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Soil Organic Carbon Stock in the Sacred Groves of Manipur, NE India

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ABSTRACT

Sacred groves contribute significantly to the storage of organic carbon in biomass and restoration of soil health. We investigated the rate of carbon sequestration in the sacred groves (SGs) of Manipur by analyzing the amount of organic carbon stock in soil under them. Three sacred groves were selected in three districts of Manipur. The study area has a subtropical climate and is dominated by *Schima wallichii* (DC.) Korth. The soil samples were collected using soil corer up to 30 cm depth. The organic carbon density in SG-I ranged from 23.93 kg m⁻² to 18.94 kg m⁻², in SG-II from 28.74 kg m⁻² to 13.96 kg m⁻² and in SG-III from 28.51 kg m⁻² to 11.09 kg m⁻². The total organic carbon stocks of soil in SG-I, SG-II and SG-III were estimated at 6802.48 Mg ha⁻¹, 6892.62 Mg ha⁻¹ and 6321.58 Mg ha⁻¹, respectively. The rate of sequestration of carbon differed due to the variation in physico-chemical characteristics of the soil and steepness of the slope. Species composition also affected the productivity.

Key Words: Biomass; Carbon Density; Carbon Sequestration; Productivity; Soil Organic Matter; Species Composition.

INTRODUCTION

The soil organic carbon is the key important in maintaining the eco-system productivity and health. The soil organic carbon constitutes a major terrestrial pool of carbon in the global carbon cycle system. The total carbon stock in the world's forest eco-system is 652 billion tones in 2010, which out of these 44% ie 292 billion tones carbon remained sink in the soil organic matter (FAO 2002). The amount of organic carbon which remained in (0-30)cm soil layer is twice than the amount of global atmospheric carbon and three time of the global above ground carbon stock (Powlson et al. 2011).

Changes in the SOC largely affected the productivity and global cycle of carbon (IPCC 2000). The quantity and quality of SOC pools are strong determinant of soil quality in terms of biomass productivity and environment moderation capacity (Doran and Parkin 1994. Bendicek 1996). Soil store twice as much carbon as vegetation and two thirds as

much of the atmosphere (Smith 2004). However land use changes, deforestation, and forest degradation have been shown to decrease SOC stocks (Don et al. 2001). In fact it is essential for maintaining quality and quantity of soil properties where it play a vital root in enhancing and sustaining productivity, maintaining hydrological cycle and reducing carbon dioxide from the atmosphere to mitigate global warming. It is also estimated that the total amount of carbon world side are must greater than the carbon pool. The carbon-dioxide is again absorbed by the plant through photosynthesis and much of it accumulated in soil for proper growth and sequester carbon in plants and soil themselves.

About 77% of the total geographical area of Manipur, Meghalaya, and Tripura are under the forest land (FSI 2009). It was found that north-eastern region starts have been experiencing net forest loss during the last few years along with significant scale of forest degradation (Murthy et al. 2013). The sacred groves of the state are generally under the strict socio-cultural and religious beliefs and taboos. It is understood that the

degree of disturbances is usually less in the sacred groves than the non-sacred grove forest of unclassified type. On the other hand the soil organic carbon stock of sacred grove is not well documented. The soil organic carbon stock in the top soil layer is affected by many human activities in a very fast rate such as deforestation which caused disturbance in the carbon pool and increasing admission of GHGs. Therefore the deforestation accounts estimated at 70% of global GHGs emissions (Lal 2002). Thus the global community should have certain process of reducing green house gases and focusing on enhancing of carbon stock of the forest land by conservation and sustainable uses. Thus the soil conservation is indeed in a proper way to enhance productivity and enable to encounter the global warming.

The physico-chemical characteristic of soil is mainly responsible for affecting the organic carbon dynamic of soil (Krishnan et al. 2007). There are 365 sacred groves reported so far (Devi 2000) of which 165 sacred groves are under the total area of 756.42 hectares (Khumbongmayum et al. 2004). The soil found in the sacred groves consists of large amounts of global carbon. Thus, the present study was undertaken to analyze the amount of organic carbon stocks of the soils in the sacred groves of Manipur.

MATERIAL AND METHODS

Manipur is located at 23°80' N and 25°68' N latitudes and 93°03' E and 94°78' E longitudes in the north eastern corner of India and on the Indo-Myanmar hotspot region of the world. The sacred groves of Manipur are small patches of land acts as potential storehouse of carbon which is protected and preserved by the strict socio cultural belief system and social taboos of the places. The three sacred groves were selected in three different districts of Manipur, the SG-I is selected at the Chajinglakpa sacred grove, Imphal West District, SG-II is at the Chaning Lairembi sacred grove, Bishnupur District and SG-III is at the Kalika lairembi sacred grove in Imphal East District. The sacred grove - I is situated at 24°43' N latitude and 93°55' E longitude with an altitude of 797.9 m above the mean sea level, the sacred grove -II is situated at 24°43' N latitude and 93°50' E longitude with 802.8 m above the mean sea level and the Sacred grove - III is located at 24°51' N latitude and 94°04' E longitude with an elevation of 808.9 m above the mean sea level. Soil sampling for analysis was conducted for a period of one year from April 2013 to March 2014.

Five permanent plots measuring 20x20 m was laid out randomly and soil were collected in triplicate within each of the quadrat by using a soil corer of 8.5 x 8.5 x10 cm. Soil samples were collected from the last week to first week of every month from all the study sites at a depth of (0-10)cm, (10-20)cm, (20-30)cm respectively. The collected soil was taken for analysis of bulk density and soil moisture content by using gravimetric method. Soil pH was measured by using Cyberscan 510^{pH} in 1:5 of soil water suspension. Soil Texture was analyzed by following International Pipette Method. Air dried and sieve soil at 2mm pore size was used in the analysis of soil organic carbon content by calorimetric method as given by Anderson and Ingram (1956). Soil Organic Carbon stock was calculated using the equation given by Joao Carlos et al. (2008).

Statistical Calculation

Multiple linear regression between the physico-chemical characteristics of soil like bulk density, soil texture, soil pH, soil moisture, temperature etc. and % soil organic carbon stock was analysed using Origin Pro 8.5 version and statistical range graph were also made using the same software package. The regression equation used in determining the degree of relationship in the variance pattern between observed variables were:

$$Y = A_0 + A_1 \times X_1 + A_2 \times X_2 + A_3 \times X_3$$

where, Y= SOC % for each soil layer; $A_0 = 0.5$, A_1 - A_3 = slope, X_1 =response variable in 0-10 cm, X_2 = response variable in 10-20 cm and X_3 = response variable in 20-30 cm soil layer.

RESULTS

The soil organic carbon (SOC %) ranges from 1.48± 0.01 % to 2.27 ± 0.01 % in SG-I, 1.28 ± 0.02 % to 2.26 ± 0.01 % in SG-II and 0.82 ± 0.03 % to 2.21 ± 0.02 % in SG-III (Figure 1) across the studied groves. Soil organic carbon stock (SOCs) ranges from 18.94 ± 0.18 kg m⁻² to 23.93 ± 0.13 kg m⁻² in SG-I, 13.96 ± 0.24 kg m⁻² to 28.74 ± 0.17 kg m⁻² in SG-II and 11.09 ± 0.53 kg m⁻² to 28.51 ± 0.26 Kg m⁻² in SG-III (Figure 2). SOC % and SOCs were found maximum during summer- rainy period shows the active transformation into SOC occurred during warm moist season and decrease with depth in all the studied groves. The annual total SOCs

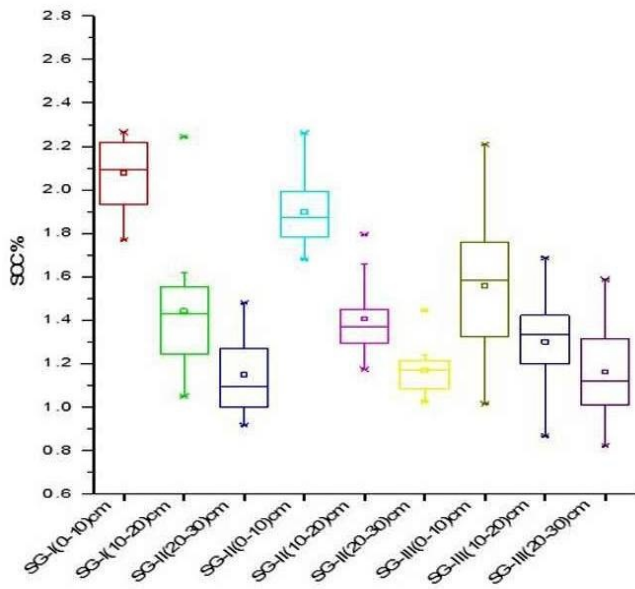


Figure 1. Soil Organic Carbon % in 0-10 cm, 10-20 cm and 20-30 cm soil layers of three sacred groves (SG-I, SG-II and SG-III) during 2013-2014.

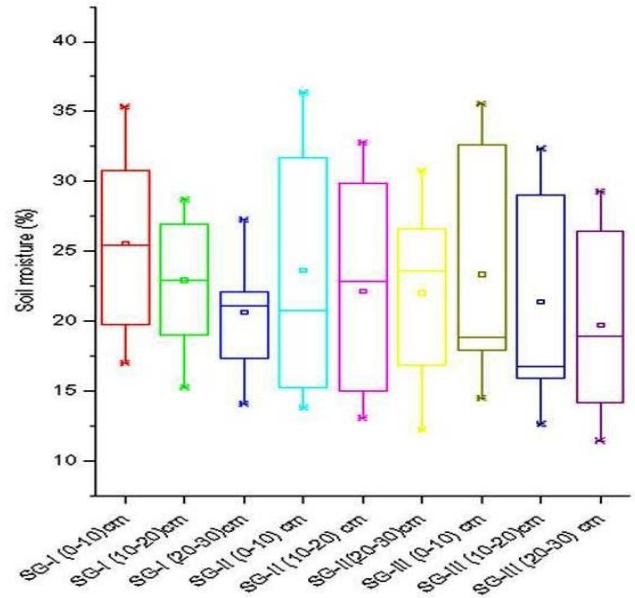


Figure 3. Soil moisture in three soil layers of SG-I,SG-II and SG-III during 2013- 2014

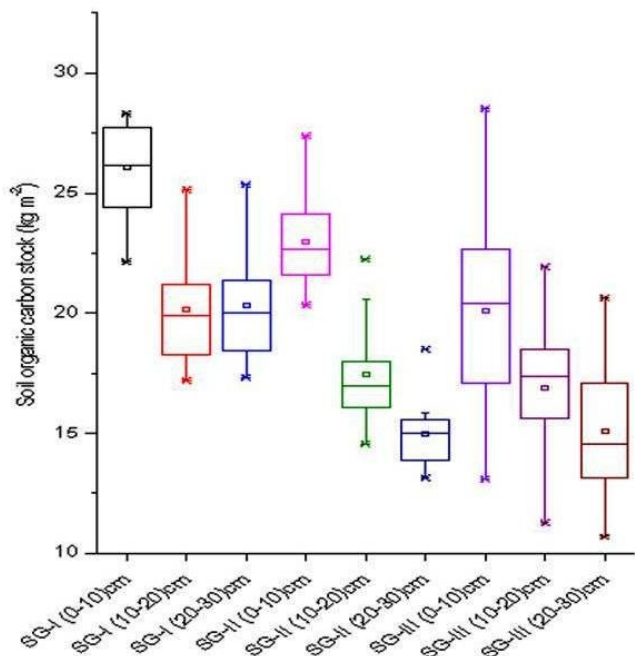


Figure 2. Total Carbon Stock (Mg ha⁻¹) of SG-I,SG-II and SG-III during 2013- 2014

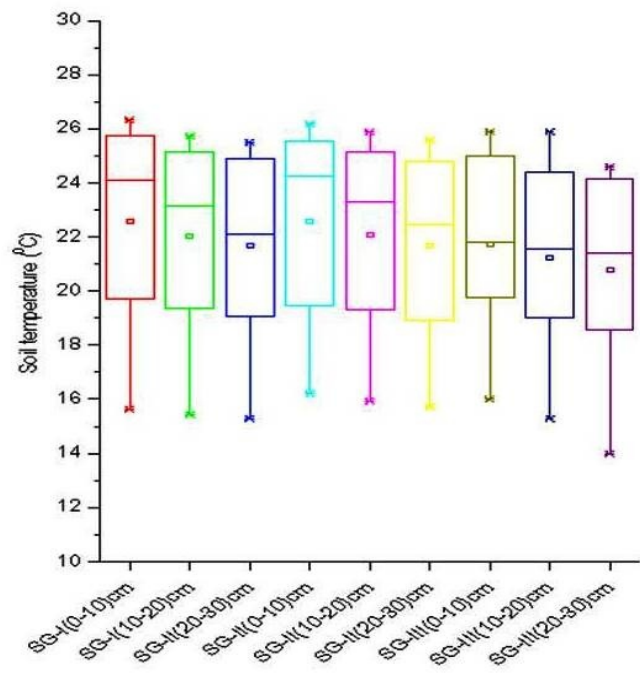


Figure 4. Soil temperature of different soil layers of SG-I,SG-II and SG-III during 2013- 2014.

were 6802.48 Mg ha⁻¹, 6892.62 Mg ha⁻¹, 6321.58 Mg ha⁻¹ in SG-I, SG-II, SG-III in 0-30 cm soil depth respectively.

Soil moisture content ranges from 14.10 ± 0.28 % to 31.45 ± 1.65 % in SG-I, 12.22 ± 0.73 % to 36.37 ± 0.80 % in SG-II and 11.44 ± 0.50 % to 35.57 ± 0.95 %

in SG-III (Figure 3). Soil temperature varies from 13.26 ± 0.24 °C to 26.32 ± 0.21 °C, 16.46 ± 0.54 °C to 26.18 ± 0.10 °C to 14.00 ± 0.01 °C to 25.90 ± 0.02 °C in SG-I, SG-II, SG-III respectively (Figure 4). Soil moisture and soil temperature in all the study groves were high during

warm moist summer-rainy season and reduces as winter approached due to low rainfall and temperature. Soil pH varies from 4.37 ± 0.01 to 5.77 ± 0.01 (Figure 5), mean surface temperature varies from 15.16 ± 0.24 °C to 30.28 ± 0.40 °C (Figure 6) and soil bulk density ranges from 1.21 ± 0.04 g cm⁻³ to 1.30 ± 0.01 g cm⁻³ (Figure 7) across the studied groves. The composition of sand, silt and clay ranged from $71.5 \pm 1.63\%$ to $77.85 \pm 1.87\%$, $15.34 \pm 0.97\%$ to $24.02 \pm 0.13\%$, $4.01 \pm 0.92\%$ to $6.45 \pm 0.76\%$, respectively (Figure 8).

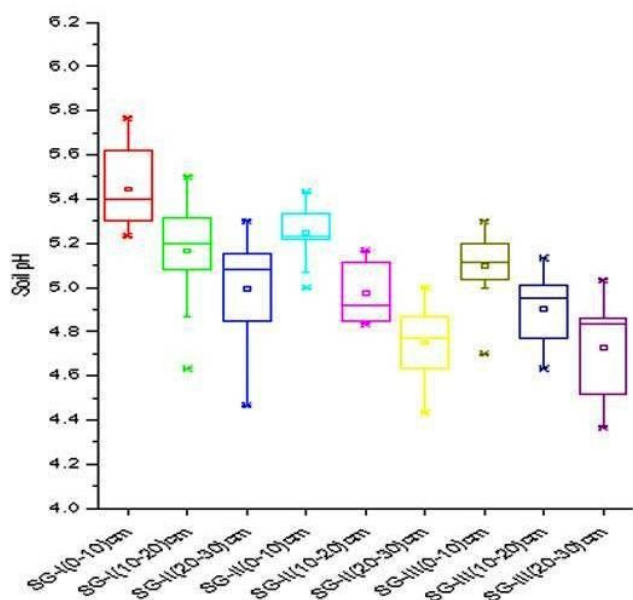


Figure 5. Soil pH of three soil layers of SG-I,SG-II and SG-III during 2013- 2014.

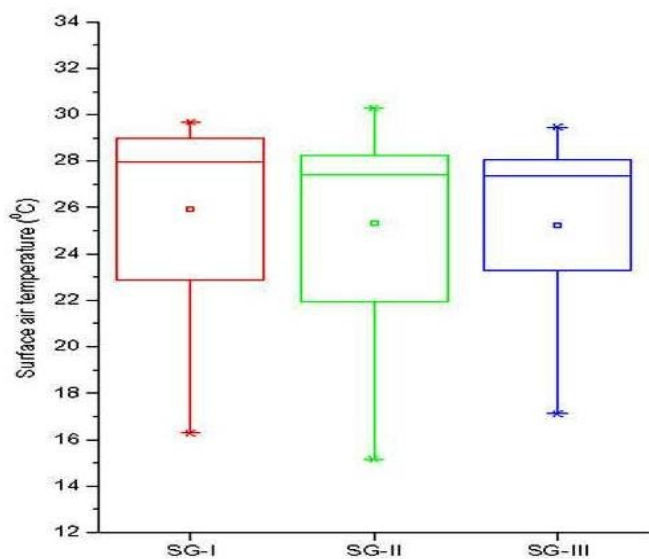


Figure 6. Surface air temperature at ground level in SG-I,SG-II and SG-III during 2013- 2014

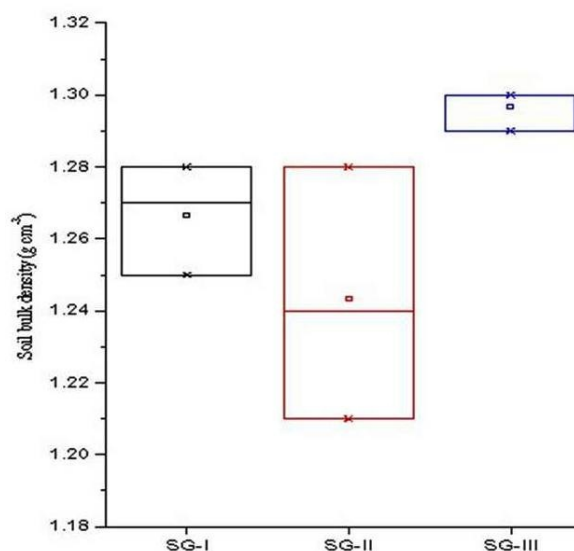


Figure 7. Bulk density of soil at three depths in SG-I,SG-II and SG-III during 2013- 2014

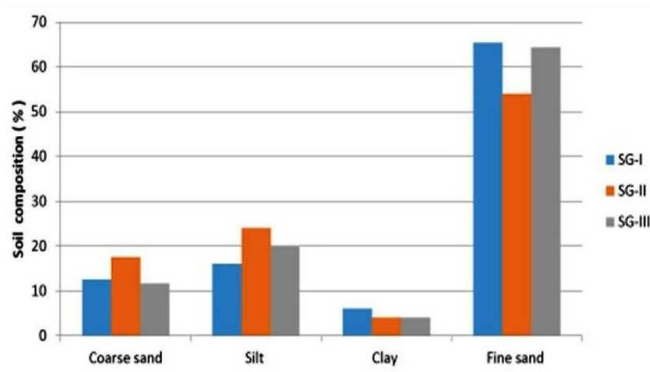


Figure 8. Soil texture showing % of clay, silt, sand in three sacred groves.

Multiple linear regression analysis between SOC % and soil moisture, soil temperature, soil pH of each soil layer for each sacred grove are presented in Tables 1-3. In all the studied groves, SOC % in 0-10 cm soil depth and soil moisture, soil temperature, pH surface air temperature of each consecutive soil layer of 10-30 cm depth show significant correlation ($P < 0.001$). Similar observation were made for SOC at 10-20 cm and 20-30 cm soil depth. The F value of soil moisture with SOC % were found to be as 177.31, 142.20, 43.98 in 0-10 cm, 108.07, 99.03, 48.61 in 10-20 cm and 175.08, 152.33, 49.28 in 20-30 cm soil depth. The F value of SOC and soil temperature were observed as 166.67, 237.76, 75.90

Table 1. Multiple linear regression showing intercept, coefficients with standard error and R^2 of Sacred Grove I. Intercept fixed at 0.5; Y= SOC % in different Soil layer: A₁= Co efficient between % Carbon and variable taken in 0-10 cm soil layer, A₂= Co efficient between % Carbon and variable taken in 10-20 cm soil layer. A₃= Co efficient between % Carbon and variable taken in 20-30 cm soil layer.

Parameters	Y (SOC %)	A ₁ (0-10) cm	A ₂ (10-20) cm	A ₃ (20-30) cm	R ²
Soil Moisture (%)	0-10 cm	0.02± 0.04	0.02 ±0.06	0.02 ±0.05	0.97
	10-20 cm	-0.05 ± 0±	0.05 ± 0.05	0.04 ± 0.05	0.96
	20-30 cm	-0.04 ± 0.02	0.03 ± 0.03	0.05 ± 0.03	0.97
Soil Temperature (°C)	0-10 cm	-0.38 ± 0.45	0.78 ± 0.79	-0.33 ± 0.35	0.97
	10-20 cm	-0.36 ± 0.43	1.04 ± 0.75	-0.64 ± 0.34	0.95
	20-30 cm	0.07± 0.34	0.07 ± 0.60	-0.12 ± 0.27	0.95
Soil pH	0-10 cm	0.30 ± 0.41	0.07 ± 0.91	-0.09 ± 0.74	0.99
	10-20 cm	0.80 ± 0.59	1.23 ± 1.30	-1.96 ± 1.07	0.96
	20-30 cm	0.61 ± 0.44	-0.04 ± 0.98	-0.49 ± 0.81	0.96

Table 2. Multiple linear regression showing intercept, coefficients with standard error and R^2 of Sacred Grove II. Intercept fixed at 0.5; Y= SOC % in different Soil layer: A₁= Co efficient between % Carbon and variable taken in 0-10 cm soil layer, A₂= Co efficient between % Carbon and variable taken in 10-20 cm soil layer. A₃= Co efficient between % Carbon and variable taken in 20-30 cm soil layer.

Parameters	Y (SOC %)	A ₁ (0-10) cm	A ₂ (10-20) cm	A ₃ (20-30) cm	R ²
Soil Moisture (%)	0-10 cm	-0.09 ± 0.05	0.13 ± 0.07	0.03 ± 0.02	0.97
	10-20 cm	-0.07 ± 0.05	0.09 ± 0.06	0.01 ± 0.01	0.96
	20-30 cm	-0.05 ± 0.03	0.06 ± 0.04	0.01 ± 0.01	0.97
Soil Temperature (°C)	0-10 cm	-0.08 ± 0.33	0.14 ± 0.59	-0.01 ± 0.27	0.98
	10-20 cm	0.14 ± 0.28	-0.24 ± 0.51	0.13 ± 0.24	0.97
	20-30 cm	0.23 ± 0.19	-0.37 ± 0.35	0.16 ± 0.16	0.98
Soil pH	0-10 cm	0.74 ± 0.27	-0.166 ± 0.65	1.21 ± 0.54	0.99
	10-20 cm	0.49 ± 0.37	-0.99 ± 0.89	0.68 ± 0.73	0.98
	20-30 cm	0.16 ± 0.26	0.14 ± 0.61	-0.19 ± 0.50	0.98

Table 3. Multiple linear regression showing intercept, coefficients with standard error and R² of Sacred Grove III. Intercept fixed at 0.5; Y= SOC % in different Soil layer: A₁= Co efficient between % Carbon and variable taken in 0-10 cm soil layer, A₂= Co efficient between % Carbon and variable taken in 10-20 cm soil layer. A₃= Co efficient between % Carbon and variable taken in 20-30 cm soil layer.

Parameters	Y (SOC %)	A ₁ (0-10) cm	A ₂ (10-20) cm	A ₃ (20-30) cm	Adj. R ²
Soil Moisture (%)	0-10 cm	0.07 ± 0.14	-0.11 ± 0.18	0.08 ± 0.07	0.92
	10-20 cm	0.02 ± 0.11	-0.02 ± 0.14	0.03 ± 0.05	0.93
	20-30 cm	0.01 ± 0.10	-0.02 ± 0.13	0.03 ± 0.05	0.92
Soil Temperature (°C)	0-10 cm	0.11 ± 0.26	-0.07 ± 0.35	0.01 ± 0.22	0.95
	10-20 cm	0.26 ± 0.20	-0.13 ± 0.26	-0.10 ± 0.17	0.96
	20-30 cm	0.30 ± 0.18	-0.21 ± 0.24	-0.06 ± 0.15	0.95
Soil pH	0-10 cm	0.57 ± 1.03	-1.99 ± 1.85	1.66 ± 1.58	0.95
	10-20 cm	0.57 ± 0.82	-1.31 ± 1.57	0.90 ± 1.25	0.96
	20-30 cm	0.43 ± 0.76	-0.64 ± 1.37	1.36 ± 1.17	0.95

Table 4. Multiple linear regression indicating coefficient with standard error and R² between SOC% and surface air temperature in the studied groves.

Grove	SOC in soil layer	AT	R ²	Texture	R ²
SG-I	0-10 cm	0.059 ± 0.003	0.974	0.629 ± 0.301	0.422
	10-20 cm	0.346 ± 0.004	0.926	0.227 ± 0.008	0.826
	20-30 cm	0.024 ± 0.002	0.954	0.013 ± 0.008	0.74
SG-II	0-10 cm	0.054 ± 0.002	0.9836	0.041 ± 0.013	0.7989
	10-20 cm	0.034 ± 0.002	0.977	0.023 ± 0.009	0.777
	20-30 cm	0.025 ± 0.001	0.9842	0.016 ± 0.006	0.8618
SG-III	0-10 cm	0.040 ± 0.004	0.9591	0.023 ± 0.011	0.7406
	10-20 cm	0.030 ± 0.003	0.9535	0.018 ± 0.008	0.7701
	20-30 cm	0.025 ± 0.003	0.9521	0.013 ± 0.007	0.7653

Table 5. Multiple linear regression indicating coefficients along standard error and R² between SOC% with Bulk density (BD) in different soil layers in the studied groves.

Grove	SOC% in soil layer	BD of soil layer	Co efficient	R ²
SG-I	0-10 cm	0-10 cm	1.265 ± 0.038	0.994
	10-20 cm	10-20 cm	0.711 ± 0.066	0.957
	20-30 cm	20-30 cm	0.504 ± 0.043	0.972
SG-II	0-10 cm	0-10 cm	1.099 ± 0.036	0.993
	10-20 cm	10-20 cm	0.778 ± 0.04	0.985
	20-30 cm	20-30 cm	0.491 ± 0.023	0.991
SG-III	0-10 cm	0-10 cm	0.529 ± 0.955	0.955
	10-20 cm	10-20 cm	0.429 ± 0.041	0.963
	20-30 cm	20-30 cm	0.377 ± 0.042	0.957

in 0-10 cm soil, 90.47, 171.33, 94.12 in 10-20 cm soil and 88.72, 249.54, 88.53 in 20-30 cm soil depth. The F values of SOC% with soil pH were 468.01, 800.23, 81.12 in 0-10 cm, 111.06, 237.18, 91.34 in 10-20 cm and 121.23, 343.07, 84.28 in 20-30 cm soil depth in SG-I, SG-II, SG-III respectively. It explained the variability existed among response variable between the studied sacred groves. The variability explained by F at P>0.0001 significance level from intercept model fitting analysis reveal the strong relationship with response variables. Slope of all the response variable was found below 1 which suggests the magnitude of change is slow and negative value reveals inverse relationship between the variables. The correlation between SOC % and soil bulk density, soil texture, surface air temperature are also presented in Tables 4 and 5.

DISCUSSION

SOC stock in the present investigation was consistent with Himalayan hill slope which is in the range of 13.5 kg m⁻² to 34.7 kg m⁻² (Martin et al. 2000), greater than the plateau of China that stores 2.64 kg C m⁻² to 4.57 kg C m⁻² (Bell and Worrel 2009), and comparable with 11.39 kg m⁻² to 15.36 kg m⁻² of carbon stock in Hawaii Island (Townsend et al. 1995). In the present investigation more than 50% of the SOC was confined in the upper soil layer. Similar results were reported by Singh et.al. (2011) where 69 % of SOC was confined in the upper 40 cm soil layer. The SOC in the studied areas might have been due to optimum conditions for transformation from plants debris and litter, roots through the action of microorganisms. Higher carbon content was

observed in 0-10 cm soil layer in all the Sacred grove studied and it decreased with depth. This may be due to abundant vegetation cover, litter and this promotes the luxurious growth of microorganism and its peak activity in the decomposition process results into higher accumulation of organic carbon in the uppermost soil layer. The rate of decomposition also depends on the species composition. In SG-II and SG-III the groves are dominated by the species belonging to Fagaceae while SG-I is dominated by Theaceae and it is a mixed forest characterized by rapid decomposition of litter which suggests the effect in the variability of distribution patterns of SOC in the soil layers. The effect of vegetation on SOC content and its vertical distribution was studied by Jobbagy et al. (2000) who agrees with the current finding of SOC content in sandy soils. The decrease in SOC stock with the decrease of soil depth could be due to soil structure. The leaching is faster in the sandy soil in SG-II whereas it is slower in sandy loam soil found in SG-I. The highest accumulation of SOC in SG-II is due to rapid leaching process to the successive soil layers. The SG-II has highest SOC comparable with other SGs studied. It may be due to high % of sand and it helps in the faster leaching rate of SOC. The rate of decomposition of litter and accumulation of SOC in 0-10 cm in SG-I is faster than other SGs studied; however, the leaching rate is slower than in SG-II. The SG-III has lowest SOC because it was steeper than SG-I and SG-II. Organic carbon associated with sand particles was readily decomposable as compared with silt and clay (Singh et al. 2007); however, higher clay content enhanced the storage capacity of SOC (Jobbagy et al. 2000). The steepness of the slope also affected the leaching action. The steeper the slope, drain off to the surrounding ecosystem is faster and vice versa. The position and aspect of slope also play an inevitable role in SOC sequestration (Awasthi 2004). In the catchment of all the SGs studied, there is high amount of organic matter and organic carbon during the pre- and post-harvest season (data not shown). This shows that the nutrients are drained off to the catchment area.

Regression analysis of Carbon % in the three soil layers of three sacred groves with soil moisture, soil temperature and soil pH shows significant correlation (Tables 1-3) and analysis of soil texture and ground air temperature with SOC% of different soil layers (Table 4) reveals that SOC content in different sacred groves was influenced by the prevailing abiotic factors (Chhabra et al. 2003, Chaudhary et al. 2013). The soil texture plays an important role in the soil SOC storage in the lowland

forest ecosystem (Silver et al. 2000) that is concomitant with the present investigation as it shows strong correlation with SOC content. The stabilization of SOCs in the studied grove may be due to formation of clay or silt organo mineral complex (Post and Kwon 2000). The effect of texture on SOC storage is related to its impact on ability of soils to retain SOC, water, and nutrients and on soil air permeability for gaseous exchange. The soil texture alters the biogeochemical cycling of important elements and H₂O (Lal 2003). The difference in the bulk density brings about differences in the organic carbon stock (Dieleman et al. 2013). Greater organic matter is associated with greater microbial activity and it is higher with higher pH (Jones et al. 2005). Soil moisture, pH and temperature help in the transformation and decomposition of SOC from the organic debris as factors though soil temperature mainly responsible for increase rate of transformation and decomposition in humid climate (Jobbagy et al. 2000) and soil bulk density, texture help in the accumulation and stabilization SOC content and reduction in soil moisture content limit the downward movement of SOC (Lee et al. 2004) in the studied sacred groves of Manipur.

Forest ecosystem have the highest organic C stocks as compared with other ecosystem (Liski et al. 2002), possibly because of higher leaf litter and extensive root system of forest trees as well as less perturbation followed in the studied sacred groves. Therefore, the maintenance of vegetation cover with a deep root system is important for providing a permanent input of organic matter into deep soil layers (Sommer et al. 2000). There are also differences in socioeconomic, cultural and the human dimensional factors. The structural organization of soil is an important factor in determining a favourable environment for plant growth in terms of temperature, oxygen, moisture, nutrient supply, rapid and uniform germination of seeds and ease of root penetration. The small changes in soil organic carbon stock can influence global the carbon cycle and affected the flora and fauna of the ecosystem (IPCC 2000). The proper management of SOC is central for sustainable land management because soil organic matter influences numerous soil properties relevant to ecosystem functioning and in mitigation of global climate change (Bezdicsek et al. 1996). The unclassified forest cover up of India including sacred grove forests which distributed in small to large scale patches of land cover in the Indian region with less disturbance could ameliorate the impact of climate and act as carbon sink.

CONCLUSION

The Soil Carbon stock is naturally high in all the sacred groves of Manipur and act as potential storehouse of carbon. The rate of carbon sequestration and stock are valuable in Sacred Groves with undisturbed vegetation. They are strictly associated with traditionally strict social beliefs and taboos which become sole and reliable factors for storage of SOC. Enhancement of productivity is, in fact, assisted by soil organic carbon and maintenance of ecosystem health. Thus the conservation and proper management of sacred grove should be promoted by avoiding overgrazing, stubble burning, removal of vegetation cover etc. Encouragement of conversion of non woody sacred groves into woody areas through plantation forestry should be practiced. Further study of SOC dynamics and its role is needed in the context of climate change.

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