ISSN (Online): 2349-1183; ISSN (Print): 2349-9265
TROPICAL PLANT RESEARCH
The Journal of the Society for Tropical Plant Research
7(3): 702–714, 2020
DOI: 10.22271/tpr.2020.v7.i3.089

Research article

Altitudinal variation of soil organic carbon stock in tropical forest of Courtallam hills, Southern Western Ghats of India

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Abstract: The climate change and carbon mitigation through forest ecosystems play an important role in the global perspective. Soil is a huge carbon reservoir and its storage capacity varied greatly with forest type and altitude. The mountain ecosystem varies in soil organic carbon stock (SOC) due to variations in soil types, climatic conditions, vegetation patterns and elevational gradients. Soil organic carbon stockswere measured at three depths (0–10, 10–20, and 20–30 cm) in five different forest elevation (200, 400, 600, 800, and 1000 m asl) on Courtallam hills, Southern Western Ghats, India. SOC stocks increased significantly with the increase in altitude ($P<0.05$) at all the three layers (0–10, 10–20 and 20–30 cm). A total of SOC stocks ranged from 42.79 mg ha^{-1} at 0–30 cm depth were observed in lower altitude (200 m) and the highest value of 50.25 mg ha^{-1} at 0–30 cm depth was observed in mid-elevation 600 m, while in other elevational showed 46.45, 48.49 and 45.05 mg ha^{-1} in 400, 800 and 1000 m respectively. SOC ranged from 17.89 to 22.37 mg ha^{-1} in soil surface layer (0–10 cm), 14.00 to 16.573 mg ha^{-1} in middle layer (10–20 cm) and 9.08 to 11.35 mg ha^{-1} in the bottom layer (20–30 cm). These results would also enhance our ability to assesses the role of these forest types in soil carbon sequestration and for developing and validating the SOC models for tropical forest ecosystems.

Keywords: Soil organic carbon -Courtallam hills - Altitudinal variation - carbon storage - Southern Western Ghats.

[Cite as: Pandian E & Ravichandran P (2020) Altitudinal variation of soil organic carbon stock in tropical forest of Courtallam hills, Southern Western Ghats of India. *Tropical Plant Research* 7(3): 702–714]

INTRODUCTION

It is obvious that soil is important for all living organisms in the terrestrial ecosystem and soil is the huge reservoir of organic carbon and plays an important role in the global carbon cycle (Gebrehiwot *et al.* 2018). Accumulates of soils carbon four times higher than vegetation and thrice than the atmosphere (Jobbagy & Jackson 2000, Lal 2004a). A small change in soil carbon consequently large changes occur in atmospheric concentration (Raich & Schlesinger 1992, IPCC 2000). Carbon contribution is about 32% in soil and 56% in the vegetation of tropical forests (Pan *et al.* 2011). Tropical forest soils are exchanging higher carbon with atmosphere than terrestrial ecosystem (Raich & Schlesinger 1992, Beer *et al.* 2010, Amundson *et al.* 2015). The carbon loss was estimated 1.6±0.8 Pg C $year^{-1}$, mainly in the tropics (Smith 2008). Moreover, Crowther *et al.* (2016) evaluated that carbon stock loss from the upper soil horizon is estimated 55±50 Pg by 2050, which is about 17% of the predictable anthropogenic emissions over this period (Ballantyne *et al.* 2015), and the concentration of SOC is used as an indicator of soil productivity and quality (Waring *et al.* 2014). The concentration of carbon dioxide (CO^2) in the atmosphere has increased from approximately 277 ppm (Joos & Spahni 2008) to 406.42 ppm (NOAA 2017), consequently increasing global warming and forest ecosystems play an important role in the climate change and mitigation of CO_2 from the atmosphere (Pandian & Parthasarathy 2016a, Pandian & Parthasarathy 2017, Gandhi & Sundarapandian 2017).

SOC estimated on a global level and have got the values of 699 Pg C in the top layer of 30 cm and 1417 Pg C for 1 m depth of the soil profile (Hiederer & Kochy 2012). SOC is evaluated to be more than 2000 Pg of carbon in the upper layer (100 cm) of soil depth (Batjes 1996) which is by far greater than the cumulative soil organic carbon stock of the atmosphere and vegetation (Lal 2004b). In the top layer of 100 cm of the soil profile,

Received: 20 August 2020 Published online: 31 December 2020
https://doi.org/10.22271/tpr.2020.v7.i3.089

nearly 50% of SOC are locked up in top layer of 30 cm (Batjes 1996, Hiederer 2009, Wang *et al.* 2014). SOC accumulation rate on the top soil (0–30 cm) ranged from 11.5 to 43.2 gm^2 yr^{-1}, of which 70–90 % accumulation was in 0–15 cm (Boutton *et al.* 2009). The top layer of 0–30 cm soil profile is more dynamic and plays an important role in the carbon cycle due to the input of organic matter and associated surface fine root dynamics, which is susceptible to human activities and natural processes. SOC storage in the soil surface of forests is larger due to the rate of low decomposition of forest floor litter. Therefore, assessment of SOC up to 30 cm of depth is of enormous importance. For example, decreasing temperatures with increasing elevation in the Sierra Nevada of California have been showed to limit SOC turnover, consequential in increased SOC accumulation at higher altitude (Trumbore *et al.* 1996). In general, several studies have been reported on the SOC stock in different forest types of India and elsewhere (Ravindranath *et al.* 1997, Chhabra *et al.* 2003, Jobbagy & Jackson 2000, Lal 2004a, 2004b, Ramachandran *et al.* 2007, Neumann-Cosel *et al.* 2011, Sheikh *et al.* 2011, Throop *et al.* 2012, Sundarapandian *et al.* 2013, Tsui *et al.* 2013, Venkanna *et al.* 2014, Gray *et al.* 2015, Santos *et al.* 2015, Gurmessa *et al.* 2016, Paz *et al.* 2016, Subashree *et al.* 2019). Yet, some tropical forests still remain unexplored. The literature survey showed that a study on soil organic carbon stock assessment in the tropical forest of Western Ghats is very limited and in particular, published information on the tropical forest of the Courtallam hills, is not available. A better understanding of carbon stocking potential in different forest ecosystems in the Western Ghats is essential in the current scenario. Therefore, the present study has been undertaken to estimate the SOC stocks in the tropical forest ecosystem of Courtallam hills along altitudinal gradient.

MATERIALS AND METHODS

Study area

The present research work was conducted in Courtallam hills of southern Western Ghats in Tirunelveli district of Tamil Nadu, India lies between 08.90211 N, 77.29772 E and 08.91093 N, 77.25842 E (Fig. 1). Elevation range is around 200 m to 1500 m. A total area of Courtallam hills is around 3963 ha and has a diverse geographical and physical features such as hills and low plains, thorn-scrub jungles, rivers and cascades and thick inland forest. The mean daily maximum temperature is 30°C. The weather is quite hot in May and June, and the maximum temperature sometime reaches 39°C. This region enjoys winter (December to March), summer (April to June), Southwest monsoon (June to September) and Northeast monsoon (October to November). The month of November generally receives maximum rainfall. The annual precipitation ranges from 801 mm to 1000 mm. Moreover, Courtallam hills are famous tourist spot where various anthropogenic activities such as forest encroachment for expansion of temple structures, The Western Ghats experience heavy anthropogenic pressures due to visit of tourists illegally the forest area for bathing, forest resource removal (fodder, firewood, medicinal plants, timber, etc.) and the impact of temple visitors by way of cooking inside the forest during festive occasions and solid waste dumping (polythene, glass bottles). The vegetation in this region is mainly dry deciduous and deciduous forests. Nevertheless, evergreen and semi-evergreen forests are also present in the high altitudes. The soil colour was mostly light brown or black colour throughout the study area and soil texture was sandy loam in most of the forest plots while the plots near to the rivulet were sandier than the other study plots.

Methods

Soil samples were collected from all the five 1-ha plots (100 m × 100 m) along the elevational gradient by using soil core sampler (cylindrical corer of diameter 3.5 cm) from November 2017 to February 2018. Dominant tree species for each elevation: *Aglaia elaeagnoidea* (A. Juss.) Benth. (100–200 m); *Glycosmis pentaphylla* (Retz.) DC. (200–400 m); *Dimocarpus longan* Lour. (400–600 m); *Schleichera oleosa* (Lour.) Oken (600–800 m); and *Xanthophyllum flavescens* Roxb. (800–1000 m). From each plot, 10 soil samples were randomly collected at three different depths *viz.*, 0–10 cm, 10–20 cm, and 20–30 cm. A total of three composite samples in each plot were prepared by mixing three sets together each for further analysis. Soil samples were first air-dried and sieved through a 2 mm mesh. For organic C estimation, Walkley and Black's method (Walkley 1947) was used, which is a widely used procedure (Pearson *et al.* 2005). In Walkley and Black's method, about 60–86% of soil organic carbon (SOC) is oxidized; therefore, a highly recommended standard correction factor of 1.58 was used to obtain the corrected SOC values (de Vos *et al.* 2007, Latte *et al.* 2013). Totally ten undisturbed soil samples were collected from each plot from three depths for measuring the soil pH and soil moisture (five samples each), these five samples were airdried and sieved through 2 mm sieve for measuring pH of soil was measured through pH meter (Elico LI 615) in a 1:2 (w/v) soil-water ratio. A set of five, fresh soil samples were collected from which gravel, small stones and coarse roots are separate by passing through a 2 mm sieve and measured fresh weight in the field itself and the samples were brought to the laboratory. That soil samples were kept in an oven at 105±5°C for 72 h and then re-weighed. Soil moisture content was determined from the difference of initial and final readings.

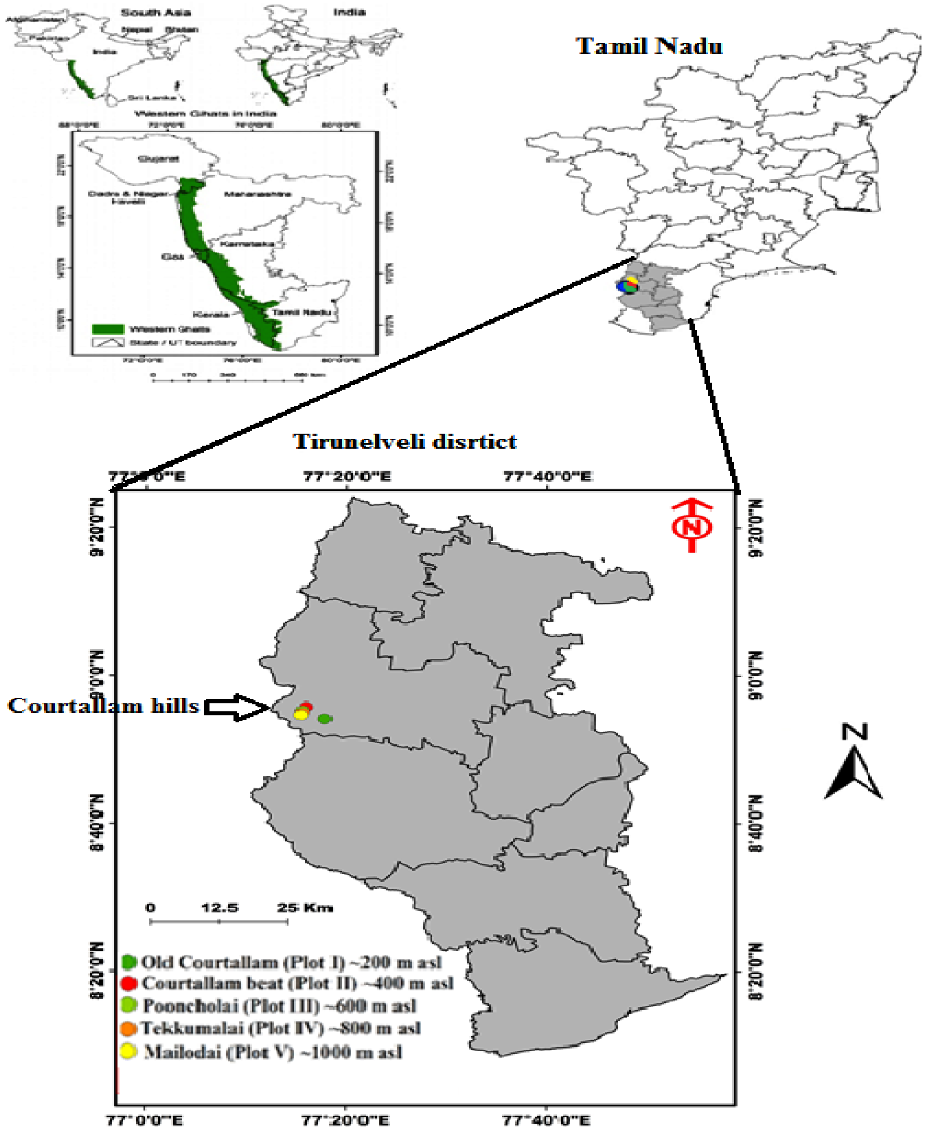

Figure 1. Map showing the location of study plotsalong the elevation gradients on the Courtallam hills of southern western Ghats of India.

A total of ten soil samples were collected from each plot from tree depths for measuring bulk density. While taking these cores which was taken to avoid any loss of soil from these samples. The soil samples were weighed, and kept in an oven-dried at 105±5°C for 72 h and then re-weighed. The coarse fragments were removed by sieving and then the samples were weighed. Soil bulk density and SOC stocks were calculated using the formulae of Pearson, Walker, and Brown (2005):

$$\text{Bulk density } (\text{g m}^{-3}) = \frac{\text{Oven dry mass } (\text{g m}^{-3})}{\text{Core volume } (\text{m}^{3}) - \left[\dfrac{\text{Mass of coarse fragments (g)}}{2.65\ (\text{g m}^{-3})}\right]}$$

Where, 2.65 was taken as a constant for the density of rock fragments (g cm^{-3})

Total carbon content of 0–30 cm depth was finally assessed by summing up the carbon content of all three surface layers. The total SOC was quantified by following Pearson *et al.* (2005):

$$\text{SOC } (\text{mg ha}^{-1}) = [(\text{Soil bulk density } (\text{g m}^{-3}) \times \text{Soil depth (cm)} \times \text{C}] \times 100$$

Statistical analysis

One-way ANOVA was used to evaluate the differences among SOC stocks by altitude. The relationship between SOC stocks and altitude was examined with linear regression and the relationship between SOC concentration and bulk density was also examined with linear regression using Microsoft Excel.

RESULT AND DISCUSSION

Soil moisture and pH values showed a variation along the elevational gradients. Our results showed that soil pH is slightly acidic (pH ranged 6.2 to 6.9 in five 1-ha plots; Fig. 2) along the elevational gradient, this similar findings are documented in the recreational and natural forest in West Bengal (pH range 5.90 to 7.01; Jana *et al.* 2010). However, this present study values are greater than the tropical dry deciduous forest in West Bengal (pH range 4.3 to 4.94; Joshi 2012), moist tropical forest of Sunsari district, Nepal (pH range 5.6 to 6.6; Gautam & Mandal 2013), tropical forest stands in Malla wildlife sanctuary, Sri Lanka (pH range 5.78 to 6.19; Kuruppuarachchi *et al.* 2016) and the tropical dry deciduous forest Sathanur reserve forest, India (pH range 5.9 to 7.1; Gandhi & Sundarapandian 2017). Generally, tropical forest soils are an acidic range due to the organic acid formation from the moderately decomposed organic matter on the upper layers of soil profile (Brouwer & Riezebos 1998). Moreover, the acidic pH could be possibly due to the presence of acidic exudates (Shen *et al.* 2001).

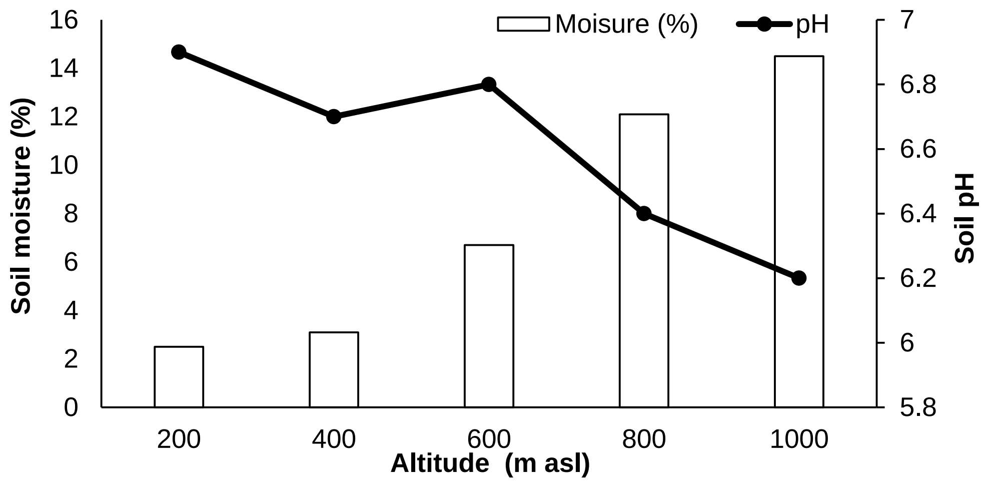

Figure 2. Mean soil moisture and soil pH along the elevational gradient in tropical forest of Courtallam hills, Southern Western Ghats of India.

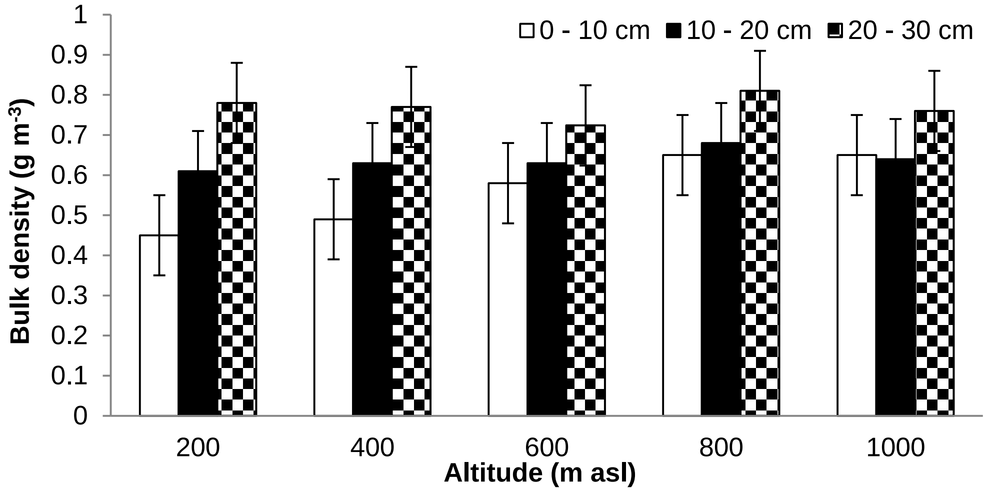

Figure 3. Bulk density of soil (mean±SE) in three different depths in tropical forest along the elevation gradients on the Courtallam hills, Southern Western Ghats of India.

The soil bulk density in five 1-ha plots varied along the elevational gradient of the tropical forest (Fig. 3). A significantly ($P<0.05$) increasing trend was observed in soil bulk density with increasing soil depth in all the study plots (200, 400, 600, 800, 1000 m asl). Soil bulk density ranged from 0.45 to 0.62 gm^{-3} in the surface layer (0–10 cm), 0.63 to 0.69 gm^{-3} in the middle layer (10–20 cm) and 0.78 to 0.83 gm^{-3} in the bottom layer (20–30 cm). The mean bulk density differ from 0.61 to 0.72 gm^{-3} with a mean value of 0.65±0.047 gm^{-3} in Courtallam hills along the elevational gradient and this values are compared with tropical forest reports: dry tropical forest in Jharkhand (1.852 to 1.259 g cm^{-3}; Kujur & Patel 2012), tropical dry deciduous forest Sathanur reserve forest, India (1.21 to 1.82 gm^{-3}; Gandhi & Sundarapandian 2017), in tropical forests of Kanyakumari Wildlife Sanctuary, Western Ghats, India (1.32 to 1.59 gm^{-3}; Subashree *et al.* 2019) and Achanakmar-Amarkantak Biosphere Reserve of Chhattisgarh (1.02 to 1.19 g cm^{-3}; Iqbal & Tiwari 2016). The coarse fragment of fraction is also one of the important factors influencing the bulk density (Throop *et al.* 2012). The bulk density of soils is closely connected to total porosity (Singh *et al.* 2011). Few previous studies also documented that the bulk density of a soil can be altered by the soil type, soil organic matter, texture and mineral composition (Neumann-Cosel *et al.* 2011, Santos *et al.* 2015).

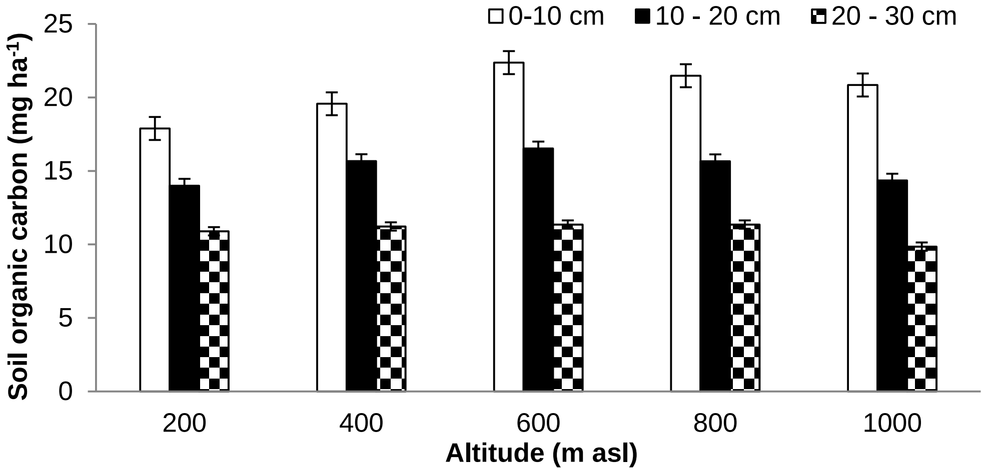

Figure 4. Soil organic carbon stocks (mean±SE) at three different depths in tropical forest along the elevation gradients on the Courtallam hills, Southern Western Ghats of India.

The soil organic carbon stock varied across the different forest elevation, increased significantly with increase in altitude ($P<0.05$) at all the three layers (0–10, 10–20 and 20–30 cm) (Fig. 4). At low altitude, SOC stocks of 42.79 mg ha^{-1} at 0–30 cm depth was observed in 200 m and the highest value of 50.25 mg ha^{-1} at 0–30 cm depth was observed in mid-elevation 600 m. The SOC stock values at high altitude 600–800 m and 800–1000 forests have showed almost the similar trend. SOC decreased with increasing soil depth in all the elevations. SOC exhibited a negative trend with an increase in soil depth. SOC ranged from 17.89 mg ha^{-1} to 22.37 mg ha^{-1} in soil surface layer (0–10 cm), 14.00 to 16.573 mg ha^{-1} in middle layer (10–20 cm) and 9.08 to 11.35 mg ha^{-1} in the bottom layer (20– 30 cm) (Fig. 4). In Ecuador, the higher mean SOC was found at higher elevation (169.6±76.9 mg ha^{-1}) and middle altitudes (110.2±77.3 mg ha^{-1}) and the lowest mean SOC at low altitude (82.5±48.6 mg ha^{-1}; De la Cruz-Amo *et al.* 2020). In addition, SOC increase with altitude (Townsend *et al.* 1995, Schrumpf *et al.* 2001, Kitayama & Aiba 2002, Raich *et al.* 2006, Moser *et al.* 2011, Dieleman *et al.* 2013), whereas in Garhwal Himalaya, SOC decreased along the altitude gradient (Sheikh *et al.* 2009), few other studies report no change at all (Soethe *et al.* 2007, Zimmermann *et al.* 2010, Phillips *et al.* 2019). The correlation analyses of SOC with predicting variables are presented (Table 1). Our result revealed that mean SOC stock in all the depth of the tropical forest ranged from 14.26 to 16.75 mg ha^{-1} with a mean value of 15.54±0.97 mg ha^{-1}, which is lesser value than other reported values in tropical dry deciduous forest Sathanur reserve forest, India (16.92 to 44.65 mg ha^{-1}; Gandhi & Sundarapandian 2017), in Odisha, tropical dry deciduous forests (57.9 mg ha^{-1}, Sahu *et al.* 2015), in Andhra Pradesh, semiarid tropical forest at Warangal

Table 1. Correlation (r-value) between soil organic carbon (SOC) and predictor variables along the elevational gradient in tropical forest of Courtallam hills, Southern Western Ghats of India.

Predictor variables	***r*-Value**
Climber species richness	-0.663
Climber density	-0.413
Climber basal area	-0.457
Climber above grond biomass	-0.506
Soil pH	-0.055
Soil moisture	0.234
Bulk density	0.88
Bulk density (0–10 cm)	0.499
Bulk density (10–20 cm)	0.514
Bulk density (20-–30 cm)	-0.316

Note. *Bulk density correlated with soil organic carbon (%).

district (76.51 mg ha^{-1}, Venkanna *et al.* 2014), in the forest of central Amazon (47.7–61.4 mg ha^{-1}, Santos *et al.* 2015; 51.9–84.2 mg ha^{-1}, Vanlalfakawma *et al.* 2014), in tropical forests of Kanyakumari Wildlife Sanctuary, Western Ghats, India (58.0–123.6 mg ha^{-1}; Subashree *et al.* 2019), in Tamil Nadu, Kolli hills (175–368 mg ha^{-1},

Table 2. Comparisons of estimates of soil C densities (Mg C ha^{-1}) of present and previous studies.

Location	**Forest type**	**Depth (cm)**	**C stock ($mgha^{-1}$)**	**Source**
Andean	Tropical Montane Forests	-	26.65–268.09	De la Cruz-Amo *et al.* (2020)
Tamil Nadu (Kanyakumari)	Tropical forests	0–30	58.54–123.6	Subashree *et al.* (2019)
Andhra Pradesh	Tropical dry forest	0–30	27.59–32.3	Ramana *et al.* (2017)
Sathanur reserve forest, Eastern Ghats	Tropical dry deciduous forest	0–30	16–47	Gandhi & Sundarapandian (2017)
South India (Kerala, Karnataka & Andhra Pradesh)	Agro forests	0–100	98–156	Hombegowda *et al.* (2016)
Chhattisgarh	Tropical dry forest	0–100	122.55	Iqbal & Tiwari (2016)
Uttarakhand	Alpine forest	NA	91.29	Kumar & Sharma (2016)
Gujarat	Tropical forest	0–30	0.9–1.7 (Mean)	Yadav *et al.* (2015)
Andhra Pradesh	Three different land uses	0–30	1.3–9.6	Mastan *et al.* (2015)
Haryana	Tropical dry forest	0–30	37.6	Gupta *et al.* (2014)
Haryana	Tropical dry forest	0–30	58.24	Gupta & Sharma (2014)
Maharashtra	Tropical dry forest	0–30	13.5–50.2	Patil *et al.* (2014)
Barak Valley, Assam	Dipterocarpus Forests	0–100	91.40–141.13	Debajit *et al.* (2014)
Haryana	Tropical dry forest	0–30	9.0–14.08	Singh *et al.* (2014)
Mizoram	Tropical bamboo forests	0–30	51.91–84.23	Vanlalfakawma *et al.* (2014)
India	Different forest types (entire India)	0–30	22.42–100.33	Velmurugan *et al.* (2014)
Andhra Pradesh	Different land uses	0–60	87.29	Venkanna *et al.* (2014)
Himachal Pradesh	Tropical dry forest	0–30	36.04	Panwar & Gupta (2013)
Sivagangai district, Tamil Nadu,	Tropical dry forests	0–30	33.36–48.82	Sundarapandian *et al.* (2013)
Uttar Pradesh	Tropical dry forest	0–30	21.8	Chaturvedi *et al.* (2011)
Uttar Pradesh	Agroecosystems	0–40	8.5–15.2	Singh *et al.* (2011)
Aravally mountain	Tropical forest	NA	172.84	Kumar *et al.* (2010)
Kolli hills Tamil Nadu	Tropical dry forest	0–30	175–369	Mohanraj *et al.* (2011)
Kolli Hills Tamil Nadu	Tropical forest	0–90	63.19–274.06 (mean 96.05)	Ramachandran *et al.* (2007)
India	Tropical dry deciduous forest	0–50	7.7–85. 6 (mean 37.5)	Chhabra *et al.* (2003)
Various climate zones	Europe	0–10	11.3–126.3	Baritz *et al.* (2010)
Tropical evergreen forests	India/Dadra and Nagar Haveli	0–50	31.6–94.6	Biswas (1985)
Montane temperate forests	India	0–50	12.1–184.3	Chhabra *et al.* (2003)
Mixed strands	USA	0–15	56	Compton *et al.* (1998)
Scots pine	Europe	0–80	57	de Vries *et al.* (2003)
Scot pine	Mediterranean	0–50	35–70	Diaz-Pines *et al.* (2011)
Permafrost soil	China	0–30	19–193	Dorfer *et al.* (2013)
Pinus roxburghii	India/Garhwal Himalaya	0–30	62.8	Gupta & Sharma (2011)
Pinus wallichiana	India/Garhwal Himalaya	0–30	102.96	Gupta & Sharma (2011)
Piceasmithiana and Abies pindrow	India/Garhwal Himalayas	0–30	132	Gupta & Sharma (2011)
Grasslands	India/Uttrakhand	0–30	37.09–142.14	Gupta & Sharma (2013)
Temperate deciduous forests	Eastern US	0–60	55–229	Mcfarlane *et al.* (2013)
Coniferous forests	Sweden	0–50	69–73	Ortiz *et al.* (2013)
Scot pine	Central Spain	0–8	49	Schindlbacher *et al.* (2010)
Broadleaf and coniferous	Netherlands	0–10	39.5–66	Schulp *et al.* (2008)
Schima-Castanopsis	Nepal	0–20	52.45	Shrestha (2009)
Norway spruce white-fir	Italy	0–20	53	Thuille *et al.* (2000)
Moist evergreen and submontane forests	Uganda	0–30	54.6–82.6	Twongyirwe *et al.* (2013)

Mohanraj *et al.* 2011), and Africa tropical and subtropical region of forests (mean 57 mg ha^{-1}, Kirsten *et al.* 2016) and followed in table 2. Moreover, our value is closer to several reports (Bhattacharyya *et al.* 2000, Henry *et al.* 2009, Panwar & Gupta 2013, Brahim *et al.* 2014, Gupta *et al.* 2014, Patil *et al.* 2014, Gray *et al.* 2015, Paz *et al.* 2016), whereas greater than the other reported values in the tropical dry and moist forests of India (8.9 to 177 mg ha^{-1}, Chhabra *et al.* 2003). Comparison of SOC values are difficult with other studies, because of different methods used to assess the SOC as well as difficulties in the measurement of bulk density of soils (Throop *et al.* 2012). Campo & Merino (2016) also stated that large spatial variation in SOC in tropical forest soils are influenced by combined effects on seasonal drought and length, quality and quantity of organic matter, which are determined the level of decomposition and associated sinking ability of the soil.

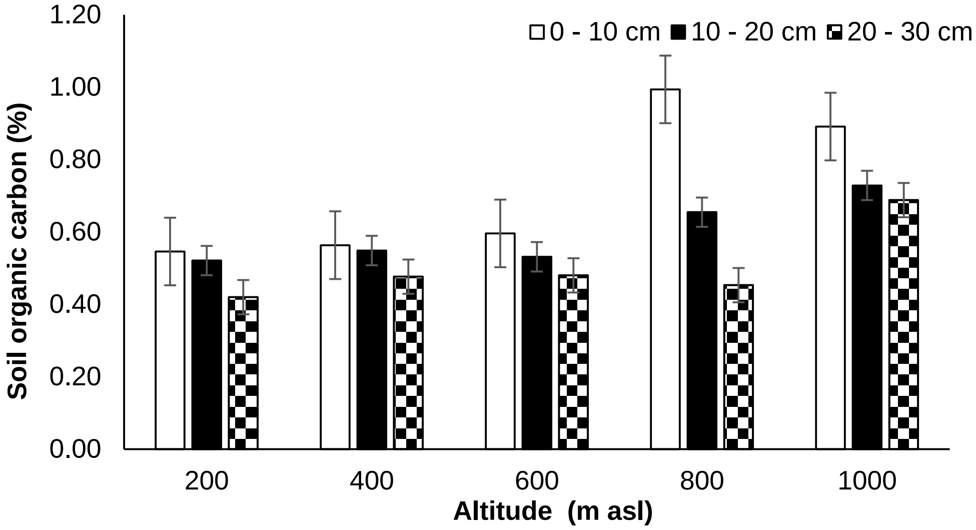

Figure 5. Soil organic carbon (%) at three different depths (mean±SE) in tropical forest along the elevation gradients on the Courtallam hills, Southern Western Ghats of India.

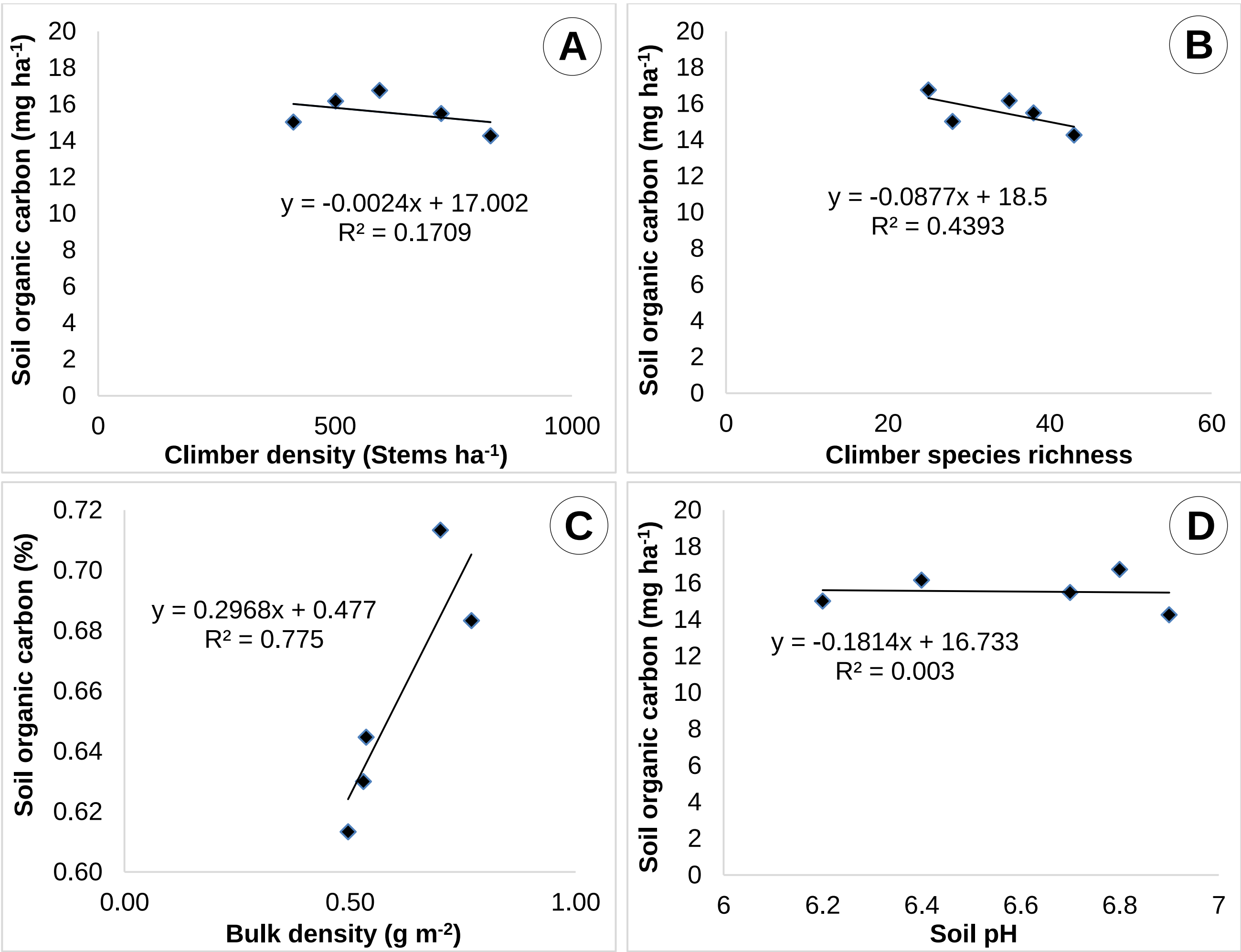

Figure 6. Relationship between soil organic carbon and **A**, Climber density; **B**, Climber species richness; **C**, Bulk density; **D**, Soil pH variables along the elevational gradient in tropical forest of Courtallam hills, Southern Western Ghats of India.

The SOC (%) significantly ($P < 0.001$) decreased with increase in soil depth (Fig. 5). SOC (%) ranged from 0.55 to 0.99% in the surface layer (0–10 cm) with a mean value of 0.72±0.035%, 0.52–0.73% in the middle layer (10–20 cm) with a mean value of 0.60±0.033% and 0.42–0.69% in the bottom layer (20–30 cm) with a mean value of 0.51±0.026%. About 36.54% of SOC is accumulated in the surface layer followed by the middle layer (34.41%) and bottom layer (29.04%). Gandhi & Sundarapandian (2017) stated that SOC (%) ranged from 0.57 to 1.31% in the surface layer (0–10 cm) with a mean value of 0.83±0.035%, 0.34–1.03% in the middle layer (10–20 cm) with a mean value of 0.626±0.032% and 0.30–0.89% in the bottom layer (20–30 cm) with a mean value of 0.516±0.028%. Higher SOC (%) observed in lower layer of soil (0–10 cm), this could be attributed to maximum litter and plant residues existing on the surface of soil and associated microbial activities. This similarly result was observed by Gray *et al*. (2015) who reported that vegetation cover is important factors the controlling the SOC stock in the surface layer of soil. The larger organic carbon in the upper layer of soils, this may be due to huge litter accumulation by the processes of decomposition on the forest floor (Gautam & Mandal 2016). In contrast, SOC (%) was greater in plots (11–20 and 21–30 cm depth), this may be due to the prevalence of favorable conditions *viz.*, relatively less anthropogenic activities, high aboveground biomass (Gandhi 2016). Pandian & Parthasarathy (2016b) documented that anthropogenic disturbance not only alters the structure and composition of the forest ecosystem and also one of the main factors responsible for changes in SOC stock between the plots in the study sites (Chiti *et al.* 2016).

A significant negative correlation was obtained between SOC stocks (mg ha^{-1}) and some vegetation characteristics *viz.* climber density, climber species richness and soil pH while a significant positive correlation was observed with bulk density (Fig. 6), this similar find was observed by Jobbagy & Jackson (2000) who documented, a negative relationship of SOC with bulk density. Dinakaran *et al.* (2014) reported that the climate (temperature, rainfall and soil moisture) is an important factor to affect the accumulation of carbon in soil. Jobbagy & Jackson (2000) also reported that SOC higher with increasing the rainfall, decreasing temperature and evapotranspiration. Similarly, Post *et al.* (1982) stated that the generally, warm temperate and dry tropical forests had the lowest soil carbon content and near the rivulet where showed low SOC in plots (20–30 cm depth) it may be due to the high rate of organic matter decomposition, consequently leaching due to water runoff (Gandhi & Sundarapandian 2017). The climate is major factor for better understanding of the soil carbon pool changes (Dinakaran *et al.* 2014).

CONCLUSION

Even though bulk density is the major parameter for estimating the soil organic carbon stock. The SOC stocks increased significantly along the elevation and it decreased with increase in soil depth. Whereas soil bulk density decreased significantly with elevation and it increased in soil depth. Our results showed that the soils of tropical forests of Courtallam hills have a greater potential of soil carbon sequestration particularly at a higher elevation, and this higher elevation of Courtallam hills are more vulnerable to climate change and found greater SOC stocks at a higher elevation than at low elevation, this changes in SOC stocks were mainly the climatic conditions of diminishing the temperature and increasing precipitation with elevation, consequential in reduced litter decomposition rates at high altitudes. Anthropogenic activities such as fuelwood collection, selective felling, grazing, agricultural seepage, this could also modify the certain levels of SOC storage in the long-term. It is the predominant duties to conservation measurements are important to restore the carbon sequestration potential of tropical forests and anthropogenic activities should be minimized for the wealth of the forest, and ultimately enhances the carbon sequestration potential.

ACKNOWLEDGMENTS

This study was supported by DST-SERB–N PDF (PDF/2015/000874) for financial support. We thank the Courtallam forest department for permitting us access to the forests and deep thanks for Range officers and my special thanks to M.P. Senthil Kumar (Ranger), Sankarapandian Sanmugavel (Guard) and field assistant Arun Ajithkumar and Raj Cortallam forest department for his timely help, supports and encouragement throughout the study.

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