ASIAN JOURNAL OF FORESTRY
Volume 6, Number 2, December 2022
Pages: 91-96

E-ISSN: 2580-2844
DOI: 10.13057/asianjfor/r060205

Vertical distribution of soil properties and soil organic carbon in community managed forest of Siwalik Hill, Nepal

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Manuscript received: 29 August 2022. Revision accepted: 13 October 2022.

Abstract. *Lamichhane U, Ghimire P. 2022. Vertical distribution of soil properties and soil organic carbon in community managed forest of Siwalik Hill, Nepal. Asian J For 6: 91-96.* Nepal's Community Forestry (CF) approach is globally recognized as an innovative and successful approach to forest resource management. *Shorea robusta* Gaertn. is the dominant tree species of Nepal's forest which covers 19.28% of the total stem volume of the country's forest area. Soil represents a significant terrestrial Carbon (C) pool and can play a significant role in mitigating global warming. Therefore, analyzing soil physicochemical properties and Soil Organic Carbon (SOC) stock is essential because they are key parameters for evaluating land use management systems. The present study was conducted in the Durga Mai Community Forest (DMCF) of Makawanpur District, Nepal, to assess the vertical distribution of soil physicochemical properties and SOC stock. Soil samples within a 1 m profile in five depth layers (0-20 cm, 21-40 cm, 41-60 cm, 61-80cm, and 81-100 cm) were collected and analyzed for Bulk Density (BD), soil texture, soil pH, soil carbon content, Total Nitrogen (TN), Available Phosphorous (AP), Available Potassium (AK) and SOC stock. Sandy loam was the dominant soil textural class reported throughout the study area. Average BD, soil pH, TN, AP, and AK in the *S. robusta* forest's soil in 1 m soil profile depth were found to be 1.16 ±0.07 $gmcm^{-3}$, 5.78 ±0.62, 0.14 ±0.04 %, 5.94 ±1.04 $kgha^{-1}$, and 104.20 ±19.66 $kgha^{-1}$, respectively. The results estimated 107.57 ±3.06 tha^{-1} of SOC stock in 1 m soil profile, with 0.93 ±0.21% average SOC content. Further, average TN, AP, and AK were found to be decreased with an increase in soil profile depths. Similarly, soil profile depths significantly affected SOC stock and soil properties like BD, soil pH, TN, AP, and AK.

Keywords: Community forest, soil organic carbon, soil profile, soil properties

INTRODUCTION

Carbon (C) sequestration through forest soil has been reported to be a cost-effective means for mitigating global climate change. Soil can store three times more C than the amount in the atmosphere and 3.8 times more than in the biotic pool (Brown et al. 1996; FAO 2001; Lal 2004). Environmental degradation due to continuing land use and land cover changes is a major worldwide issue that has attracted the attention of global soil science studies (Ayoubi et al. 2011). The sustainability and functions of soil depend on dynamic symmetry among its physicochemical and biological properties, and the types and patterns of land constantly influence these uses (Shrestha et al. 2004; Ghimire et al. 2018;). Soil properties and soil C are often influenced by land use practices and have been reported to differ with the change in land use systems. In addition, forested land uses can largely influence the quality of the soil, which could be essentially linked to the sustainable functioning and production of forests and agroecosystems (Kotowska et al. 2015; Manpoong and Tripathi 2019). Studies have reported a significant decline in soil properties and soil C due to forest conversion to plantations (van Straaten et al. 2015; Guillaume et al. 2016). Those have raised serious concerns regarding the sustainability of such land use types in the tropics, particularly in Nepal (Lal 2010).

Soil C and soil properties are important factors in the global biogeochemical cycle of the terrestrial ecosystem and are vital for enhancing plant productivity, reducing land degradation, and mitigating global warming (Lal 2004; Ghimire et al. 2019; Yunanto et al. 2022). Additionally, they are the focus of a study on the global C balance and climate change. Soil C and soil properties have strong spatial variability (Zhao et al. 2000), and various factors such as forest types, land use types, and topography can influence soil C and soil properties at various scales (Twongyirwe et al. 2013; Fusaro et al. 2019; Ngaba et al. 2020). For example, Sal (*Shorea robusta* Gaertn.) is the most dominant tree species in the Terai and Chure ecological region of Nepal (Jackson 1994; DFRS 2016). This species shares the highest tree stem volume (i.e.31.76 m^3ha^{-1}), which is 19.28% of the tree stem volume of the country (DFRS 2016). The total C stock in Nepal's forests has been estimated as 1054.57 million tonnes (176.96 tha^{-1}), out of which forest soils constitute 37.80% (DFRS 2016). Therefore, forest land is one of the most important elements that regulate the SOC and soil properties build up because SOC and soil properties are greatly influenced by vegetation through the organic matter intake (Shi et al. 2015).

Forest ecosystems are the world's largest terrestrial C sinks, and their significance for the global C cycle and climate regulation cannot be ignored (Brown and Pearce 1994; Lal 2005). Community Forestry has been regarded as the highest priority of Nepal's forestry sector and is widely acclaimed as a successful forest management approach. About 40% of the national forest in Nepal is under Community Forestry, where more than 3 million households are beneficiary users (DoF 2017; Ghimire and Lamichhane 2020). Recently, the opportunity for management of forests for enhancement of biomass and soil carbon sequestration and as a sink of greenhouse gases (GHGs) has emerged as a potential benefit for local communities participating in carbon trading under REDD+ agreements (Shrestha et al. 2013; Pandey et al. 2016). Furthermore, vertical patterns of SOC and soil properties can be used as an input or an independent validation for biogeochemical models, which can help understand how terrestrial ecosystems respond to climate change (Eswaran et al. 1993; Kern 1994; Mi et al. 2008). Previous research mainly concentrated on the topsoil C stock; however, the dynamics of C in deeper soil layers and the underlying mechanisms that govern vertical distributions of SOC and soil properties are still poorly understood (Jobbagy and Jackson 2000; Dahal and Kafle 2013). Only recently has the study of SOC in subsurface profiles attracted significant scientific attention due to the realization that subsoil carbon plays a significant role in the overall C storage within a soil profile (Batjes 1996). In Nepal, very few studies cover the vertical distribution of soil properties and SOC in forest ecosystems. Therefore, this study addresses this issue by addressing questions such as "What are the overall vertical patterns of SOC in *S. robusta* forest?" How much SOC is stored by the biosphere in the deep soil profile layers, and what impact do soil characteristics have on the soil C pool?

MATERIALS AND METHODS

Study area

The study was conducted in the Durga Mai Community Forest of Bakaiya Rural Municipality of Makawanpur District, Nepal (27° 32′ N, 85° 21′ E) (Figure 1). The forest covers 496.85 ha of the area. It consists mainly of natural *S. robusta* vegetation and other associated species such as *Terminalia tomentosa, T. bellerica, Lagerstroemia parviflora*, *Dalbergia sissoo, Acacia catechu,* and *Michelia champaca.* The study area is characterized by a tropical climate with an average temperature of 16 to 30 degrees Celsius and rainfall of 220 mm. The forest area represents sandstones, claystone, and conglomerates with quartz, feldspar, and opaque minerals of the lower and middle Chure range (DMCFUG 2017).

Soil sampling

Due to homogenous topography and forest cover density, soil samples were collected from 13 plots within the *S. robusta* forest following the simple random sampling technique. A W-type sample frame was used to represent all possible locations (Figure 1). Bulk samples were collected from a soil pit of 30 cm diameter by a cylindrical core sampler (5.5 cm diameter and 20cm length) for each incremental depth. The depth increment was 20 cm for the upper to lower soil profile (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, and 80-100 cm) down to 1 m soil profile. The fresh soil collected from each depth was kept in polythene bags and transported to the laboratory for further analysis. The selection of a 1 m soil profile was based on the literature that soil C studies usually consider a fixed soil depth, typically 1 m. In addition, global soil surveys based on vegetation units (Post et al. 1982) and soil taxonomic units indicate that the soil stores; 1500-1600 Pg of C in this first meter (Eswaran et al. 1993; Batjes 1996). Further, samples were sieved through a 2 mm mesh sieve to differentiate roots, stones, and debris, if any, and made ready for soil physicochemical analyses.

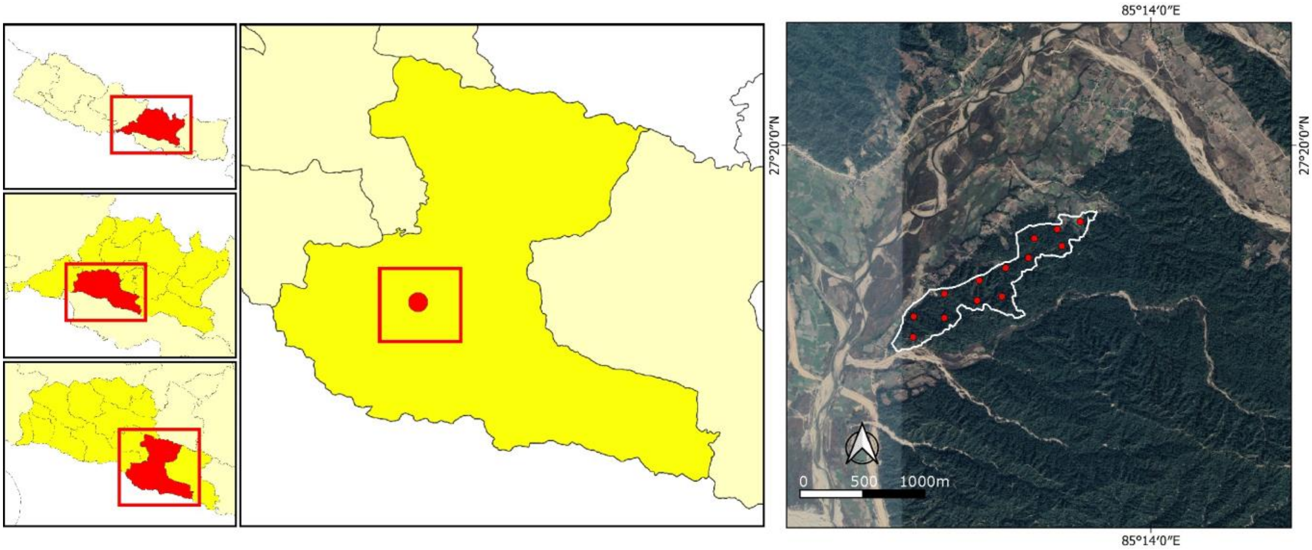

Figure 1. Map representing the study area n the Durga Mai Community Forest of Bakaiya Rural Municipality, Makawanpur District, Nepal

Analysis of SOC and soil properties

The core sampling method was used to determine soil bulk density (Blake and Hartge 1986). Then, soil texture was determined by the Bouyoucos hydrometer method (Bouyoucos 1962). Next, the textural classification, according to the United States Department of Agriculture (USDA), was followed to give the textural class of soil. Further, soil pH was measured by a digital pH meter (McLean 1982), total nitrogen (TN) by the Kjeldahl method (Bremner and Mulvaney 1982), available phosphorus (AP) by Olsen's and Somers method (Olsen and Sommers 1982), available potassium (AK) by flame photometer method (Thomas 1982) and SOC content by the colorimetric method (Anderson and Ingram 1993). Then, the total SOC stock was estimated by using the following formula recommended by Chhabra et al. (2003):

SOC (tha^{-1}) = Organic carbon content % x soil bulk density (gm cm^{-3}) × thickness of soil horizon (cm)

The one-way analysis of variance (ANOVA) was used to test the effects of different soil profile layers on soil physicochemical properties (such as bulk density, SOC content, soil pH, TN, AP, and AK), and SOC stock at a 5% level of significance. Further, the Pearson correlation test was applied to find the relationship between the studied variables.

RESULTS AND DISCUSSION

Soil physical properties

Sandy loam was the dominant soil textural class reported throughout the study area. However, the silt loam textural class was also found in the sub-soil layer. The overall mean of the sand, silt, and clay fraction was found to be 54.40± 5.07%, 30.14± 5.33%, and 15.46± 3.01% in *S. robusta* forest (Table 1). Similarly, the average BD of the *S. robusta* forest soil in 1 m soil profile depth was found to be 1.16 gmcm^{-3} which ranged from 1.03 ± 0.09 gmcm^{-3} (0-20 cm depth) to 1.29 ± 0.07 gmcm^{-3} (80-100 cm depth) (Table 1). BD increased with increasing depths throughout the 1 m soil profile.

ANOVA test showed a significant difference of soil BD (p = 0.001) between different soil layers at a 5% level of significance.

Soil texture and BD were the physical properties under investigation in the study area. Sandy loam texture was observed in the *S. robusta* forest. The result is in line with Bajracharya et al. (2007), who reported that the textural class of forest soil of Makawanpur district is sandy loam to silt loam. The study found that BD in *S. robusta* forest was increased with an increase in soil profile depths with an average BD of 1.16 gmcm^{-3} throughout 1 m soil profile depth. The mean value is in line with the result of 1.17 gmcm^{-3} as reported by Ghimire et al. (2018) in the *S. robusta* dominated forest in Makawanpur district, Nepal. Similarly, Kafle (2019) estimated that the mean value of BD was 1.28 gmcm^{-3} in the *S. robusta* dominated community forests in Chitwan, Nepal. Furthermore, the BD depended on various factors such as compaction, consolidation and amount of organic matter present in the soil but was negatively correlated to the organic carbon content (Morisada et al. 2004).

Soil chemical properties

The average soil pH in the study area was 5.78, with pH throughout the soil profile ranging from 4.65 ± 0.77 to 6.5± 0.46. The maximum soil pH was recorded in the lower soil profile layer (i.e., 80-100 cm depth) and the minimum in the top soil profile layer (i.e., 0-20 cm depth). With the increase in depth, there was a gradual increase in soil pH (Table 2). The average TN, AP, and AK in 1 m soil profile depth in the *S. robusta* forest were 0.14 %, 5.94 kgha^{-1}, and 104.20 kgha^{-1}, respectively (Table 2). The highest amount of average TN, AP, and AK were recorded in 0-20 cm, and the lowest was found in 80-100 m depth (Table 2).

Table 1. Soil physical properties in *Shorea robusta* forest

Soil physical properties			**Fraction (%)**			
Texture	Sand		Silt		Clay	
	54.40± 5.07		30.14± 5.33		15.46± 3.01	
BD			Depths (cm)			*P* value
(gmcm^{-3})	0-20	20-40	40-60	60-80	80-100	
	1.03± 0.09	1.12± 0.07	1.18± 0.06	1.20± 0.05	1.29± 0.07	0.001*

Note:*p < 0.05 is considered statistically significant at a 5% level of significance

Table 2. Soil chemical properties in *Shorea robusta* forest

Soil chemical properties	**Depths (cm)**					***P* Value**
	0-20	**20-40**	**40-60**	**60-80**	**80-100**	
pH	4.65± 0.77	5.34± 0.80	6.02± 0.60	6.38 ± 0.48	6.50± 0.46	0.001*
TN (%)	0.21± 0.06	0.18± 0.05	0.13± 0.04	0.10± 0.04	0.07± 0.02	0.001*
AP(kgha^{-1})	10.62± 1.40	8.20± 0.90	5.70± 1.02	3.38± 1.09	1.80± 0.78	0.001*
AK(kgha$^{-1)}$	166.84± 36.30	125.22± 24.96	98.90± 16.60	74.18± 8.78	55.85±11.68	0.001*

Note:*p < 0.05 is considered statistically significant at a 5% level of significance

Table 3. Correlation analysis of different variables

Variables	SOC stock	pH	BD	TN	AP	AK
SOC stock	1	-0.664*	-0.301*	0.601*	0.854*	0.793*
pH	-0.664*	1	-	-	-	-
BD	-0.301*	-	1	-	-	-
TN	0.601*	-	-	1	-	-
AP	0.854*	-	-	-	1	-
AK	0.793*	-	-	-	-	1

Note:*$p < 0.05$ is considered statistically significant at a 5% level of significance

Table 4. SOC content % and SOC stock in different soil layers

Soil depths (cm)	SOC content (%)	*P* Value	SOC stock (t/ha^{-1})	*P* Value
0-20	1.24± 0.11	0.001*	25.78 ± 3.90	0.001*
20-40	1.01± 0.09		22.86 ± 2.51	
40-60	0.92± 0.11		21.75± 3.24	
60-80	0.78± 0.09		19.10 ± 1.94	
80-100	0.69± 0.07		18.08 ± 2.90	
Total			107.57± 3.06	

Note:*$p < 0.05$ is considered statistically significant at a 5% level of significance

The studied chemical properties (pH, TN, AP, and AK) of the soil were found to be significantly different (p=0.001) between different soil layers at a 5% level of significance (Table 2). Furthermore, the study also revealed a significant relationship between the calculated variables. The pH of the forest soil was negatively correlated with SOC stock (r = -0.664; p = 0.001). However, SOC stock had strong positive correlation with TN (r = 0.601; p = 0.001), AP (r = 0.854; p = 0.001) and AK (r = 0.793; p = 0.001). Those indicate that SOC stock has a negatively strong correlation with soil pH. In contrast, TN has a moderate positive correlation, while AP and AK have a positively strong correlation with SOC stock (Table 3).

The soils in the study area were acidic, with an average pH of 5.78. Kafle (2019) reported average soil pH of 5.30 in the *S. robusta* dominated forest of Chitwan district, Nepal. Previous studies also revealed that moderately acidic soils dominate Nepal due to parent material (such as sandstone, siltstone, quartzite, and shale) and the atmospheric nature of aluminum in these soils (Ghimire and Bista 2016; Pandey et al. 2018). Similarly, the average TN, AP, and AK in the study area were in the range of 0.07 % to 0.21%, 1.80 to 10.62 kgha$^{-1,}$ and 55.85 to 166.84 kgha^{-1}, respectively (Table 2). With the increase in soil depth, there was a gradual reduction in TN, AP, and AK throughout the soil profile depth. That could be attributed to increased uptake and less contribution of nitrogen, phosphorous, and potassium nutrients by the litters (Shrestha et al. 2004; Twongyirwe et al. 2013; Manpoong and Tripathi 2019;). The higher amount of soil nutrients like nitrogen, phosphorous, and potassium in the top soil profile can be accounted for by a considerable amount of litter decomposition and higher inputs of organic matter through litter fall (Manpoong and Tripathi 2019).

Soil organic carbon stock

Soil depth ($p < 0.05$) had a significant effect on both SOC content % and the SOC stocks in the *S. robusta* forest soil (Table 4). The average SOC content in *S. robusta* forest was recorded highest at the top soil layer, i.e., 0-20 cm depth with 1.24 ±0.11%, whereas the lowest was at 80-100 cm depth with 0.69 ±0.07% (Table 4). Accordingly, the total SOC stock within 1 m soil profile depth in *S. robusta* forest was 107.57 ±3.06 tha^{-1} (Table 4). Both SOC content and SOC stock were found higher at the upper layer of soil in all depth intervals. The greater the depth, the lower the organic carbon content and SOC stock in all depth intervals of *S. robusta* forest. For example, in 0-20 cm soil profile depth, SOC content and SOC stock were found to be 1.24 ±0.11% and 25.78 ±3.90 tha^{-1}, respectively; whereas in 80-100 cm soil depth, it was reported 0.69 ±0.07% % and 18.08 ±2.90 tha^{-1} respectively (Table 4).

ANOVA test showed that both SOC content and SOC stock were significantly higher ($p \leq 0.001$) in the topsoil compared to the subsoil in the *S. robusta* forest (Table 3). Furthermore, the study found that BD of the forest soil was strongly negatively correlated with SOC stock (r = -0.301; p = 0.001). Those suggest that SOC stock negatively correlates weakly with soil pH (Table 3).

Forest soils are natural reserves and sinks of C and play an important role in sequestrating atmospheric carbon to mitigate global climate change (Wang et al. 2004; Lewis et al. 2009; Ghimire et al. 2018). The variables investigated for the analysis of SOC stock were soil BD and SOC content percentage (%). Significant variations in all tested variables were found among all the soil profile depths in the *S. robusta* forest (Table 3). The mean value of SOC content (0.93%) reported in the study was in line with that of Ghimire et al. (2018) and Kafle (2019), who reported SOC content of 0.99% and 0.95%, respectively, in *S. robusta* dominated community forest in Chitwan and

Makawnpur districts of Nepal respectively. Total SOC stock in 1 m soil profile depths of *S. robusta* was estimated to be 107.57 tha^{-1}. The finding was in line with the value 96.53 tha^{-1} and 110 tha^{-1} of SOC stocks in the *S. robusta* forest in Nepal, as reported by Gurung et al. (2015) and Ghimire et al. (2019), respectively.

Similarly, Kafle (2019) estimated a SOC stock of 122.36 tha^{-1} in the 1 m soil profile depth in *S. robusta* dominated community forest in Chitwan, Nepal. The modest range of variation could be due to difference in forest conditions, soil properties, soil sampling techniques, and management practices (Spurgeon et al. 2013; Kafle 2019). The higher concentration of SOC content and SOC stock were observed in the top soil layer, which could be attributed to higher soil organic matter content and less influence of parent materials (Dhakal et al. 2010). Pandey and Bhusal (2016) reported the declining trend of SOC stocks with the increase in soil depth in *S. robusta* dominated forests of hills and Terai regions of Nepal. Gautam and Mandal (2013) also reported a decreasing SOC content and SOC stock trend with increased soil depth in a tropical moist forest in eastern Nepal. Land use types and management practices significantly impact SOC and soil properties (Spurgeon et al. 2013; Ghimire et al. 2018; Ghimire et al. 2019).

In conclusion, this study was mainly focused on analyzing the vertical distribution of SOC stock and soil physicochemical properties within a 1 m soil profile depth in the *S. robusta* dominated community forest of Nepal. The study revealed the potential of *S. robusta* dominated community forest in C storage and enhancing soil physicochemical properties. The total SOC stock of the forest soil in 1 m soil profile depth was 107.57 tha^{-1}. Average TN, AP, and AK gradually decreased with increased soil profile depth. Soil profile depth had a significant effect on both SOC stock and soil physicochemical properties in forest soil.

ACKNOWLEDGEMENTS

We would like to acknowledge the Durga Mai Community Forest User Group, Makawanpur, Nepal, for providing this study's working environment and facilities. In addition, the authors are thankful to the Regional Soil Laboratory, Hetauda, Nepal, for extending laboratory facilities. The authors declare no conflicts of interest affecting the publication of this paper.

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