International Journal of Ecology and Environmental Sciences 50: 393-404, 2024
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2024.0036

Variation of Soil Organic Carbon in Different Plantations in Mizoram

LALREMPUII HRAHSEL AND UTTAM KUMAR SAHOO*
Department of Forestry, School of Earth Sciences & Natural Resource Management, Mizoram University, Aizawl, 796004, Mizoram, India
E-mail: lalrempuii.h@gmail.com; uksahoo_2003@rediffmail.com
***Corresponding author**

ABSTRACT
Plantations are important in reducing logging on natural forests, carbon sequestration and restoration of degraded lands. Soil organic carbon is an important indicator of soil fertility, quality and productivity. A study was conducted in various plantations to assess the soil organic carbon status along with other soil parameters in Mizoram. The SOC stock was found to decrease with the soil depth except in oil palm plantation. The other soil parameters were also seen to decrease along with the soil profile. Teak was found to have the highest SOC stock at 39.03±5.3 Mg C ha^{-1} while areca nut plantation has the lowest at 28.91±0.67 Mg C ha^{-1}. Proper management of land use can be beneficial for both economy as well as carbon storage in a more sustainable way.

Key words: SOC stock, Soil health, Soil nutrients, Monoculture plantation

INTRODUCTION

Tropical forests can either act as a sink or source for carbon and they play a key factor in the modification of atmospheric carbon (Wei et al. 2013). They are converted into other land use types such as plantation or croplands through human activities. Since these anthropogenic activities changes the properties of soil and its processes have a detrimental impact on soil carbon storage (Fan et al. 2016, Iqbal and Tiwari 2016). Cultivated soils lost 21-36% of total organic carbon when compared to an uncultivated soil in northern India (Benbi et al. 2015) which was found to be lesser than the values (30-60%) reported from various agro-climatic regions of India (Lal 2004). The conversion of natural forests to croplands leads to disruption of soil structure which leads to SOC loss (Golchin and Asgari 2008). The largest carbon sink on earth is soil and it stores ~1.5x10^3 Pg (1 Pg = 10^{15}g) of Carbon up to a depth of 1 m. This is two and three folds higer than the atmosphere and total vegetation, respectively (Jobbágy and Jackson 2000, Batjes 2014, Scharlemann et al. 2014, Lal 2016, Vicente-Vicente et al. 2016). They contribute to GHG emissions as a part of the carbon stored in soil is lost as carbon dioxide (CO_2) and methane to the atmosphere. Part of the GHG emissions can be mitigated by enhancement of soil organic carbon (SOC) sequestration throught agricultural and monoculture management practices (Yang et al. 2020). Introduction of tree crops in forestry and agroforestry systems showed a significantly higher potential for sequestration at longer time when compared with normal agricultural crops (Soto-Pinto et al. 2010).

Soil organic carbon (SOC) is influenced by numerous factors such as the land use, type of soil and climate (Lawrence et al. 2015, Hoyle et al. 2016). The quality of soil is related to the physical, chemical as well as biological attributes of soil and is influenced by management practices (Yang et al. 2020). It is broadly well known that the amount of SOC is lower in sub-surface layers than the suface and greater in fine-textured soil than medium or coarse textured soils (Jian et al. 2020). Additionally, the quantity of SOC typically increases with increase in annual precipitation because more water is available for plant growth and a decrease in soil temperature as there is decrease in reduction in decomposition of organic matter (Hoyle et al. 2016). SOC can differ spatially and temporally due to the climate, flora and fauna, topography and lithological factors which influence the loss and gain of the carbon in soil. An important indicator of soil fertility, productivity, quality and decline is SOC since it negatively impacts land productiveness (van der Werf et al. 2010). In the recent years, there is a notable decline in soil productivity and loss of SOC stock which are crucial for many vital ecosystem services (Bai et al. 2008).

Major conversion in land use is happening in Northeast India, where the natural forest in converted for shifting cultivation. About 85% of such conversions are due to shifting cultivation in Northeast India (Singh et al. 2018), since it involves slashing and burning of natural forest, it will have a pernicious impact on soil organic carbon stock and soil health (Sahoo et al. 2019). Conversion of jhum lands to other sustainable land uses like plantation and agroforestry have potential to ameleorate this degradation. The changes in soil and vegetation influenced the rate of carbon build-up or loss in soil (Poeplau and Don 2013). Plantations account for 5% of global forest cover (Anonymous 2010) and are established at an accelerating rate throughout the world. There is an increasing need of conservation of plantations to reduce logging on natural forests, carbon sequestration and restoration of degraded land (Kelty 2006). Plantations such as rubber trees on degraded fallow lands have shown to supply large amount of carbon sink (Brahma et al. 2017). Globally as well as locally, many studies have suggested that SOC stock increases especially with the maturity of the stands (Choudhary et al. 2016, Brahma et al. 2017, Nath et al. 2018). This will not only be sustainable but economical as it will still provide livelihood for the farmers involved in shifting cultivation. Assessment of the overall SOC storage can provide information needed for climate change mitigation and adaptation in monoculture plantation. The present study attempts to better understanding of SOC in different plantation, through estimation of the SOC stock and other selected soil properties as well as their inter-relationships.

STUDY AREA

The present study was carried out in selected plantations and are spread out in Sakawtuichhun (23.76° N Latitude and 92.67° E Longitude) and PTC Lungverh (23.92° N Latitude and 92.60° E Longitude). The plantations selected were rubber, oil palm, teak and areca nut based monocultures. The age of the plantations was 16 years and has been well maintained for a certain period of time.

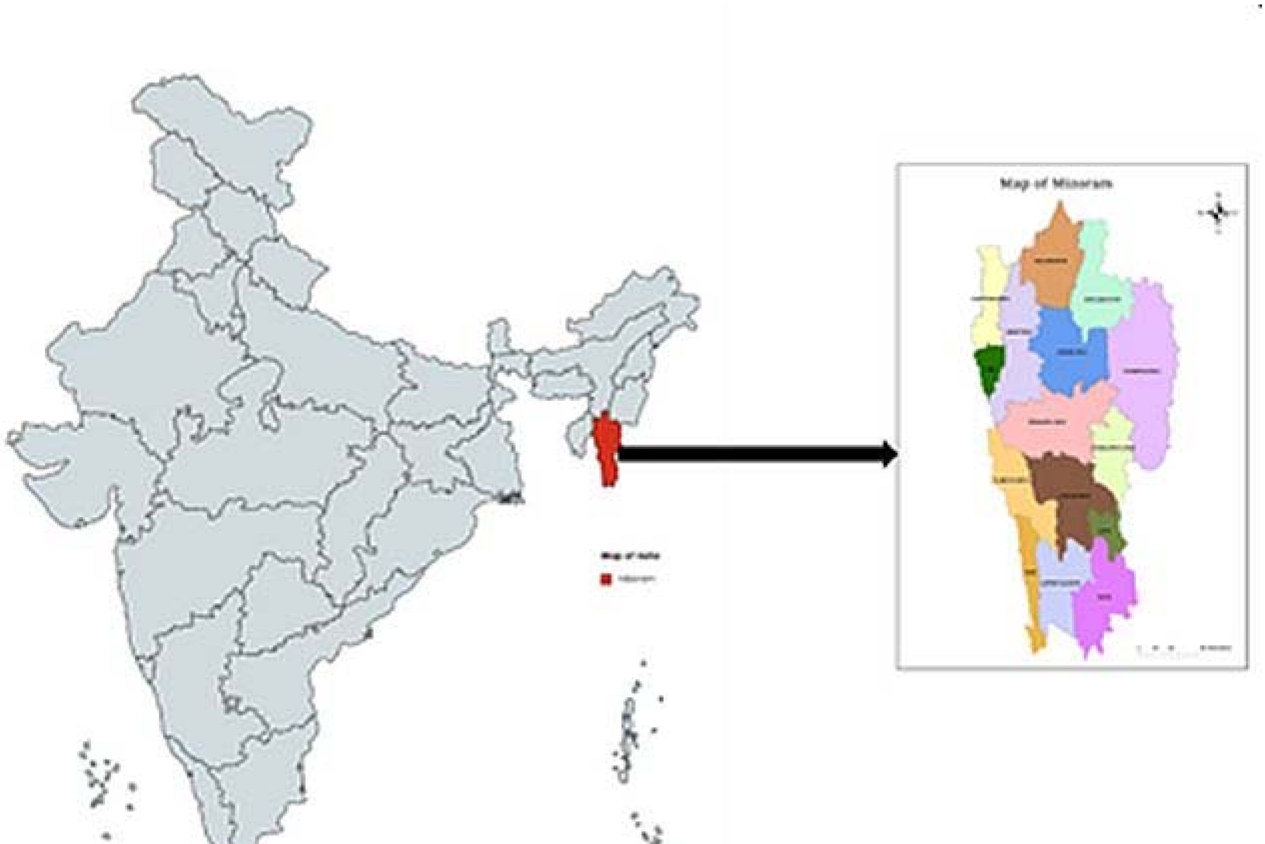

Figure 1. Study site, Mizoram, Northeast India

Figure 2. General view of a. Rubber plantation, b. Oil palm plantation, c. Teak plantation and d. Areca nut plantation

METHODS

Soil sampling

Soil sampling was done in December 2020 from each plantation. In each plantation, four quadrats (30 x 30 m) were laid and in each quadrat, soil was collected using an soil sampler having 5 cm diameter at the depths of 0-20 and 20-40 cm. Sampling was done at least 1 m distance away from the trees. Undisturbed soil core samples were used for bulk density analysis using standard methods. The soil samples were air dried and passed through a 2 mm sieve, stored for analyzing the physicochemical properties. Soil pH was measured using soil-water suspension at the ratio of 1:2 using a digital pH meter. Soil moisture content was estimated by drying 10 g of fresh soil at 105°C for 24 hrs. Bulk density was measured using corer method where undisturbed soil cores were collected and were taken to the laboratory to be kept in the oven at 105°C for 72 hrs or till the constant weight achieved.

$$\text{Bulk density (Mg m}^{-3}\text{)} = \frac{\text{(Fresh weight - Dry weight)/}}{\text{Volume of Corer}}$$

Soil organic carbon was determined by Walkley-Black rapid titration method and the SOC stock was determined by considering SOC concentration, bulk density (corrected for coarse fraction) and soil depth.

$$\text{SOC stock (Mg ha}^{-1}\text{)} = (\text{SOC\%*corrected BD*T*}10^{4})/100$$

Total Carbon of soil was measured by Vario TOC Analyzer (IR type analyzer). Available nitrogen was determined by Subbiah and Asija (1956) method.Calcium and Magnesium was estimated using ammonium acetate extracts of soils by EDTA Titrimetry method. Ammonium acetate method (Hanway and Heidel 1952) using Flame photometer was used for estimating exchangeble potassium present in the soil.

Statistical analysis

Analysis of data was performed using Microsoft Excel 2016 and SPSS (IBM SPSS Statistics 25). One-way and two-way ANOVA was performed between the different plantation and soil depth along with the various soil parameters. Test of significance was performed using Tukey's HSD with $p \leq 0.05$, where *p* value greater than 0.05 were rejected. SPSS was used for estimating Pearson's correlation between the soil depth and other soil parameters.

RESULTS

Variations in soil physico-chemical characteristics

The physico-chemical properties of the soil in the four different plantations are presented in Table 1. There was no significant relationship between type of plantation and physico-chemical properties at the two soil depths except for soil organic carbon (SOC) stock. In the four plantations studied, significant ($p<0.005$) variation was observed in the soil properties (Table 2). The pH of all plantations showed a similar pattern since there is an increase with the depth of the soil (Table 1). Significant variation was present between the pH of areca nut plantation with rubber and teak plantation. The value of pH ranges from 4.79 to 5.46 in 0-20 cm soil depth and 4.93 to 5.64 in 20-40 cm soil depth. Soil moisture content increased with depth and was significantly ($p<0.005$) different among the plantations (Table 2). It was lowest in teak plantation (15.77 % ± 1.78 and15.89 % ± 1.78, respectively). Soil moisture content also increased with the depth of the soil. Bulk density varied from 0.88 to 1.17 g cm^{-3} in 0-20 cm and 1.01 to 1.34 g cm^{-3} in 20-40 cm soil depths. It was lowest in oil palm plantation and a significantly ($p<0.005$) varied with rubber and teak plantations. Bulk density increased with the depth of the soil (Table 3).

SOC concentration was in the range of 1.17 to 1.92% while the SOC stock varied between 23.04 and 49.09 Mg C ha^{-1} among the plantations. Furthermore, areca nut plantation was significantly differed with rubber and teak plantation in its SOC stock content. All the plantations, except oil palm plantation, showed a decrease in SOC concentration and SOC stock with the increase in soil depth. While total carbon content differed significantly between rubber plantation and areca nut plantation, potassium and magnesium content showed differences between rubber and teak plantations (Table 2). All the plantations showed lower total carbon (TC) with the increase in soil depth. Available nitrogen was highest (435.12 kg ha^{-1} in 0-20 cm and 424.63 kg ha^{-1} in 20-40 cm depth) in rubber plantation. Plantations did not show any significant differences in their SOC concentration (%), available nitrogen and calcium

Table 1. Soil physico-chemical properties in different plantations

Soil property	RUBBER		OIL PALM		TEAK		ARECA NUT	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
pH	5.46 ± 0.15^{a}	5.64 ± 0.15^{a}	5.36 ± 0.15^{a}	5.59 ± 0.15^{a}	5.05 ± 0.15	5.26 ± 0.15	4.78 ± 0.15^{a}	4.93 ± 0.15^{a}
Moisture (%)	29.58 ± 1.78^{a}	30.05 ± 1.78^{a}	26.78 ± 1.78^{a}	28.42 ± 1.78^{a}	15.77 ± 1.78^{a}	15.89 ± 1.78^{a}	22.78 ± 1.78^{a}	25.73 ± 1.78^{a}
BD (g cm^{-3})	1.17 ± 0.08^{a}	1.32 ± 0.08^{a}	0.88 ± 0.08^{a}	1.01 ± 0.08^{a}	1.14 ± 0.08^{a}	1.34 ± 0.08^{a}	1.03 ± 0.08	1.14 ± 0.08
SOC (%)	1.92 ± 0.20	1.17 ± 0.20	1.47 ± 0.20	1.66 ± 0.20	1.61 ± 0.20	1.47 ± 0.20	1.97 ± 0.20	1.64 ± 0.20
SOC Stock (Mg C ha^{-1})	45.03 ± 5.16^{a}	31.23 ± 5.16^{a}	26.05 ± 5.16	34.31 ± 5.16	49.09 ± 5.16^{a}	28.98 ± 5.16^{a}	30.08 ± 5.16^{a}	27.73 ± 5.16^{a}
TC (%)	1.85 ± 0.20^{a}	1.35 ± 0.20^{a}	1.79 ± 0.20	1.73 ± 0.20	2.37 ± 0.20	1.77 ± 0.20	2.62 ± 0.20^{a}	1.92 ± 0.20^{a}
Avl. N (kg ha^{-1})	428.79 ± 3.32	424.63 ± 3.32	434.14 ± 3.32	422.55 ± 3.32	435.14 ± 3.32	420.69 ± 3.32	429.89 ± 3.32	423.67 ± 3.32
K (kg ha^{-1})	144 ± 46.18^{a}	104.84 ± 46.18^{a}	243.06 ± 46.18	167.04 ± 46.18	316.77 ± 46.18^{a}	199.29 ± 46.18^{a}	185.47 ± 46.18	130.18 ± 46.18
Mg (Meq L^{-1})	0.615 ± 0.05^{a}	0.57 ± 0.05^{a}	0.73 ± 0.05	0.64 ± 0.05	0.82 ± 0.05^{a}	0.68 ± 0.05^{a}	0.66 ± 0.05	0.60 ± 0.06
Ca (Meq L^{-1})	1.01 ± 0.04	0.94 ± 0.04	1.05 ± 0.04	0.91 ± 0.04	1.06 ± 0.04	0.92 ± 0.04	1.06 ± 0.04	0.96 ± 0.04

BD = bulk density; SOC = soil organic carbon; TC = total carbon; N = available nitrogen; K = potassium; Mg = magnesium; C = calcium; *values followed after ± are standard error of men; a indicates significant difference between the plantations (Tukey HSD @0.05)

Table 2. Two-way ANOVA showing significant differences in soil characteristics

Source	pH	Moisture (%)	BD (g cm^{-3})	SOC (%)	SOC Stock (Mg C ha^{-1})	TC (%)	Available N (kg ha^{-1})	K (kg h^{-1})	Mg (Meq L^{-1})	Ca (Meq L^{-1})
Plantation	8.836*	23.892*	5.794*	0.127	4.001*	4.243*	0.122	3.168*	3.18*	0.303
Soil depth	3.379	1.064	6.317*	0.383	2.469	10.963*	15.026*	4.859*	5.101*	19.567*
Plantation x Soil depth	0.028	0.26	0.106	2.442	3.772*	0.96	1.022	0.269	0.278	0.482

BD = bulk density; SOC = soil organic carbon; TC = total carbon; N = available nitrogen; K = potassium; Mg = magnesium; C = calcium; *indicate significant differences between the soil properties with plantation and soil depth (Tukey HSD @0.05) contents. All the plantations showed a decline in their potassium, magnesium and calcium concentrations with the soil depth and a negative relationship was observed between these soil properties and the depth of the soil (Table 3).

Variation in SOC concentration and SOC stock

Plantation type and their interaction with soil greatly influenced the soil properties as well as their SOC content in the soil (Fig. 3). Bulk density of the plantations showed a specific trend of increase with the depth of the soil (Fig. 4) and there is a positive correlation between the bulk density and the depth of the soil. Bulk density of the oil palm plantation showed significant variation with rubber and teak plantations. However, SOC concentration and SOC stock in the plantations did not indicate any particular trend with the depth of the soil (Fig. 3). The SOC stock showed a significant variation (p<0.05) among the plantations except oil palm plantation (Fig. 5).

Relationship between various soil parameters

The correlation matrix between the soil depth with soil properties (Table 3) indicates a significant positive relationship with the bulk density (p<0.05) and negative relationship with the total carbon, available nitrogen and calcium (p<0.01), potassium and magnesium (p<0.05). SOC Stock have a positive relationship with bulk density and SOC concentration (p<0.01) and negative correlation with calcium.

DISCUSSION

Variations in soil physico-chemical characteristics

Soil physical and chemical properties are governed by various factors and the results of the present study revealed that these properties have significant differences among the studied plantations. pH has an important role between soil and plants since it controls the biochemical process in the soil. This in turn influenced the soil's fertility. In the present study soil pH was slightly acidic and increased with the soil depth in all the plantations. This was in contrast to other studies on monoculture and agricultural land use (Sharma et al. 2000, Yang, et al. 2020) where the decrease in soil pH with depth were due to the decrease in concentration of exchangeable ions as well as application of lime in the fields to increase

Table 3. Pearson's correlation between soil depth and soil properties

Pearson's correlation	Soil depth (cm)	pH	Moisture (%)	Bulk density ($g\ cm^{-3}$)	SOC (%)	SOC ($Mg\ C\ ha^{-1}$)	Total carbon (%)	Available nitrogen ($kg\ ha^{-1}$)	Potassium ($kg\ ha^{-1}$)	Magnesium ($Meq\ L^{-1}$)	Calcium ($Meq\ L^{-1}$)
Soil depth (cm)	1										
pH	0.25	1									
Moisture (%)	0.104	.436*	1								
Bulk density ($g\ cm^{-3}$)	.363*	0.128	-0.265	1							
SOC (%)	-0.109	0.137	0.119	-0.089	1						
SOC ($Mg\ C\ ha^{-1}$)	0.223	0.325	-0.078	.599**	.612**	1					
Total carbon (%)	-.466**	-0.337	-0.218	-0.183	0.283	-0.031	1				
Available nitrogen ($kg\ ha^{-1}$)	-.595**	-0.301	-0.013	-0.327	-0.087	-0.281	0.144	1			
Potassium ($kg\ ha^{-1}$)	-.352*	-0.26	-0.327	-0.08	-0.317	-0.212	0.137	0.338	1		
Magnesium ($Meq\ L^{-1}$)	-.359*	-0.26	-0.328	-0.079	-0.313	-0.211	0.134	0.341	1.000**	1	
Calcium ($Meq\ L^{-1}$)	-.653**	-0.209	-0.001	-0.258	-0.179	-.368*	.425*	.387*	.633**	.636**	1

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

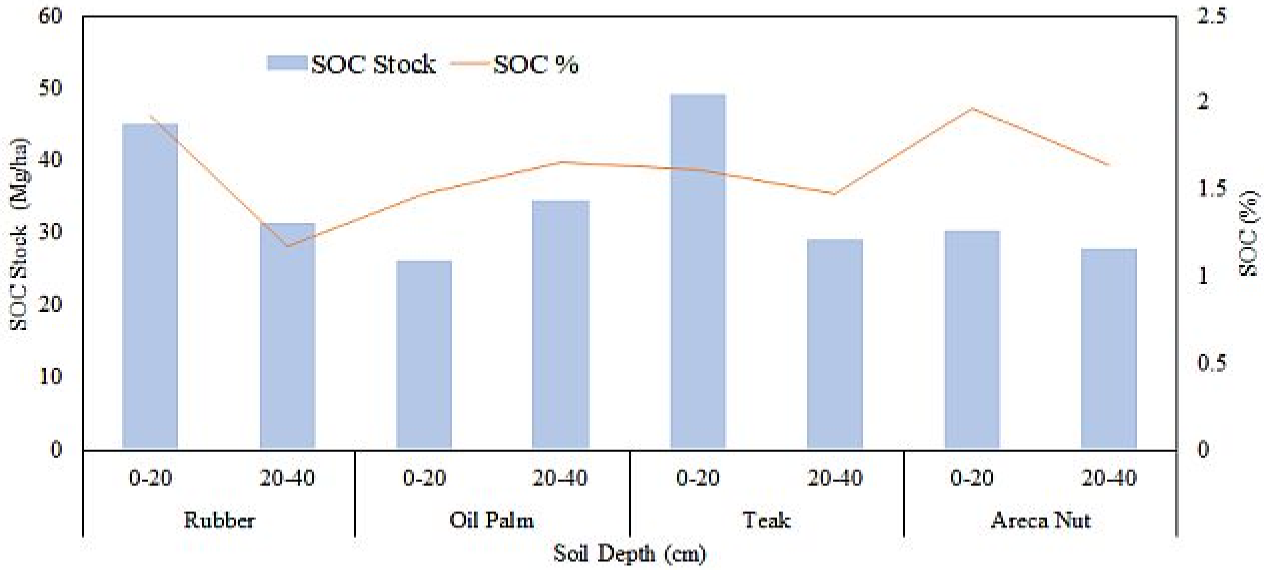

Figure 3. Soil Organic Carbon (SOC) stock and concentration of different plantations

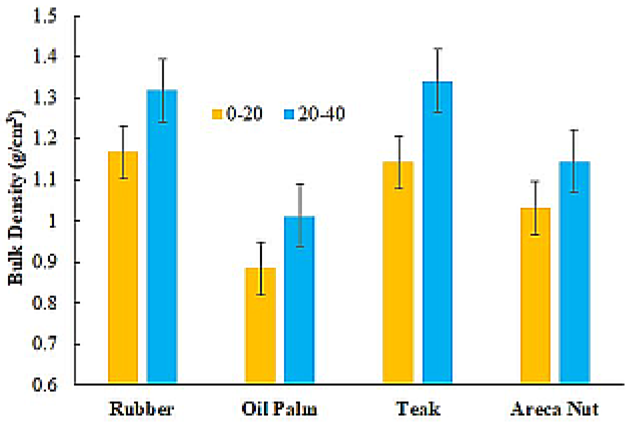

Figure 4. Soil bulk density (mean ± SE) in plantations Similar alphabet show significance @ p<0.005.

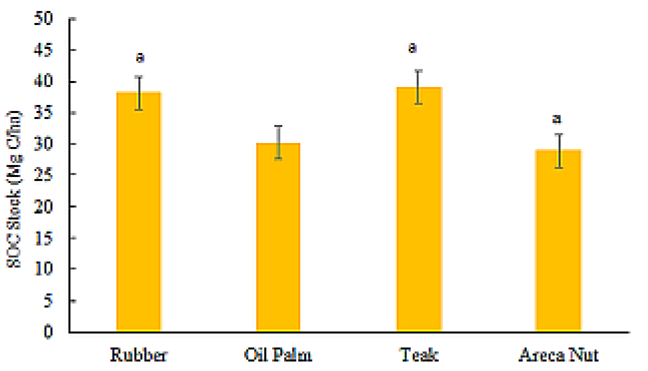

Figure 5. Sum of SOC Stock (mean ± SE) of selected plantations Similar alphabet (a) show significance @ p<0.005.

the soil pH. However, in our study, we found no correlation between the soil pH and the nutrients although the depth of the soil has a negative relationship with the micronutrients.

Soil nutrient content (available nitrogen, potassium, magnesium and calcium) decreased with the increasing soil depth in all the monoculture plantations. It could be due to decrease in organic matter content with increasing soil depth (Chima et al. 2014). The concentration of available nitrogen was influenced by organic matter and the decrease in concentration of available nitrogen with increasing soil depth could be due to reduced SOM (Chima et al. 2014). The decline of carbon and nitrogen content could be due to the lowering of net primary production, litter and fine root biomass in the plantations (Liao et al. 2012). The increase in soil pH could be due to the alteration in litter quality, root exudates and the trees increased their uptake of cations (Gunina et al. 2017). Another factor could be the presence of organic matter in soil and other elements present in the plantation soil (Kulkarni 1951). The aggregation and decomposition of organic matter is the main cause for soil acidification. Humic substances are produced by the decomposition of plant residues in soils and they release hydrogen ions which are pH dependent (Sparks et al. 2023). Soil pH can also be influenced by low moisture content since there could be insufficient soil moisture for limestone present in the soil to react (Camberato 2022).

Moisture content showed a significant increase with soil depth in all the plantations. Harianti et al. (2021) reported that in monoculture plantations, the moisture content is lower in the upper layer of the soil and is most likely to be incluenced by the soil organic matter and soil texture. Soil moisture content was highest in rubber plantation (nearly 30%) and lowest in teak plantation (almost 16%). The thick litter layer on the floor of the plantation and the shade provided by the mature rubber trees may retain the moisture in the soil (Wang et al. 2011, Das et al. 2021), thus, the high moisture content in rubber plantation. Teak is vulnerable to poor drainage conditions and it restricts the development of roots as well as has an impact on the growth of the trees (Choudhari et al. 2018), hence the low moisture content in soil compared to other plantations. There is a direct correlation between the growth of teak and other soil parameters such as pH, calcium, magnesium but not with soil organic matter content (Choudhari et al. 2018). Soil bulk density is an indicator of the compactness of the soil and it helps in determining the infiltration, soil water porosity, available water capacity, soil microorganism activity, root proliferation and nutrient availabilty (Indoria et al. 2020). The bulk density increasead with the soil depth in all the plantations studied. Oil palm plantation in the present study shows a lower bulk density which was also reported by Shrivastava et al. (2021). Das et al. (2021) reported the bulk density of rubber decreased till 5-20 years and gradually increased with the age of the rubber plantation. However, our results are in contrast to the studies of Yasin et al. (2014) and Choudhary et al. (2016) which reported decrease in bulk density of soil in rubber plantations with depth. The decrease in bulk density could be due to destruction of soil structure by land preparation. One of the main reasons for decrease in soil nutrients and variation in micororganism's diversity in rubber plantation is extraction of latex from the trees and weed control measures used in these plantations (Sungthongwises and Taweekij 2019).

SOC stock increased with depth in all the plantations studied except rubber plantation. Singh et al. (2018) observed that the SOC concentration of oil plam plantation gradually decreased during the initial years of planting and increased after they bear fruits. The increase in SOC stock of oil plam plantation may be the result of application of fertilzers and other management paractices. The decrease in SOC stock in plantations could be due to the differences in the annual leaf litter decomposition on the plantation floor, which may have assisted in build-up organic matter (Das et al. 2021).

Variation in SOC concentration and SOC stock

In our study, we found that all the plantations except oil palm have a significant variation in the SOC stock, but there was no particular trend. Bulk density is negatively correlated with organic carbon, hence the increase in bulk density with soil depth and the decrease in SOC in all the plantations, except in oil palm, can be justified. The bulk density tends to increase with the increase in soil depth which is due to the compaction of the soil and the presence of organic carbon or organic matter in soil can make the soil porous and loose (Yihenew and Getachew 2013). Due to the presence of more organic matter from trees, SOC tend to decrease with the soil depth since the top soil contain the maximum amount of SOC. The trees regularly add litter in the upper layer of the soil and accelerate the root turnover, this enchanced the SOC by positive priming (Wu et al. 1993). This was also reported by Soleimani et al. (2019) and Lepcha and Devi (2020), thus the decrease in SOC of our study can be justified. In plantation and agriculture, there can be lower SOC content due to lack of input of organic matter and many soil disturbances, thus resulting in high carbon mineralization (Singh et al. 2018). SOC content can also be reduced due to biomass removal during harvesting and regular tillage ends up breaking the soil macro aggregates (Schroeder 1994).

The loss of SOC in the soil layers of rubber plantation may have been due to vegetation cover loss (Brahma et al. 2017). Choudhary et al. (2016) and Das et al. (2021) observed that the age of rubber plantations may have a role in their SOC content. They found that SOC stock in younger rubber plantations (5-15 years) have lower SOC stock compared to those over 15 years of age. The lower canopy density of younger rubber plantations could lead to vulnerability of soil surface to sunlight, thus leading to loss of SOC on the upper layers. Usuga et al. (2010) reported that SOC of teak plantations tend to decrease gradually with increase of soil depth, which is an indicator that penetration of organic carbon is slow in the soil. A study from Myanmar (Suzuki et al. 2007) also showed a similar trend in teak plantations. The decrease in SOC stock can be caused by poor leaching of nutrients and lesser intake of the trees for their growth. Singh et al. (2018) also showed that in areca plantation SOC decreased with the soil depth. It may be due to input of higher organic matter and increase of microbial activities in the upper layer of the soil (Van Noordwijk et al. 1996). In our study, only oil palm showed a positive corelation between the bulk density and SOC concentration along with SOC stock as both increase with depth. Rahman et al. (2018) also reported a similar pattern where SOC stocks were lower in the top soil of the oil palm plantations in Malyasia. This could be the result of increase rate in mineralisation accompanied by disturbance of soil due to clearing of land, repeated removal of crop residues and soil erosion (Nair et al. 2011). The shallow root system of the oil palm and the density of soil during the establisment period of the plantations caused a hindrance to transportation of soil organic matter into further layers of the soil (Kukal and Bawa 2014).

Relationship between various soil parameters

In our study, the relationship between the various soil parameters and soil depth showed that there is a positive relationship between the soil depth and bulk density, while total carbon, available nitrogen, potassium, magnesium and calcium showed a negative relationship. Thus, bulk density increased with the depth of the soil while the other parameters decreased. Choudhari et al. (2018) observed a direct relation between growth of the trees and the soil parameters (pH, calcium, magnesium) but not with soil organic matter. This align with our study which shows only a positive correlation between bulk density and SOC stock. Chima et al. (2014) concludes that the decrease in micronutrients and available nitrogen is due to the decrease in organic carbon as also seen in the present study. Liao et al. (2012) concluded that the contents of carbon and nitrogen may decline because of lower net primary productivity, litter and fine root biomass in the plantations. Md. Abdullah et al. (2017) reported a negative relationship between the soil depth and nitrogen present in the soil in monoculture plantations. They also reported that potassium is negatively corelated with the soil depth which was also reported by Vadivelu et al. (1993).

CONCLUSION

The present study showed the type of plantation and its relationship with soil is heavily influenced with soil properties. The SOC stock (with the exception of oil palm) has an negative correlation with bulk density. There were variations within the plantations with the different soil properties. There was a significant variation between the bulk density of the oil palm plantation with rubber and teak plantations. The soil nutrients exhibited negative relationship with the soil depth and were seen to decrease with depth. This was similar to the SOC trend since the presence of organic matter decreases with the soil depth. The SOC concentration and SOC stock diminished with the soil depth and thus may have negative effects on the soil health such as its quality, long-term productivity of the soil and the carbon balance on a global scale. However, the SOC stocks were not low when compared to other studies and were in a good range, thus, although the SOC stock may decrease with depth, it does not mean that the value of SOC in the plantations under current study were low. Increased addiction of litter through plant residues may help in maintaining the SOC stock in these plantations and improved management practices can be further adapted to aid with SOC stock. The findings of the study will aid in better understanding of monoculture plantation and their potential to store SOC in their soil.

ACKNOWLEDGEMENTS

The study was financially supported by the Department of Science and Technology, Government of India, New Delhi (Grant No. DST/CCP/MRDP/189) under Climate Change Research Programme.

Authors' contributions: Both the authors contributed equally

Conflict of interest: Authors declare no conflict of interest

REFERENCES

Anonymous. 2010. Global Forest Resources Assessment 2010, Main Report. Food and Agriculture Organization of the United Nations, Rome.

Bai, Z.G., Dent, D.L., Olsson, L. and Schaepman, M.E. 2008. Proxy global assessment of land degradation. Soil Use and Management, 24, 223-234. https://doi.org/10.1111/j.1475-2743.2008.00169.x.

Batjes, N. 2014. Total carbon and nitrogen in the soils of the world. European Journal of Soil Sciences, 65, 4-21. https:/ / doi.org/10.1111/ejss.12114_2.

Benbi, D.K., Brar, K., Toor, A.S. and Singh, P. 2015. Total and labile pools of soil organic carbon in cultivated and undisturbed soils in northern India. Geoderma, 237-238, 149–158. https://doi.org/10.1016/j.geoderma.2014.09.002.

Brahma, B., Sileshi, G.W., Nath, A.J. and Das, A.K. 2017. Development and evaluation of robust tree biomass equations for rubber tree (*Hevea brasiliensis*) plantations in India. Forest Ecosystems, 4(1), 1-10. https://doi.org/ 10.1186/s40663-017-0101-3.

Camberato, J. 2022. Keep in mind soil test K and pH are affected by low soil moisture. ENTM Extension Newsletters, October.

Chima, U, Popo-Ola, F.S. and Ume, K.K. 2014. Physico-chemical properties of topsoil under indigenous and exotic monoculture plantations in Omo Biosphere Reserve, Nigeria. Ethiopian Journal of Environmental Studies & Management, 7(2), 117-123. http://dx.doi.org/10.4314/ ejesm.v7i2.2.

Choudhari, P.L. and Prasad, J. 2018. Teak supporting soils of India: A review. Journal of Science, 2(3), 198-200. https:/ /doi.org/10.15406/oajs.2018.02.00070.

Choudhary, B.K., Majumdar, K. and Datta, B.K. 2016. Carbon sequestration potential and edaphic properties along the plantation age of rubber in Tripura, North-eastern India. Current World Environment, 11(3), 756-766. http:// dx.doi.org/10.12944/CWE.11.3.10.

Das, S., eb, S., Bani, B. and Deb, D. 2021. Estimation of soil organic carbon pools and biomass carbon stocks in different aged rubber (*Hevea brasiliensis* Muell. Arg.) plantations of Tripura. Journal of the Indian Society of Soil Science, 69(3), 248-260. https://doi.org/10.5958/0974-0228.2021. 00052.9.

Fan, S., Guan, F., Xu, X., Forrester, D.I., Ma, W. and Tang, X. 2016. Ecosystem carbon stock loss after land use change in subtropical forests in China. Forests, 7, 142. https:// doi.org/10.3390/f7070142.

Golchin, A. and Asgari, H. 2008. Land use effects on soil quality indicators in north-eastern Iran. Australian Journal of Soil Research, 46 (1), 27-36. https://doi.org/10.1071/ SR07049.

Gunina, A., Smith, A.R., Godbold, D.L., Jones, D.L. and Kuzyakov, Y. 2017. Response of soil microbial community to afforestation with pure and mixed species. Plant and Soil, 412, 357-368. https://doi.org/10.1007/s11104-016-3073-0.

Hanway, J.J. and Heidal, H. 1952. Soil analysis methods as used in Iowa State College Soil Testing Laboratory. Iowa State College of Agriculture Bulletin, 57, 1-31.

Harianti, M., Junaidi, J., Emalinda, O., Herviyanti, H., Azizah, A. and Pulunggono, H.B. 2021. The soils physicochemical properties of monoculture land inseveral slopes at Northern Areas of Mount Talang. IOP Conference Series: Earth and Environmental Science, IOP Publishing. https://doi.org/ 10.1088/1755-1315/741/1/012027.

Hoyle, F.C, O'Leary, R.A. and Murphy, D.V. 2016. Spatially governed climate factors dominate management in determining the quantity and distribution of soil organic carbon in dryland agricultural systems. Scientific Reports, 6, 31468. https://www.nature.com/articles/srep31468.

Indoria, A.K., Sharma, K.L. and Reddy, K.S. 2020. Hydraulic properties of soil under warming climate. Pp. 473-508. In: Prasad, M.N.V. and Pietrzykowski, M. (Eds.). Climate Change and Soil Interactions, Elsevier. https://doi.org/ 10.1016/B978-0-12-818032-7.00018-7.

Iqbal, S. and Tiwari, S.C. 2016. Soil organic carbon pool under different land uses in Achanakmar Biosphere Reserve of Chhattisgarh, India. Current Science, 110, 771-773. https:/ /www.jstor.org/stable/24907957

Jian, J., Du, X., Reiter, M.S. and Stewart, R.D. 2020. A meta-analysis of global cropland soil carbon changes due to cover cropping. Soil Biology and Biochemistry. 143, 107735. https://doi.org/10.1016/j.soilbio.2020.107735.

Jobbágy, E.G. and Jackson, R.B. 2000. The vertical distribution of soil organic carbon and its reclamation to climate and vegetation. Ecological Applications, 10, 423-436. https:// doi.org/10.1890/051-0761(2000)010[0423:TVDOSO] 2.0.CO;2.

Kelty, M.J. 2006. The role of species mixtures in plantation forestry. Forest Ecology and Management, 233 (2-3), 195-204. https://doi.org/10.1016/j.foreco.2006.05.011.

Kukal, S. and Bawa, S. 2014. Soil organic carbon stock and fractions in relation to land use and soil depth in the degraded Shiwalik hills of lower Himalayas. Land Degradation and Development, 25, 407-416. https:// doi.org/10.1002/ldr.2151.

Kulkarni, D.H. 1951. Distribution of teak (*Tectona grandis*) on the northern slopes of the Satpuras, with special relation to geology. Proceedings 8th Silviculture Conference, Dehradun.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science, 304, 1623-1627. https://doi.org/10.1126/science.1097396

Lal, R. 2016. Soil health and carbon management. Food and Energy Security, 5(4), 212-222. https://doi.org/10.1002/ fes3.96.

Lawrence, C.R., Harden, J., Xu, X. and Schulz, M.S. 2015. Long-term controls on soil organic carbon with depth and time: A case study from the Cowlitz River Chronosequence, WA USA. Geoderma, 247, 73–87.

Lepcha, N.T. and Bijayalaxmi Devi, N. 2020. Effect of land use, season, and soil depth on soil microbial biomass carbon of Eastern Himalayas. Ecological Processes, 9(65), 1-14. https://doi.org/10.1186/s13717-020-00269-y.

Liao, C., Luo, Y., Fang, C., Chen, J. and Li, B. 2012. The effects of plantation practice on soil properties based on the comparison between natural and planted forests: a meta-analysis. Global Ecology and Biogeography, 21(3), 318-327. https://doi.org/10.1111/j.1466-8238.2011.00690.x

Md. Abdullah, A.M., Rahman, M.M. and Hossain, M.K. 2017. The effects of teak monoculture on forest soils: a case study in Bangladesh. Journal of Forestry Research, 29, 1111-1120. https://doi.org/10.1007/s11676-017-0515-3.

Nair, P., Saha, S.K., Nair, V.D. and Haile, S.G. 2011. Potential for greenhouse gas emissions from soil carbon stock following biofuel cultivation on degraded lands. Land Degradation and Development, 22, 395-409. https://doi.org/10.1002/ldr.1016

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

Poeplau, C. and Don, A. 2013. Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe. Geoderma, 192, 189-201. https://doi.org/10.1016/j.geoderma.2012.08.003

Rahman, N., de Neergaard, A., Gerrie, J.M., van de Ven, W.J., Giller, K.E. and Bruun, T.B. 2018. Changes in soil organic carbon stocks after conversion from forest to oil palm plantations in Malaysian Borneo. Environmental Research Letters, 13, 105001. https://doi.org/10.1088/1748-9326/aade0f.

Rozieta, R., Sahibin, A.R. and Wan Mohd Razi, I. 2015. Physico-chemical properties of soil at oil palm plantation area, Labu, Negeri, Sembilan. AIP Conference Proceedings, 1678(1), 020031. https://doi.org/10.1063/1.4931216

Sahoo, U.K., Singh, S.L., Gogoi, A., Kenye, A. and Sahoo, S.S. 2019. Active and passive soil organic carbon pools as affected by different land use types in Mizoram, Northeast India. PLoS ONE, 14(7), 1-16. https://doi.org/10.1371/journal.pone.0219969.

Scharlemann, J.P.W., Tanner, E.V., Hiederer, R. and Kapos, V. 2014. Global soil carbon: Understanding and managing the largest terrestrial carbon pool. Carbon Management, 5, 81-91. https://doi.org/10.4155/cmt.13.77

Schroeder, P. 1994. Carbon storage benefits of agroforestry systems. Agroforestry Systems, 27, 89-97. https://doi.org/10.1007/BF00704837.

Sharma, B.D., Mukhopadhyay, S.S., Sidhu, S.P. and Katyal, J. 2000. Pedospheric attributes in distribution of total and DTPA extractable Zn, Cu, Mn and Fe in Indo-Gangetic plains. Geoderma, 96, 131-151. https://doi.org/10.1016/S0016-7061(00)00008-2

Shrivastava, P., Khongphakdi, P., Palamanit, A., Kumar, K. and Tekasakul, P. 2021. Investigation of physicochemical properties of oil palm biomass for evaluating potential of biofuels production via pyrolysis processes. Biomass Conversion and Biorefinery, 11, 1987-2001. https://doi.org/10.1007/s13399-019-00596-x.

Singh, S.L., Sahoo, U.K., Kenye, A. and Gogoi, A. 2018. Assessment of growth, carbon stock and sequestration potential of oil palm plantations in Mizoram, Northeast India. Journal of Environmental Protection, 9, 912-931. https://doi.org/10.4236/jep.2018.99057

soil organic matter and a proposed modification of chromic acid titration method. Soil Science, 37 (1), 29-38. https://dx.doi.org/10.1097/00010694-193401000-00003

Soleimani, A., Hosseini, S.M., Bavani, A.R.M., Jafari, M. and Francaviglia, R. 2019. Influence of land use and land cover change on soil organic carbon and microbial activity in the forest of northern Iran. Catena, 177, 227-237. https://doi.org/10.1016/j.catena.2019.02.018

Soto-Pinto, L., Anzueto, M. and Mendoza, J. 2010. Carbon sequestration through agroforestry in indigenous communities of Chiapas, Mexico. Agroforestry Systems, 78, 39-51. https://doi.org/10.1007/s10457-009-9247-5

Sparks, D.L., Singh, B. and Siebecker, M.G. 2023. The Chemistry of soil acidity. Pp. 381-410, In: Valentino, S. (Ed.). Environmental Soil Chemistry (Third Edition), Katey Birtcher, United States of America.

Subbiah, B.V, and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. Current Science, 25, 259-260. https://doi.org/ 10.12691/aees-2-5-1

Sungthongwises, K. and Taweekij, S. 2019. Soil fertility and diversity of microorganism under rubber plantation. Asian Journal of Plant Sciences, 18(4), 148-152. https://doi.org/10.3923/ajps.2019.148.152.

Suzuki, R., Takeda, S. and Thein, H.M. 2007. Chronosequence changes in soil properties of teak (*Tectona grandis*) plantations in the Bago Mountains, Myanmar. Journal of Tropical Forest Science, 19(4), 207-217. https://www.jstor.org/stable/43595389

Usuga, J.C.L., Toro, J.A.R., Alzate, M.V.R. and Tapias, A.D.J.L. 2010. Estimation of biomass and carbon stocks in plants, soil and forest floor in different tropical forests. Forest Ecology and Management, 260(10), 1906-1913. https://doi.org/10.1016/j.foreco.2010.08.040

Vadivelu, S., Muralidharan, A. and Bandyopadhyay, A.K. 1993. Soils of Lakshadweep Islands. CARI Bulletine, 9,83.

van der Werf, G.R., Randerson, J.T., Giglio, L., Collatz, G.J., Mu, M., Kasibhatla, P.S., Morton, D.C., DeFries, R.S., Jin, Y. and van Leeuwen, T.T. 2010. Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009). Atmospheric Chemistry and Physics, 10, 11707-11735. https://doi.org/10.5194/acp-10-11707-2010.

van Noordwijk, M., Lawson, G., Soumare, A., Groot, J.J.R. and Hairiah, K. 1996. Root distribution of trees and crops: Competition and/or complementarity. In: Black, C.R., Wilson, J. and Ong, C.K. (Eds.). Tree-crop Interactions - A Physiological Approach, CAB International, Wellington, UK.

Vicente-Vicente, J.L., Garcia-Ruiz, R., Francaviglia, R., Aguilera, E. and Smith, P. 2016. Soil carbon sequestration rates under Mediterranean woody crops using recommended management practices: A meta-analysis. Agriculture, Ecosystems and Environment, 235, 204-214. https://doi.org/10.1016/j.agee.2016.10.024

Walkley, A. and Black, A.I. 1934. An examination of the degtjareff method for determining

Wang, B., Liu, G.B., Xue, S. and Zhu, B. 2011. Changes in soil physico-chemical and microbiological properties during natural succession on abandoned farmland in the Loess Plateau. Environmental Earth Sciences, 62(5), 915-925. https://doi.org/ 10.1007/s12665-010-0577-4

Wei, X., Shao, M., Gale, W.J., Zhang, X. and Li, L. 2013. Dynamics of aggregate-associated organic carbon following conversion of forest to cropland. Soil Biology and Biochemistry, 57, 876-883. https://doi.org/ 10.1016/ j.soilbio.2012.10.020

Wu, J., Brookes, P.C. and Jenkinson, D.S. 1993. Formation and destruction of microbial biomass during decomposition of glucose and ryegrass in soil. Soil Biology and Biochemistry, 25 (10), 1435-1441. https://doi.org/10.1016/ 0038-0717(93)90058-J

Yang, Y-Y., Goldsmith, A., Herold, I., Lecha, S. and Toor, G.S. 2020. Assessing soil organic carbon in soils to enhance and track future carbon stocks. Agronomy, 10, 1139. https:/ /doi.org/10.3390/agronomy10081139.

Yasin, S., Junaidi, A., Wahyudi, E., Silvia, H. and Darmawan. 2010. Changes of soil properties on various ages of rubber trees in Dhamasraya, West Sumatra, Indonesia. Journal of Tropical Soils, 15(3), 221-227. http://dx.doi.org/10.5400/ jts.2017.v22i3.175-181

Yihenew, G.S. and Getachew, A. 2013. Effects of different land use systems on selected physicochemical properties of soils in North-western Ethiopia. The Journal of Agricultural Science, 5, 112-120. https://doi.org/ 10.5539/ jas.v5n4p112

Received: 30th November 2023
Accepted: 23rd January 2024