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Research Article

Vertical Distribution of Soil Organic Carbon and Nitrogen in a Tropical Community Forest of Nepal

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This paper reports the findings of a research conducted in Kankali community forest, Chitwan, Nepal, to quantify the vertical distribution of soil organic carbon (SOC) and nitrogen in 1 m soil profile depth. This community forest represents a tropical *Shorea robusta*-dominated community forest. It was found that the soil had 122.36 t/ha SOC and 12.74 t/ha nitrogen in 1 m soil profile in 2012, with 0.99% soil organic matter and 0.10% nitrogen concentration in average. Carbon and nitrogen ratio (C/N ratio) of the soil was found to be 9.90. Both bulk density and C/N ratio were found increasing with increase in soil depth. The SOC and nitrogen were found significantly different across different soil layers up to 1 m soil profile depth. The average pH of the forest soil was found to be 5.3. Looking into the values of stocks of SOC and nitrogen, it is concluded that Kankali community forest has played a role in global climate change mitigation by storing considerable amounts of SOC. Involvement of local community in management of tropical forest cannot be overlooked in the process of climate change mitigation.

1. Introduction

Soils are considered as viable sinks of atmospheric carbon (C) and may significantly contribute to climate change mitigation [1–3]. Soil carbon sequestration is something that we cannot afford to ignore [2]. Soils store a large share of organic carbon—twice more than vegetation and two-thirds more than the atmosphere [3]. Soils serve as both source and sink of CO_2. Therefore, they have a great potential to reduce emissions and enhance carbon sequestration through better soil management. In recent years, soil organic carbon (SOC) has received worldwide attention in the context of international policy agendas of CO_2 emission [4]. Forests are the largest carbon stock in terrestrial ecosystems [5]. Soil nitrogen (N) stocks and carbon-nitrogen ratio (C/N ratio) are considered as indicators of carbon sequestration potential in soils [6, 7]. Soil pH and C/N ratio are considered as major factors in the soil microbial structure and activities [8–10]. The C/N ratio may be treated as an approximate indicator of the quality of organic matter inflowing to forest soils and of its transformation to SOC. To increase SOC and nitrogen or to maintain these quantities close to native levels is one of the goals of conservation [11]. Vertical patterns of SOC can contribute as an input or as an independent validation for biogeochemical models and thus provide valuable information for examining the responses of terrestrial ecosystems to global change [12]. Previous studies (e.g., [13]) primarily focused on the topsoil carbon stock, and carbon dynamics in deeper soil layers and driving factors behind vertical distributions of SOC remain poorly understood [14]. SOC in subsoil horizons has become the subject of intensive research only in recent years because it was recognised that subsoil carbon contributes greatly to the total carbon stocks within a soil profile [15]. Song et al. [16] suggests that deep soil layers contribute considerable amounts and should not be omitted in soil carbon estimates. Nitrogen plays a crucial role through the interaction with carbon in the ecosystem productivity and carbon sequestration [17–19]. Many previous studies on the topsoil layers, i.e., 0–20 cm or slightly more [20, 21], are indication for need for studies on deeper soil layers. Thus, improved knowledge of distribution of SOC and nitrogen across different soil depths is essential to determine whether carbon in deep soil layers will react to global change and accelerate the increase in atmospheric carbon dioxide (CO_2) concentration [22]. Applying the concept of biogeochemistry provides a framework to identify and evaluate the sources and fates of chemical elements in a system approach. Predicting the future nutrient balance in forest ecosystems requires an estimation of forest carbon pools and fluxes [23]. Estimating carbon pools under existing land uses and their distribution within the soil profile provides baseline data to carbon sequestration over time [24]. Field data on C and N pools are also needed for the estimation of sources and sinks of greenhouse gases at the national level to be reported to the UNFCCC, to predict the carbon sequestration potential of nation's forest resources and to promote nutrient balance for enhanced productivity of the ecosystems. Modelling of biogeochemistry of major nutrients is useful in predicting the changes in the carbon pools in the forest lands over time in the context of changing management practices and climate. Several authors have indicated about the uncertainties associated with estimating SOC due to lack of extensive soil sampling data [15, 25, 26]. In this context, the objective of this research was to quantify SOC and nitrogen in different soil layers in a tropical community forest of Nepal up to 1 m soil depth.

2. Materials and Methods

2.1. Research Site. The research was conducted in Kankali community forest (27.65°N, 84.57°E, and 749.18 ha) in Chitwan district located in the tropical region of Nepal (Figure 1). It is a natural tropical forest on 220–580 m above mean sea level handed over to local community for management in 1995. The average annual maximum and minimum temperatures in the research site were 31 degree Celsius and 18 degree Celsius, respectively, and the average relative humidity and average annual rainfall of the area were 78% and 190 mm, respectively [28]. The forest is dominated by *Shorea robusta*. Other associated plant species are *Semecarpus anacardium*, *Lagerstroemia parviflora*, *Holarrhena pubescens*, *Buchanania latifolia*, *Terminalia alata*, *Dalbergia sissoo*, and *Acacia catechu* [27, 28]. The forest contains sandstone and mudstone of the lower and middle Siwaliks with quartz, biotite, muscovite, feldspar, and opaque minerals [28].

2.2. Soil Sampling. Soil samples, each around half kilogram, were collected from 0 to 20 cm, 21 to 40 cm, 41 to 60 cm, 61 to 80 cm, and 81 to 100 cm depths of soil profile from 12 randomly distributed pits dug in both Dalbergia Acacia/Riverine forest and *Shorea robusta* forest. The collected soil samples were packed in plastic bags, labelled, air-dried, and taken to the Regional Soil Test Laboratory, Makwanpur, for analysis. The overall field measurement methods were based on guidelines of ANSAB [29].

2.3. Soil Analysis. Soil bulk density was determined using the soil core sampler having a diameter of 5.7 cm [30]. The SOC concentration was determined by dry combustion of oven-dry soil samples [31]. The percentage of soil organic matter was converted to SOC by multiplying with 0.58, as soil organic matter is assumed to contain 58% of organic carbon. Total nitrogen (TN) was determined by the Kjeldahl digestion-distillation method [32]. Soil pH of a composite sample (of all soil layers and soil pits) was determined using a pH probe with a glass-calomel electrode (Suntronics pH electrode, Suntronics India), keeping 1 : 1 soil: water ratio [33]:

$$\begin{aligned}\text{bulk density of soil} &= \frac{\text{oven dry weight of soil in gram}}{\text{volume of soil in cubic centimeter}},\\ \text{soil organic carbon in ton per hectare} &= \text{organic carbon content}\,(\%) \times \text{soil bulk density} \times \text{depth of soil layer},\\ \text{total nitrogen in ton per hectare} &= \text{nitrogen content}\,(\%) \times \text{soil bulk density} \times \text{depth of soil layer}.\end{aligned} \tag{1}$$

The significance difference of bulk density, SOC, nitrogen, and C/N ratio was tested using ANOVA at 5% level of significance. The correlation test was applied to find out relationship between the variables. SPSS software (IBM SPSS Statistics, IBM Corporation, Version 20) was used for statistical analysis of the data.

3. Results and Discussion

The average soil organic matter and nitrogen concentration in 1 m soil profile depth of tropical community forest was found to be 0.99% ± 0.45% and 0.10% ± 0.05%, respectively (Table 1). These values were close to the values reported by Paudel and Sah [34] (1.74% ± 0.31% SOC and 0.111% ± 0.01% soil nitrogen in the mixed *S. robusta* forest), Sharma and Chhetri [28] (0.09% soil nitrogen) and Ghimire et al. [35] (0.95% SOC in the *S. robusta*-dominated forest). This may be due to a similar forest type containing *S. robusta* as dominant forest species, physiographical range, climatic condition, and soil sampling. Our finding on soil organic matter was lower than the value reported by Sharma and Chhetri [28] (1.28%) in the same forest. It may be due to the fact that they reported the soil organic matter concentration of only 0–30 cm soil profile depth.

In this research, the average C/N ratio of the soil was found to be 9.90 (Table 1). Calculations were made on the basis of Kirkby et al. [36]. Data presented by Ostrowska and Porębska [37] indicated that the mean C/N ratio for humus was 12.7, the mean C/N ratio in the arable soils examined by the authors was 13.6, and the mean C/N ratio for an

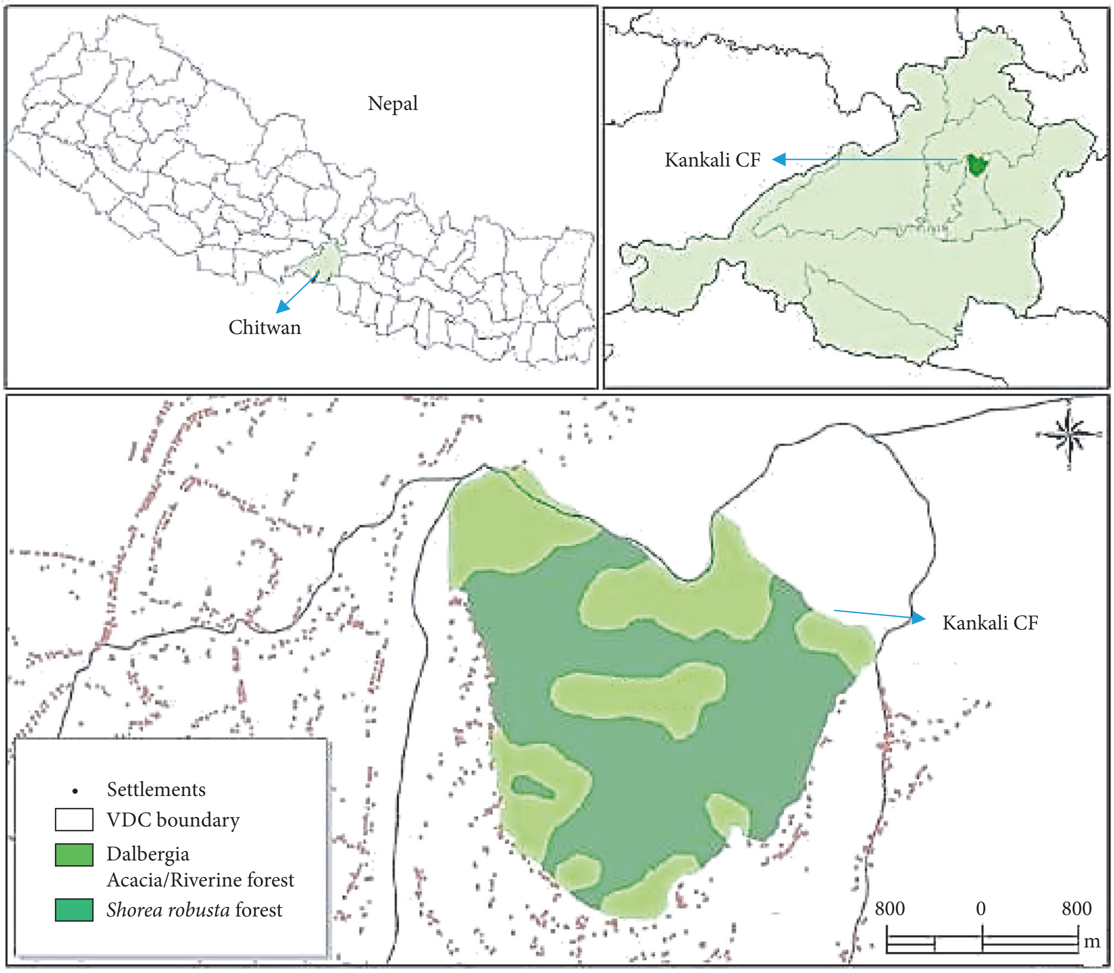

Figure 1: Kankali community forest (source: [27]).

Table 1: Bulk density, organic carbon, nitrogen, and C/N ratio in different soil layers.

Soil layer (cm)	Average bulk density (gm/cm^3)	p value	Average organic carbon (%)	p value	Average nitrogen (%)	p value	C/N ratio	p value
0–20	1.18	0.193	1.46	0.001*	0.17	0.001*	8.59	0.001*
21–40	1.28		1.10		0.13		8.46	
41–60	1.24		0.84		0.09		9.33	
61–80	1.34		0.77		0.07		11.00	
81–100	1.36		0.76		0.05		15.20	
Mean (0–100 cm)	**1.28**		**0.99**		**0.10**		9.90	

*Significance difference at 5% level of significance. A p value is a measure of probability used for hypothesis testing. If we have a p value less than 0.05, the null hypothesis would be rejected in favor of the alternative hypothesis indicating dissimilarity of at least one mean from the rest.

international soil amounted to 11.6, close to the value reported in this research (9.90).

The average soil pH was found to be 5.3 ± 0.67. The pH range in this research was close to the values reported by Paudel and Sah [34] (5.26 ± 0.58 in the mixed *S. robusta* forest) and Singh and Singh [38] (4.5–5.5 in the *S. robusta* forest). This may be due to similar forest types containing *S. robusta* as dominant species. pH was lower than the values reported by Sigdel [39] (5.90–6.42), by Karki [40] (6.4–7.1), Sharma and Chhetri [28] (4.64), or by Singh and Singh [38] (6.7–6.8). This may be due to variation in topography, forest condition, and soil sampling.

The average bulk density of the soil in 1 m soil profile depth was found to be 1.28 ± 0.21 gram per cubic centimetre (Table 1), close to the value 1.17 gram per cubic centimetre [41] and 1.18 gram per cubic centimetre found by Ghimire et al. [35] in two *S. robusta*-dominated tropical forests of Nepal.

Table 2: Organic carbon and nitrogen stocks in different soil layers.

Soil layer (cm)	SOC stock (t/ha)	Soil nitrogen stock (t/ha)
0–20	34.35	3.97
21–40	27.33	3.22
41–60	20.23	2.13
61–80	20.11	1.98
81–100	20.34	1.44
Total	122.36	12.74

The ANOVA test shows that there was significant difference of SOC (p = 0.001) and nitrogen (p = 0.001) between different soil layers at 5% level of significance. There was no significant difference in bulk density of soil between different soil layers (p = 0.193) at 5% level of significance (Table 1).

The stock of SOC and nitrogen in tropical community forest was found to be 122.36 t/ha and 12.74 t/ha, respectively, within 1 m soil profile depth (Table 2). Ghimire et al. [35] quantified 110 t/ha SOC in 1 m soil profile depth in a tropical forest dominated by *Shorea robusta* in Makwanpur district of Nepal. Our study district (Chitwan) is the neighboring district to Makwanpur district where Ghimire et al.'s [35] study was conducted and our finding on SOC stock within 1 m soil profile depth is close to theirs. Result of this research on SOC stock in 1 m soil profile depth is more than that reported by Gurung et al. [42] (96.53 t/ha) in *S. robusta*-dominated forests. This variation could be due to their different soil sampling techniques (up to 30 cm soil depth) and forest management regimes.

The SOC and nitrogen were found to decrease with increased soil depth; for example, in 0–20 cm soil depth, SOC stock was found to be 34.35 t/ha, but in 81100 cm soil depth, it was found to be 20.34 t/ha (Table 2). The higher organic carbon percentage in the top layer may be due to rapid decomposition of forest litter in a favorable environment. Soils with rich organic carbon levels generally indicate high fertility, and therefore, it is important to maintain its optimum level that requires a careful land use and management practices [4]. A study by Tiwari et al. [43] also reported declining trend of total nitrogen with increasing soil depths. Gautam and Mandal [44] also reported a decreasing trend of SOC and nitrogen with increased depths of soil in a tropical moist forest in eastern Nepal. Similar findings on the decline of stocks of SOC with the increase in soil depth were reported by Pandey and Bhusal [45] in *S. robusta*-dominated forests of hills and Terai regions of Nepal and Ghimire et al. [41] in the *S. robusta*-dominated tropical community forest of Nepal. Song et al. [16] also reported that the concentrations of SOC and nitrogen decreased with depth, and the greatest concentration was in the 0–10 cm topsoil in selected forests of China.

Bulk density of the soil was negatively correlated with SOC ($r = -0.425$) and nitrogen ($r = -0.308$). However, there was a positive correlation between SOC and nitrogen ($r = 0.429$). Gautam and Mandal [44] also reported positive correlation between SOC and nitrogen in a tropical moist forest in eastern Nepal. Negative correlation between SOC and bulk density of soil was also reported by Ali et al. [46] and Ghimire et al. [35].

4. Conclusions

This article indicates the first reporting of SOC and nitrogen in Kankali community forest, Chitwan, up to 1 m soil profile depth. Results of this study show evidence of a tropical community forest having role in storage of SOC and nitrogen within 1 m soil profile depth in Nepal. The average bulk density of the soil in 1 m soil profile depth was 1.28 gram per cubic centimetre. The average carbon to nitrogen ratio (C/N ratio) of the soil was found to be 9.90. The SOC and nitrogen were found decreasing with increased soil depths, with a statistically significant difference in values among across different soil layers. Bulk density and C/N ratio of the soil was found increasing with increased soil depths. The forest soil was found slightly acidic. It is found that the soil of tropical *Shorea robusta*-dominated community forest had high potentiality of storage of organic carbon and nitrogen and is playing a role in global climate change mitigation. The topsoil contained higher amounts of SOC and nitrogen, so the forest management practices should consider retaining organic matter in the forest floor.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

This research was a part of author's regular academic activity.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

References

[1] R. M. Bajracharya, R. Lal, and J. M. Kimble, "Soil organic carbon distribution in aggregates and primary particle fractions as influenced by erosion phases and landscape position," in *2004. Soil organic carbon status and dynamics in the Central Nepal Middle Mountains. Forestry*, R. Lal, R. M. Bajracharya, B. K. Sitaula et al., Eds., vol. 12, pp. 353–367, Academia, San Francisco, CA, USA, 1998.

[2] R. Lal, "Soil carbon sequestration to mitigate climate change," *Geoderma*, vol. 123, no. 1-2, pp. 1–22, 2004.

[3] P. Smith, "Carbon sequestration in croplands: the potential in Europe and the global context," *European Journal of Agronomy*, vol. 20, no. 3, pp. 229–236, 2004.

[4] N. Dahal and R. M. Bajracharya, "Prospects of soil organic carbon sequestration: implications for Nepal's mountain agriculture," *Journal of Forest and Livelihood*, vol. 9, no. 1, pp. 45–56, 2013.

[5] G. B. Bonan, "Forests and climate change: forcings, feedbacks, and the climate benefits of forests," *Science*, vol. 320, no. 5882, pp. 1444–1449, 2008.

[6] C. Akselsson, B. Berg, V. Meentemeyer, and O. Westling, "Carbon sequestration rates in organic layers of boreal and temperate forest soils—Sweden as a case study," *Global Ecology and Biogeography*, vol. 14, no. 1, pp. 77–84, 2005.

[7] W. De Vries, G. J. Reinds, P. Gundersen, and H. Sterba, "The impact of nitrogen deposition on carbon sequestration in European forests and forest soils," *Global Change Biology*, vol. 12, no. 7, pp. 1151–1173, 2006.

[8] E. Bååth and T.-H. Anderson, "Comparison of soil fungal/bacterial ratios in a pH gradient using physiological and PLFA-based techniques," *Soil Biology and Biochemistry*, vol. 35, no. 7, pp. 955–963, 2003.

[9] J. Rousk, E. Bååth, P. C. Brookes et al., "Soil bacterial and fungal communities across a pH gradient in an arable soil," *The ISME Journal*, vol. 4, no. 10, pp. 1340–1351, 2010.

[10] J. Rousk, P. C. Brookes, and E. Bååth, "Fungal and bacterial growth responses to N fertilization and pH in the 150-year "park grass" UK grassland experiment," *FEMS Microbiology Ecology*, vol. 76, no. 1, pp. 89–99, 2011.

[11] R. T. Odell, S. W. Melsted, and W. M. Walker, "Changes in organic carbon and nitrogen of morrow plot soils under different treatments, 1904–1973," *Soil Science*, vol. 137, no. 3, pp. 160–171, 1984.

[12] N. Mi, S. Wang, J. Liu, G. Yu, W. Zhang, and E. Jobbágy, "Soil inorganic carbon storage pattern in China," *Global Change Biology*, vol. 14, no. 10, pp. 2380–2387, 2008.

[13] K. N. Dahal and G. Kafle, "Organic carbon in soil and biomass of an Alnus nepalensis forest in Kathmandu, Nepal," *International Journal of Agriculture and Forestry*, vol. 3, no. 6, pp. 240–243, 2013.

[14] E. G. Jobbágy and R. B. Jackson, "The vertical distribution of soil organic carbon and its relation to climate and vegetation," *Ecological Applications*, vol. 10, no. 2, pp. 423–436, 2000.

[15] N. H. Batjes, "Total carbon and nitrogen in the soils of the world," *European Journal of Soil Science*, vol. 47, no. 2, pp. 151–163, 1996.

[16] Z. Song, K. McGrouther, and H. Wang, "Occurrence, turnover and carbon sequestration potential of phytoliths in terrestrial ecosystems," *Earth-Science Reviews*, vol. 158, pp. 19–30, 2016.

[17] J. M. H. Knops and D. Tilman, "Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment," *Ecology*, vol. 81, no. 1, pp. 88–98, 2000.

[18] P. B. Reich, B. A. Hungate, and Y. Luo, "Carbon-nitrogen interactions in terrestrial ecosystems in response to rising atmospheric carbon dioxide," *Annual Review of Ecology, Evolution, and Systematics*, vol. 37, no. 1, pp. 611–636, 2006.

[19] L. Liu and T. L. Greaver, "A global perspective on belowground carbon dynamics under nitrogen enrichment," *Ecology Letters*, vol. 13, no. 7, pp. 819–828, 2010.

[20] L. Deng, G.-B. Liu, and Z.-P. Shangguan, "Land-use conversion and changing soil carbon stocks in China's "grain-for-green" program: a synthesis," *Global Change Biology*, vol. 20, no. 11, pp. 3544–3556, 2014.

[21] X. Song, C. Peng, G. Zhou, H. Jiang, and W. Wang, "Chinese grain for green program led to highly increased soil organic carbon levels: a meta-analysis," *Scientific Reports*, vol. 4, no. 1, p. 4460, 2014.

[22] S. Fontaine, S. Barot, P. Barré, N. Bdioui, B. Mary, and C. Rumpel, "Stability of organic carbon in deep soil layers controlled by fresh carbon supply," *Nature*, vol. 450, no. 7167, pp. 277–280, 2007.

[23] D. Gaumont-Guay, T. A. Black, T. J. Griffis, A. G. Barr, R. S. Jassal, and Z. Nesic, "Interpreting the dependence of soil respiration on soil temperature and water content in a boreal aspen stand," *Agricultural and Forest Meteorology*, vol. 140, no. 1–4, pp. 220–235, 2006.

[24] S. P. Hamburg, "Simple rules for measuring changes in ecosystem carbon in forestry offset projects," *Mitigation and Adaptation Strategies for Global Change*, vol. 5, no. 1, pp. 25–37, 2000.

[25] H. L. Bohn, "Estimate of organic carbon in world soils: II1," *Soil Science Society of America Journal*, vol. 46, no. 5, pp. 1118-1119, 1982.

[26] H. Eswaran, E. Van Den Berg, and P. Reich, "Organic carbon in soils of the world," *Soil Science Society of America Journal*, vol. 57, no. 1, pp. 192–194, 1993.

[27] S. G. Baral, H. Vacik, B. B. K. Chhetri, and K. Gauli, "The pertinent role of forest inventory in making choice of silvicultural operations in community forests of Nepal," *Banko Janakari*, vol. 4, pp. 65–75, 2018.

[28] R. P. Sharma and B. B. K. Chhetri, "Analysis of rocks, soils and vegetation characteristics of Kankali (Chitwan) and Tibrikot (Kaski) community forests of Nepal," *Journal of Nepal Geological Society*, vol. 44, pp. 13–22, 2012.

[29] ANSAB, *Forest Carbon Stock Measurement: Guidelines for Measuring Carbon Stocks in Community-Managed Forests*, ANSAB, Kathmandu, Nepal, 2010.

[30] G. R. Blake and K. H. Harte, "Bulk density," in *Methods of Soil Analysis Part 1. Physical and Mineralogical Methods-Agronomy Monograph*, A. Klute, Ed., pp. 363–375, American Society of Agronomy-Soil Science Society of America, Madison, WI, USA, 2nd edition, 1986.

[31] D. W. Nelson and L. E. Sommers, "Total carbon, organic carbon and organic matter," in *Methods of Soil Analysis Part 2. Chemical and Microbiological Properties*, A. L. Page, R. M. Miller, and D. R. Keeney, Eds., pp. 539–580, American Society of Agronomy, Madison, WI, USA, 2nd edition, 1982.

[32] J. M. Bremner and C. S. Mulvaney, "Nitrogen—total 1," in *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*, pp. 595–624, American Society of Agronomy, Soil Science Society of America, Madison, WI, USA, 1982.

[33] E. O. McLean and C. S. Mulvaney, "Soil pH and lime requirement. Methods of soil analysis. Part 2. Chemical and microbiological properties, (methodsofsoilan2)," pp. 199–224, 1982.

[34] S. Paudel and J. P. Sah, "Physiochemical characteristics of soil in tropical Sal (*Shorea robusta* Gaertn.) forests in eastern Nepal," *Himalayan Journal of Sciences*, vol. 1, no. 2, pp. 107–110, 2003.

[35] P. Ghimire, B. Bhatta, B. Pokhrel, G. Kafle, and P. Paudel, "Soil organic carbon stocks under different land uses in Chure region of Makawanpur district, Nepal," *SAARC Journal of Agriculture*, vol. 16, no. 2, pp. 13–23, 2018.

[36] C. A. Kirkby, J. A. Kirkegaard, A. E. Richardson, L. J. Wade, C. Blanchard, and G. Batten, "Stable soil organic matter: a comparison of C/N: P: S ratios in Australian and other world soils," *Geoderma*, vol. 163, no. 3-4, pp. 197–208, 2011.

[37] A. Ostrowska and G. Porębska, "Assessment of the C/N ratio as an indicator of the decomposability of organic matter in forest soils," *Ecological Indicators*, vol. 49, pp. 104–109, 2015.

[38] S. P. Singh and J. S. Singh, "Structure and function of the forest ecosystem of central Himalayas: implication for management," in *Environmental Regeneration in Himalayas*, J. S. Singh, Ed., pp. 83–113, Central Himalayan Environment Association and Gyanodya Prakashan, Nainital, India, 1985.

[39] E. R. Sigdel, *Physico-Chemical Properties of Soil in Royal Chitwan National Park*, Central Department of Botany, Tribhuvan University, Kirtipur, Nepal, 1994.

[40] S. Karki, *Ecological Study of Riverine Forest in Koshi Tappu Wildlife Reserve (KTWR)*, Central Department of Botany, Tribhuvan University, Kirtipur, Nepal, 1999.

[41] P. Ghimire, G. Kafle, and B. Bhatta, "Carbon stocks in *Shorea robusta* and *Pinus roxburghii* forests in Makawanpur district of Nepal," *Journal of AFU*, vol. 2, pp. 241–248, 2018.

[42] M. B. Gurung, H. Bigsby, R. Cullen, and U. Manandhar, "Estimation of carbon stock under different management regimes of tropical forest in the Terai Arc Landscape, Nepal," *Forest Ecology and Management*, vol. 356, pp. 144–152, 2015.

[43] S. D. Tiwari, J. Ritesh, and R. Arjun, "Physico-chemical properties of soils in cool-temperate forests of the Nanda Devi biosphere reserve in Uttarakhand (India)," *Journal of Ecology and the Natural Environment*, vol. 5, no. 6, pp. 109–118, 2013.

[44] T. P. Gautam and T. N. Mandal, "Soil characteristics in moist tropical forest of Sunsari district, Nepal," *Nepal Journal of Science and Technology*, vol. 14, no. 1, pp. 35–40, 2013.

[45] H. P. Pandey and M. Bhusal, "A comparative study on carbon stock in Sal (*Shorea robusta*) forest in two different ecological regions of Nepal," *Banko Janakari*, vol. 26, no. 1, pp. 24–31, 2016.

[46] S. Ali, F. Begum, R. Hayat, and B. J. M. Bohannam, "Variation in soil organic carbon stock in different land uses and altitudes in Bagrot Valley, Northern Karakoram," *Acta Agriculturae Scandinavica, Section B—Soil and Plant Science*, vol. 67, p. 551561, 2017.