30 cm it was found to be 1.55, 1.66 and 1.53% site I, site II, site III, respectively (Fig. 2).

SOC does not show any trend with soil depth. Seasonally, SOC was found to be in the range between 1.47-1.69% for site I, 1.54-1.77% for site II and 1.38-1.62% for site III. Seasonal trend shows that SOC was comparatively higher in the post-monsoon season and lowest in the winter season (Fig. 3).

The SOC stock ranged from 13.1 to 13.3 (site I), 12.5 to 13.3 (site II) and 13.0 to 13.5 (site III) Mg C ha^{-1} at 0-10, 10-20 and 20-30 cm depths, respectively. The SOC stock does not varied significantly among the three different study sites ($F = 0.351$, $P > 0.05$). The SOC stock upto the depth of 0-30 cm, ranged from 38.8 to 39.7 Mg C ha^{-1} among the three study sites with a mean of 39.3 Mg C ha^{-1}. Among the study sites, SOC stocks were lowest in the surface layer (0-10 cm) and increased with increasing depth in site II and site III, where as in site I SOC stock was found almost stable in lower depths. Similar to the SOC stock at different sites, no significant variation was observed among different depths ($F = 0.431$, $P > 0.05$). However, significant difference in SOC stock was observed for different seasons ($F = 29.809$, $P < 0.0001$).

Correlation of SOC with different variables

Pearson correlation (r) analysis shows that many variables have a positive or negative effect on SOC (Table 2). A significantly positive correlation of SOC

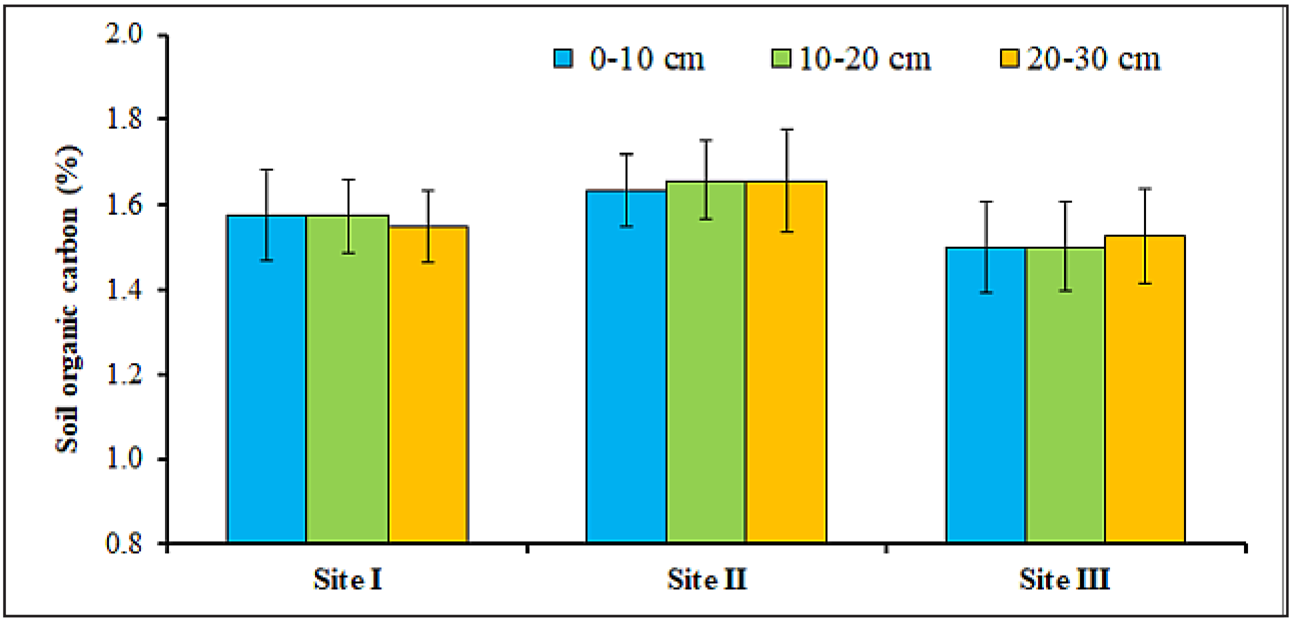

Figure 2. Variation in soil organic carbon (SOC) percentage along different depth

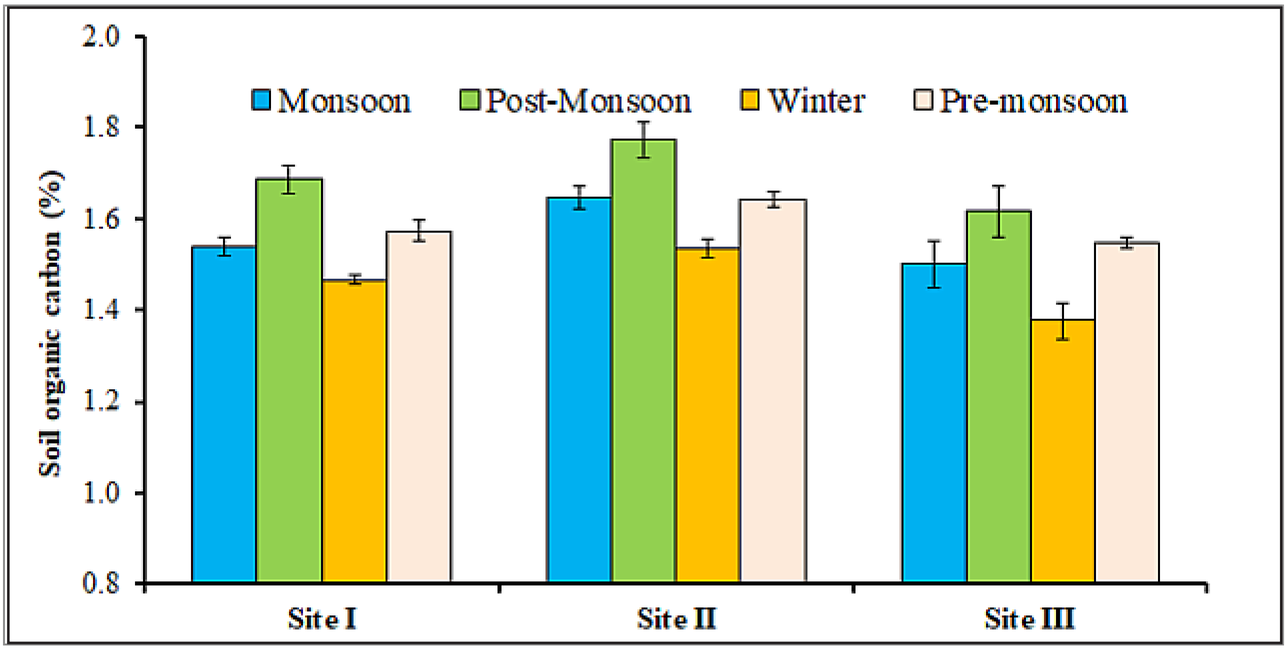

Figure 3. Seasonal variation in soil organic carbon (SOC) percentage

with soil moisture content (SMC) ($r = 0.509$, $p < 0.05$), soil pH ($r = 0.503$, $p < 0.05$), soil electric conductivity (EC) ($r = 0.437$, $p < 0.05$), soil organic matter (SOM) ($r = 0.973$, $p < 0.05$) and total kjeldahl nitrogen (TKN) ($r = 0.611$, $p < 0.05$) showed that all these factors together are responsible for variability in the SOC concentration. On the other hand, soil bulk density (BD) showed high negative correlation ($r = -0.434$, $p < 0.05$) with SOC concentration.

DISCUSSION

Li et al. (2020) reported that physical and chemical properties dominantly control SOC stocks at any local scale. Alterations in the physical and chemical properties of soils result in variability in the distribution and concentration of SOC (Johnson et al. 2011). As indicators of the SOC, Pearson correlation was measured between various soil parameters. In the current study SMC, pH, EC, SOM

Table 2. Correlation (R values) between SOC (%) and soil properties in the three study sites

Variables	SOC	BD	SMC	pH	EC	SOM	TKN
BD	-0.4348* (0.0081)	1					
SMC	0.5097* (0.0051)	0.1553 (0.3656)	1				
pH	0.5035* (0.0017)*	0.1379 (0.4226)	0.5290* (0.0009)	1			
EC	0.4371* (0.0077)	-0.2266 (0.1839)	0.3330* (0.0472)	-0.0683 (0.6922)	1		
SOM	0.9731* (< 0.0001)	-0.4442* (0.0066)	0.5367* (0.0007)	0.4054* (0.0142)	0.6155* (< 0.0001)	1	
TKN	0.6114* (< 0.0001)	0.1285 (0.4552)	0.3006 (0.0749)	0.3700* (0.0264)	0.2495 (0.1422)	0.5588* (0.0004)	**1**

*Correlation is significant at the 0.05 level, BD- Bulk density, SMC- Soil moisture content, EC- electric conductivity, SOM- Soil Organic Matter, TKN- total kjeldahl nitrogen. Values in parentheses indicate p-value.

and TKN were observed to positively influence on SOC, whereas BD was observed to have a negative influence. A significant positive correlation of SOC with SMC, pH, EC, SOM and TKN showed that all these factors are collectively control the variability in the SOC concentration in the studied systems. Significant negative correlation of SOC with BD for different plantations and natural systems was also reported in several earlier studies (Sheikh et al. 2009, Kalita et al. 2016, Kumari et al. 2022). The positive relationship between SOC and soil moisture content implies that SOC increases with increase in soil moisture content (Kenye et al. 2019). A significant positive correlation was observed between SOC and soil pH demonstrating that it assists the accumulation of SOC (Tian et al. 2016, Pawri et al. 2022). It was reported that soil pH can indirectly affect SOC through the regulation of microbial communities and enzyme activities (Zhang et al. 2022, Shu et al. 2023). SOC was positively correlated with soil EC and TKN as also reported in the earlier studies (Tasung and Ahmed 2017, Zhang et al. 2023). An increase in soil nitrogen promotes the buildup of SOC, as indicated by a positive and strong correlation found between SOC and TKN. SOC and SOM have a notably strong and positive correlation, indicating a direct relationship between SOC and the quantity of organic matter in soil (Ontl and Schulte 2012). Higher SOM concentration can be considered a key indicator of soil with higher fertility. Very few attempts were made to access the variation of SOC concentration in the homestead plantation systems of the eastern Himalayan region (Nath et al. 2015, 2018 Kalita et al. 2016, Kenye et al. 2019).

SOC concentration in all the three sites were found relatively high, ranging between 1.51 and 1.65%. Seasonal soil organic carbon concentrations range from 1.47-1.67% for site I, 1.54-1.77% for site II and 1.38-1.62% for site III. Mina et al. (2023) reported an average SOC (%) of the soil samples of monocropped rubber plantation, monocropped coconut plantation, and homestead agroforestry system in Kerela to be 1.03, 0.64 and 2.48%, respectively. Homegardens in Mizoram were found to have a mean SOC of 1.90%, whereas teak, oil palm and bamboo plantation, were found to be 1.76, 1.51 and 1.19%, respectively (Kenye et al. 2019). SOC concentration along age gradient under tea agroforestry system in Barak Valley, Assam was found to be between 1.18% - 1.36% (Kalita et al. 2016). In Karbi Anglong of Assam, the mean values of SOC concentration for natural forest, homestead garden, rubber plantation, bamboo plantation, jhum land, crop land was found to be 0.77, 0.66, 0.62, 0.57, 0.51 and 0.42%, respectively (Kalita et al. 2023). Similarly, the SOC concentration up to 30 cm soil depth for teak and *Acacia* plantations in Pondicherry was found to be 1.53 and 2.1%, respectively

(Sundarapandian et al. 2016). The present study showed a marginally higher content of SOC than other plantation systems. The higher percentage of carbon in *Aquilaria* based homestead plantations may be due to soil characteristic, elevated litter inputs and higher biological activity. In addition, the leaves of *Aquilaria* have high lignin content which may be a reason of slower decomposition rate, leading to the buildup of humus throughout the year and high SOC in these sites.

In the current study, SOC stocks did not show any significantly variation among the sites and also in depths within the sites. The SOC stock upto the depth of 0-30 cm varied between 38.8 to 39.7 Mg C ha^{-1} among the three study sites with a mean of 39.3 Mg C ha^{-1}. Kalita et al. (2016) reported a SOC stock ranging from 41.4 to 49.7 Mg C ha^{-1} in different age tea agroforestry system in Barak Valley. The mean SOC stock upto the depth of 0-30 cm in different plantation systems of Mizoram estimated to be 26.95 Mg C ha^{-1} for Oil palm plantation, 35.63 Mg C ha^{-1} for teak plantation, 37.49 Mg C ha^{-1} for homegarden and 21.72 Mg C ha^{-1} for bamboo plantation (Kenye et al. 2019). Gupta and Pandey (2008) estimated the soil organic carbon stock (0-30 cm) under *Eucalyptus*, Poplar, Shisham and Teak plantations of Uttarakhand and Haryana to be 27.29, 21.98, 25.37 and 36.73 Mg C ha^{-1}, respectively. However, higher level of SOC stock has been reported for natural forest (69.29 Mg C ha^{-1}), jhum (43.08 Mg C ha^{-1}), fallow jhum (45.28 Mg C ha^{-1}) and pine apple (53.63 Mg C ha^{-1}) in Arunachal Pradesh (Kumar et al. 2023). Zade et al. (2020) also reported that SOC content of orchards soil at 0-30 cm depth ranged from 21.60 to 25.86 Mg ha^{-1}.

Significant difference in SOC stock can be observed for different seasons in the present study. However, it showed no significant difference among soil depth. SOC (%) was found to be highest in the post-monsoon season (average of all the depth to be 1.69, 1.77 and 1.62% for site I, site II and site III, respectively) and lowest during the winter season (1.47, 1.54 and 1.38% for site I, site II and site III, respectively). Similarly, SOC stock was found to be highest in the post-monsoon season (i.e., average of all the depth to be 13.9, 13.7 and 14.1 Mg C ha^{-1} for site I, site II and site III, respectively) and lowest during the winter season (12.3, 11.7 and 11.8 Mg C ha^{-1} for site I, site II and site III, respectively). While Saha and Handique (2022) reported 53% of seasonal fluctuations in SOC at the same site without any major changes in land cover, Baruah et al. (2018) reported a higher value of SOC during post-monsoon followed by pre-monsoon, monsoon and winter seasons, for two different semi evergreen and deciduous forest areas of Assam. Seasonal variation in SOC can be attributed to environmental factors such as precipitation, temperature, etc., which in turn are determined by seasons.

CONCLUSIONS

This study provides an account on the relationship between soil organic carbon and other soil characteristics under *Aquilaria* based homestead plantation system. Assessment of SOC (%) and stocks in different soil depths under these systems revealed its potential towards carbon stock in soil compartment. In the present study chronosequence approach has not been employed, which can be considered as a limitation. However, it was expected that the study will denitely serve as a baseline for further research on spatial and temporal variations in SOC stock under *Aquilaria* based homestead plantation system.

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REFERENCES

Agevi, H., Onwonga, R., Kuyah, S. and Tsingalia, M. 2017. Carbon stocks and stock changes in agroforestry practices: A Review. Tropical and Subtropical Agroecosystems, 20, 101-109. https://doi.org/10.56369/tsaes.2291

Allen, S.E., Grimshaw, M.H., Parkinson, J.A. and Quarmby, C. 1974. Chemical Analysis of Ecological Materials. Blackwell Scientific, Oxford.

Anderson, J.M. and Ingram, J.I.S. 1993. Tropical Soil Biology and Fertility: A Handbook of Methods. 2nd Edition, C.A.B. International, Wallingford, UK, 221 pages.

Bajigo, A., Tadesse, M., Moges, Y. and Anjulo, A. 2015. Monitoring of seasonal variation in physico-chemical water parameters in Nalasopara region. Journal of Ecosystem and Ecography, 5, 157. https://doi.org/10.4172/2157-7625.1000157

Baruah, A., Bora, I.P. and Barua, K.N. 2018. Seasonal fluctuation of soil fertility status associated with *Mikenia micrantha* H.B.K. infestation in Abhoypur and Dilli Reserve Forest of Assam, India. Research Journal of Agriculture and Forestry Sciences, 6(10), 1-5.

El-Ramady, H.R., Alshaal, T.A., Amer, M., Domokos-Szabolcsy, É., Elhawat, N., Prokisch, J. and Fári, M. 2014. Soil quality and plant nutrition. Pp. 345-447. In: Ozier-Lafontaine, H. and Lesueur-Jannoyer, M. (Eds.). Sustainable Agriculture Reviews volume 14, Springer, Cham. https://doi.org/10.1007/978-3-319-06016-3_11

Gupta, M. and Pandey, R. 2008. Soil organic carbon pool under different plantations in some districts of Uttarakhand and Haryana. Indian Journal of Forestry, 31(3), 369-374. https://doi.org/10.54207/bsmps1000-2008-45gjm2

Johnson, K.D., Scatena, F.N. and Silver, W.L. 2011. Atypical soil carbon distribution across a tropical steep land forest catena. Catena, 87, 391-397. https://doi.org/10.1016/j.catena.2011.07.008

Kalita, N., Dutta, S., Das, K.N., Kurmi, K. and Patgiri, D.K. 2023. Impact of different land uses on soil organic carbon stock in Karbi Anglong district of Assam, India. Journal of Soil and Water Conservation, 22(1), 15-22. https://doi.org/10.5958/2455-7145.2023.00003.6

Kalita, R., Das, A.K. and Nath, A.J. 2016. Assessment of soil organic carbon stock under tea agroforestry system in Barak Valley, North East India. International Journal of Ecology and Environmental Sciences, 42(2), 175-182. https://www.nieindia.org/Journal/index.php/ijees/article/view/808/266

Kenye, A., Sahoo, U.K., Singh, S.L. and Gogoi, A. 2019. Soil organic carbon stock of different land uses of Mizoram, Northeast India. AIMS Geosciences, 5(1), 25-40. https://doi.org/10.3934/geosci.2019.1.25

Kumar, J., Kalita, H., Rekhung, W., Alone, R. A., Angami, T., Jini, D., Makdoh, B., Touthang, L., Khatri, N., Singh, A. P., Sinha, N. K., Kumar, D. and Chaudhary, R. S. (2023). Dynamics of soil organic carbon of jhum agriculture land-use system in the heterogeneous hill of Arunachal Pradesh, India. Scientific Reports, 13, 12156. https://doi.org/10.1038/s41598-023-38421-1

Kumari, B., Tiwari, A., Sharma, S. and Anjum, J. 2022. Soil organic carbon variation under sub-tropical forest of Himachal Pradesh, India. Current Science, 122(1), 56-60. https://doi.org/10.18520/cs/v122/i1/56-60

Lehmann, J., Bossio, D.A., Kögel-Knabner, I. and Rillig, M.C. 2020. The concept and future prospects of soil health. Nature Reviews Earth and Environment, 1, 544-553. https://doi.org/10.1038/s43017-020-0080-8

Li, J., Nie, M. and Pendall, E. 2020. Soil physico-chemical properties are more important than microbial diversity and enzyme activity in controlling carbon and nitrogen stocks near Sydney, Australia. Geoderma, 366, 114201. https://doi.org/10.1016/j.geoderma.2020.114201

Makumba, W., Akinnifesi, F.K., Janssen, B. and Oenema, O. 2007. Long-term impact of a *Gliricidia*-maize intercropping system on carbon sequestration in southern Malawi. Agricultural Ecosystem and Environment, 118, 237-243. https://doi.org/10.1016/j.agee.2006.05.011

Marin-Spiotta, E. and Sharma, S. 2012. Carbon storage in successional and plantation forest soils: A tropical analysis. Global Ecology and Biogeography, 22, 105-117. https://doi.org/10.1111/j.1466-8238.2012.00788.x

Mina, U., Geetha, G., Sharma, R. and Singh, D. 2023. Comparative assessment of tree carbon sequestration potential and soil carbon dynamics of major plantation crops and homestead agroforestry of Kerala, India. Anthropocene Science, 2(1), 93-100. https://doi.org/10.1007/s44177-023-00052-6

Mishra, G., Sarkar, A., Giri, K., Nath, A.J., Lal, R. and Francaviglia, R. 2021. Changes in soil carbon stocks under plantation systems and natural forests in Northeast India. Ecological Modelling, 446,109500. https://doi.org/10.1016/j.ecolmodel.2021.109500

Nath, A.J., Brahma, B., Sileshi, G.W. and Das, A.K. 2018. Impact of land-use changes on the storage of soil organic carbon in active and recalcitrant pools in a humid tropical region of India. Science of the Total Environment, 624, 908-917. https://doi.org/10.1016/j.scitotenv.2017.12.199

Nath, A.J., Lal, R. and Das, A.K. 2015. Managing woody bamboos for carbon farming and carbon trading. Global Ecological Conservation, 3, 654-663. https://doi.org/10.1016/j.gecco.2015.03.002

Negash, M. and Kanninen, M. 2015. Modelling biomass and soil carbon sequestration of indigenous agroforestry systems using CO_2FIX approach. Agriculture, Ecosystems and Environment, 203, 147-155. https://doi.org/10.1016/j.agee.2015.02.004

Ngatia, L.W., Moriasi, D., Grace III, J.M., Fu, R., Gardner, C.S. and Taylor, R.W. 2021. Land use change affects soil organic carbon: An indicator of soil health. In: Otsuki, T. (Ed.) Environmental Health, IntechOpen. https://doi.org/10.5772/intechopen.95764

Oelbermann, M. and Voroney, R.P. 2007. Carbon and nitrogen in a temperate agroforestry system: Using stable isotopes as a tool to understand soil dynamics. Ecological Engineering, 29, 342-349. https://doi.org/10.1016/j.ecoleng.2006.09.014

Ontl, T.A. and Schulte, L.A. 2012. Soil carbon storage. Nature Education Knowledge, 3(10), 35. https://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/

Parrotta, J.A. 1992. The role of plantation forests in rehabilitating degraded tropical ecosystems. Agriculture, Ecosystems and Environment, 41, 115-133. https://doi.org/

10.1016/0167-8809(92)90105-K

Parwi, M., Dewanti, F.D. and Priyadashini, R. 2022. Soil chemical properties and microbial biomass respond during land use change. IOP Conference Series: Earth and Environmental Science, 985(1), 012032. https://doi.org/10.1088/1755-1315/985/1/012032

Saha, A. and Handique, S. 2022. Variation of soil organic carbon in a university campus in temperate north-eastern India. Environmental Challenges, 7, 100493. https://doi.org/10.1016/j.envc.2022.100493

Sainepo, B.M., Gachene, C.K. and Karuma, A. 2018. Assessment of soil organic carbon fractions and carbon management index under different land use types in Olesharo catchment, Narok County, Kenya. Carbon Balance and Management, 13, art 4. https://doi.org/10.1186/s13021-018-0091-7

Sheikh, M.A., Kumar, M. and Bussmann, R.W. 2009. Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. Carbon Balance and Management, 4, art 1. https://doi.org/10.1186/1750-0680-4-6

Shu, X., Hu, Y., Liu, W., Xia, L., Zhang, Y., Zhou, W., Liu, W. and Zhang, Y. 2023. Linking between soil properties, bacterial communities, enzyme activities, and soil organic carbon mineralization under ecological restoration in an alpine degraded grassland. Frontiers in Microbiology, 14,1131836. https://doi.org/10.3389/fmicb.2023.1131836

Sundarapandian, S.M., Amritha, S., Gowsalya, L., Kayathri, P., Thamizharasi, M., Dar, J.A., Srinivas, K., Gandhi, D.S. and Subashree, K. 2016. Soil organic carbon stocks in different land uses in Pondicherry University campus, Puducherry, India. Tropical Plant Research, 3(1), 10-17. https://www.tropicalplantresearch.com/archives/2016/vol3issue1/2.pdf

Tasung, A. and Ahmed, N. 2017. Effect of different land use system and altitude on soil organic carbon and soil fertility of Siang river basin in Arunachal Pradesh, India. Journal of Crop and Weed, 13(3), 126-134. https://www.cropandweed.com/archives/2017/vol13issue3/13-3-25.pdf

Tian, Q., He, H., Cheng, W., Bai, Z., Wang, Y. and Zhang, X. 2016. Factors controlling soil organic carbon stability along a temperate forest altitudinal gradient. Scientific Reports, 6(1), 18783. https://doi.org/10.1038/srep18783

Walkley, A.J. and Black, I.A. 1934. Estimation of soil organic carbon by the chromic acid titration method. Soil Science, 37, 29-38. https://journals.lww.com/soilsci/citation/1934/01000/an_examination_of_the_degtjareff_method_for.3.aspx

Waxman, S.A. and Stevens, K.R. 1930. A critical study of the methods for determining the nature and abundance of soil organic matter. Soil Science, 30, 97-116. https://journals.lww.com/soilsci/Citation/1930/08000/A_Critical_Study_of_the_Methods_for_Determining.2.aspx

Young, I.M. and Crawford, J.W. 2004. Interactions and self-organization in the soil-microbe complex. Science, 304, 1634-1637. https://doi.org/10.1126/science.1097394

Zade, S.P., Bhosale, S.L. and Gourkhede, P.H. 2020. Carbon status in major fruit orchard soils of Parbhani district of Maharashtra. International Journal of Current Microbiology and Applied Sciences, 9(3), 1969-1979. https://doi.org/10.20546/ijcmas.2020.903.229

Zhang, B., Xu, C., Zhang, Z., Hu, C., He, Y., Huang, K., Pang, Q. and Hu, G. 2023. Response of soil organic carbon and its fractions to natural vegetation restoration in a tropical karst area, Southwest China. Frontiers in Forests and Global Change, 6, 1172062. https://doi.org/10.3389/ffgc.2023.1172062

Zhang, H., Zheng, X., Cai, Y. and Chang, S.X. 2022. Land-use change enhanced SOC mineralization but did not significantly affect its storage in the surface layer. International Journal of Environmental Research and Public Health, 19(5), 3020. https://doi.org/10.3390/ijerph19053020

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