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Research Article

Soil organic carbon and nutrient status in forest and agroforestry lands in tropical region of Nepal

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ABSTRACT

Soil Organic Carbon (SOC) concentration, stock and soil nutrients vary considerably according to land use practices and soil depth. The rationale for studying SOC and nutrient status in Nepal's tropical forest and agroforestry lands stems from the vulnerability of these soils to degradation, the importance of these systems in carbon sequestration and climate change mitigation, and the need for sustainable land management practices to ensure food security and biodiversity conservation. The objective of the study was to assess the soil organic carbon and nutrient status in Navajagriti community forest, Bharatpur Metropolitan-11 and home gardens (agroforestry) in Kalika Municipality-9 of Chitwan district, Nepal respectively. Soil samples were collected randomly from both land use types. Soil samples were collected from soil depths up to 30 cm at variable depth interval of 0-10 cm and 10-30 cm. The results showed that SOC stock was found higher in agroforestry (25.66 t/ha) than in forest (24.84 t/ha) whereas bulk density was found higher in forest (1.53 g/cm^3) than in agroforestry (1.31 g/cm^3). The average SOC stock of forest and agroforestry land in 0-10 cm soil depth was found to be 11.40 t/ha and 10.64 t/ha, and those in 10-30 cm soil depth was found to be 13.44 t/ha and 15.02 t/ha respectively. However, both were found non-significant ($p<0.05$). Likewise, pH (6.5) in agroforestry and 6.29 in forest, total nitrogen in agroforestry (0.216%) and (0.08%) in forest, available phosphorus 37.21 ppm in agroforestry and 7.42 ppm in forest, available potassium in agroforestry 152.22 ppm and 108.8 ppm in forest were found which showed higher nutrient status in agroforestry but these nutrients were not significantly ($P>0.05$) among both land use type. The carbon-nitrogen ratio was found higher in forest (7.466) than in agroforestry (3.78), with statistical significant difference. The study concluded that SOC concentration, stock, and soil nutrients were highly influenced by management practices like regular tillage, use of organic manure and multistory farming in agroforestry rather than old aged, degraded and unmanaged forest. Hence, forest management applying relevant silvicultural systems based on management objectives and multistory system can improve carbon and nutrient in community forest.

Keywords: Carbon, Land use, Soil organic matter

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INTRODUCTION

Soil organic carbon (SOC) is a complex mixture of decomposed plant and animal residues and other organic compounds (Lehmann & Kleber, 2015). The carbon pool in the terrestrial ecosystem can be categorized into vegetative carbon and soil carbon components in which vegetative carbon includes both aboveground and below ground biomass (Hamburg, 2000). Likewise, Soil contains about 1500 Gt of organic carbon to a depth of 1 m and further 900Gt from 1-2 m (Kirschbaum, 2000). Sustainable land management practices that increase SOC are vital for maintaining soil health, food security, and climate change mitigation. SOC is

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crucial for soil health and global carbon cycling. SOC enhances soil structure, fertility, and water retention (Six *et al.*, 2004; Hillel, 2004; Brady & Weil, 2016), acting as a significant terrestrial carbon sink that mitigates climate change (Lal, 2008; IPCC, 2022). It fuels microbial activity essential for nutrient cycling (Schimel & Schaeffer, 2012) and improves soil aggregation, reducing erosion (Pimentel *et al.*, 1995). Forest and agroforestry lands are natural carbon sink in which trees store carbon (C) by sequestrating atmospheric C in growth of wood biomass through photosynthesis, thereby increasing soil C (Brown *et al.*, 1994). These are major options for carbon sequestration, which plays important role in global carbon cycle and act both source and sink (Bass *et al.*, 1997; IPCC, 2000). Soil carbon sequestration is primarily mediated by plants through photosynthesis, with C stored in form of soil organic carbon (SOC) (Lal, 2004). Soil carbon is one of the largest stores of tree carbon which plays important role in stability and fertility of soil (Batjes, 1996; Jobbagy and Jackson, 2000; Lal, 2004), however, SOC content exhibits considerable variability both spatially and horizontally according to land use and vertically within the soil profile. The SOC diminished with depth regardless of vegetation, soil texture, and clay size fraction (Trujillo *et al.*, 2018). Along with carbon sequestration, forest and agroforestry has multifold environmental services like soil nutrient management, biodiversity conservation, and maintenance of air and water quality (Jose, 2009).

Carbon stocks are dynamic which depend upon various factors and management practices mainly land use changes, soil erosion and deforestation (Watson *et al.*, 2000). Land use and land use changes are responsible for losses of C and nutrients from forests globally which are estimated to cause at least 11 % of annual anthropogenic carbon dioxide emission (Batjes, 1996). Both carbon and nitrogen status associated with C: N ratio may play important roles in regulating soil organic matter mineralization (Yang *et al.*, 2010). The ratio of C: N indicates the rate of decomposition of organic matter and this result in release or immobilization of soil nitrogen. Deng *et al.* (2013) reported that the change of soil C: N could lead to significant declines in C storage. However, many factors, including land use, climate, topography and some basic soil properties influence the biogeochemical cycle in soil which further the changes the carbon and nitrogen storage (Watson *et al.*, 2000).

Forest soil carbon is dependent on the status of the forest, as well as, is linked with the land use practices adopted. The land use practices are linked with the management regimes. Nepal has different management practices associated with natural resource and land management. Community forest management practices support to maintain the C enhancement as well as ecosystem management. Agroforestry practices, on the other hand, are a supplementary system to bridge the requirement of food security as well as the ecosystem enrichment, allowing livelihood contribution and carbon sequestration with on-farm trees (Shrestha *et al.*, 2013). The major agroforestry practices in Nepal include home gardens, agri-silviculture, silvi-pastoral system, agro-silvo-pastoral system, alley cropping, horti-silviculture system and aquasilviculture. Shifting cultivation is still practiced in many upland areas of the country, though it is declining (Amatya *et al.*, 2018). Agroforestry and ecosystem conservation are key approaches in the integration of climate change adaptation and mitigation objectives, often generating significant co-benefits for local ecosystems and biodiversity (Matocha *et al.*, 2012).

The rationale for studying soil organic carbon (SOC) and nutrient status in Nepal's tropical forest and agroforestry lands stems from the vulnerability of these soils to degradation, the importance of these systems in carbon sequestration and climate change mitigation, and the need for sustainable land management practices to ensure food security and biodiversity

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conservation. The research addresses knowledge gaps by comparing SOC stock and nutrient levels across forest and agro-forestry lands informing policy decisions and improving agricultural practices in the region. In this context, this research was conducted to compare Soil Organic Carbon (SOC) stock and nutrient status in community forest and agroforestry in tropical region of Nepal.

MATERIALS AND METHODS

Study site

The study was carried out in January to April 2019 on Navajaagriti community forest which lies in Bharatpur metropolitan city ward No. 11 and homegarden agroforestry system of Padampur, Kalika Municipality ward No. 9 in Chitwan District which is located in Bagati Province and were located nearby settlement (Figure 1). The land uses entail 27˚21′45″to 27˚52′30″ N latitude and 83˚54′45″to 84˚48′15″E longitude. The Navajagriti community forest is natural *Shorea robusta* forest with an area 315.16 ha. The major tree species were Sal (*Shorea robusta*) and Saj (*Terminilia alata*) and other species were Karma (*Adina cordifolia*), Jamun (*Syzygium cumini*), Khair (*Acacia catechu*), Sissoo (*Dalbergia sissoo*). The soil of forest is black, coarse and red. Likewise, agroforestry was composed of different layers of plants which include *Melia azedarach* (Bakaino), *Mangifera indica* (Mango), *Zea mays* (Maize), *Phaselous vulgaries* (Beans), *Artocarpus laakochha* (Badahar), *Capsicum annuum* (Chillies), *Abel moschusesculentus* (Okra) etc. The soil of home garden is fine, black, and coarse.

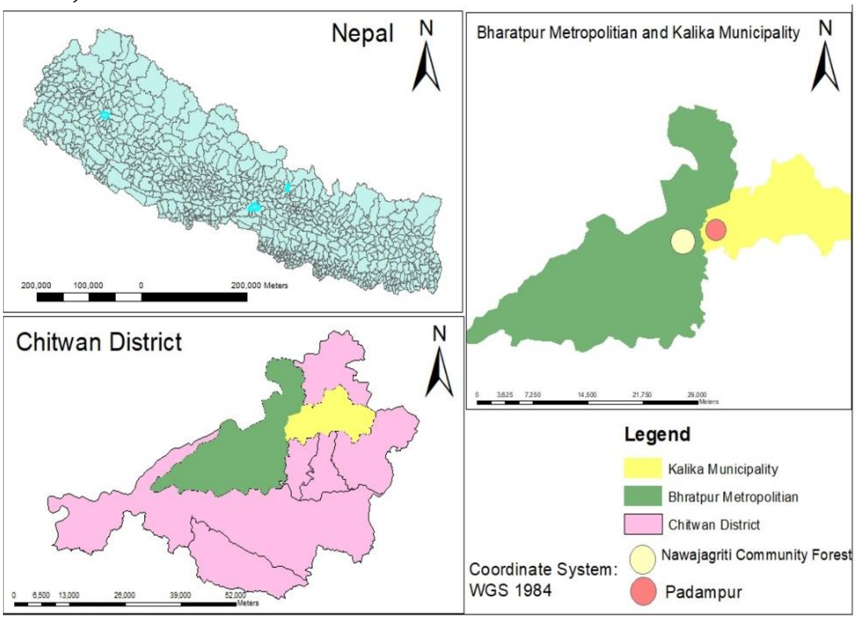

Figure 1: Map of study area

Soil Sampling

A total of 18 soil samples (2 land uses × 3replicates × 2 sampling depths and one composite sample from each pit) (9 from forests, 9 from agroforestry; and 3 composite samples from each land use type) were taken and analyzed for soil organic carbon and nutrient status. Three pits were dug by a spade on each land use. Soil samples around half kilogram, were collected from 0-10 cm and 10-30 cm depth intervals. One composite sample was collected from each pit in both land use types. Undisturbed soil samples were collected from each layer from each pit using soil core (5.7cm diameter and 20cm height). The collected soil samples were packed in plastic bags, labelled, air-dried, and taken to laboratory for analysis. The overall field

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measurements were based on guidelines of Asia Network for Sustainable Agriculture and Bio resources (ANSAB) (Subedi, 2010).

Soil analysis

Soil samples were analyzed separately of forest and agro-forestry land. Bulk density (BD) of soil was determined by using core sampling method (Blake and Harte, 1986) as mass per unit volume of oven dried soil. SOC stock was determined by Walkey-Black method (Tuffour *et al.*, 2014). The pH reading was taken by pH meter electrode Model: Orion 410A (Aziz *et al.*, 2011). Total Nitrogen (TN) was determined by using Semi Kjeldahl Method (Akinyele, 1991). Available phosphorus (AP) was determined by following Wolf and Baker (1985). Available potassium (AP) in soil was determined by flame photometer with 1M neutral ammonium acetate extracting solution.
Bulk density was computed using formula:

BD (g/cm^3) = (Oven dry weight of soil) / (volume of the soil in the core)……..…(1)

For the soil sample containing stone, volume of the soil (v) was determined by:

v= volume of core-volume of stone…………………… …(2)

BD= oven dry weight /v …………………………………(3)

The SOC stock was calculated by using the given formula by Pearson *et al.* (2007):
SOC (t/ha) = Organic Carbon content % × Soil Bulk Density (g/cm^3) × soil layer depth (cm)............................(4)
Total Nitrogen (t/ha) = % Nitrogen × Soil Bulk Density (g/cm^3) × soil layer depth (cm)…………………..(5)

Data analysis

The significant difference of BD, SOC, TN, AP, AK and pH was tested using ANOVA at 5% level of significance. SPSS software (IBM SPSS Statistics, IBM Corporation, Version 20) was used for statistical analysis of the data.

RESULTS AND DISCUSSION

Bulk density and soil organic carbon

The average BD of forest soil was found higher (1.53 g/cm^3) than average BD of agroforestry land 1.31 g/cm^3 (Table 1). There was some variation in the BD with respect to depth of soil in each land use which indicates that BD is dynamic property of soil which varies with various conditions such as, it increases with profile depth, due to changes in organic matter, porosity and compaction and land use practices (Perie & Ouimet, 2008). This study also found BD increasing with increase in depth of soil in both land uses. The lower BD in agroforestry i.e., home garden was probably due to accumulation of higher organic matter from the added organic amendments from multistory system or inorganic amendments as well as regular practice of tillage. However, the forest was composed of *Shorea robusta* with old and degraded trees with poor forest management practices. Also, the forest was highly grazed and compacted by regular movement of forest users for litter, fodder and fire wood collection which might cause reduction in the amount of organic matter than in agroforestry. The decrease in BD in agroforestry was due to the higher organic matter content, better soil aggregate, better least limiting water range and increased root growth with lower cone penetration resistance and bio pores due to high organic matter content which is similar to findings of Bandyopadhyay *et al.* (2010).

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Table 1 : Bulk Density (g/cm³) in different land uses

Land Use	BD (g/cm^3)	SD	SE	Min	Max	P value
Forest	1.53	0.07	0.03	1.39	1.61	P=0.28
Agroforestry	1.315	0.33	0.13	0.92	1.91	

The average SOC stock was found higher in agroforestry land than in forest. The organic carbon content was found higher in upper layer (0-10 cm) in both forest and agroforestry than in lower layer which is shown in Table 3. SOC stock was found higher in agroforestry (25.67 t/ha) than in forest (24.85 t/ha). However, there was no significant difference in SOC t/ha (p=0.82). The organic carbon was found higher in agroforestry which might be due to presence of more organic matter, adoption of better soil management practices, use of farm yard manure (FYM), compost manures and organic and inorganic fertilizers. Kaur *et al.* (2008) reported that soil organic matter dynamics were affected by long-term use of organic and inorganic fertilizers under maize-wheat and observed that continuous application of fertilizers increased SOC stock over its initial content. The highest increase of soil carbon stocks in home gardens was due to its highest tree density and litter production, which positively correlate with changes of soil carbon as found by (Islam, Dey and Rahman, 2015). The lower amount of SOC stock was found in forest than home garden due to farming activities such as collection of forest fodder and litter for livestock feed, bedding, and the making of compost, which was eventually applied to farm and home gardens as a nutrient source which are likely to have led to low SOC accumulation in the forest and the enrichment of farm land (Tiwari, 2008). Kassa *et al.* (2017) reported similar SOC stock under forest and agroforestry whereas in this research SOC stock was found higher in agroforestry which might be due to higher accumulation of organic matter and presence of different mixtures of plants.

Table 2: SOC % and total SOC stock of different land use at different depth interval

Land use	Depth				Mean SOC %
	0-10 cm		10-30 cm		
	avg SOC %	avg SOC t/ha	avg SOC%	avg SOC t/ha	
Forest	0.75	11.40	0.43	13.44	0.59
Agroforest	0.95	10.64	0.55	15.02	0.75

Table 3: SOC stock t/ha in different land uses

Land use	SOC t/ha	SD	SE	Min	Max	P value
Forest	24.84	2.33	0.95	8.97	15.44	P=0.82
Agroforest	25.66	3.71	1.51	9.41	19.64	

Soil Chemical Properties

Soil pH

Soil pH was found higher in the Agroforestry land (6.5) than in forest (6.29). However, there was no significant difference of soil pH (p=0.11) between both land use type at 5% level of significance (Table 2). Bhatt (2013) found that soil pH of Improved Agroforestry (6.27±0.28) was higher than forest (6.19±0.29). The lower pH of the forest reveals that the forest soil is acidic which might be due to the presence of the S*horea robusta* dominantly in the forest (Sharma and Das, 2009). The pH value of the Agroforestry land was found higher which might be due to suitable agricultural practices with compost fertilizer in proper amount and suitable supply of water. The primary reason for acidic soils in forest could be due to presence of elements such as silica, intense leaching of basic cations during monsoon season,

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and the atmospheric nature of aluminum in these soils (Pandey *et al.*, 2018). Also it might happen because of higher organic matter content and less evaporation from surface in the land. This result are consistent with the report published by Islam and Weil (2000) who found that forest and reforested soils contributed significantly lower pH values than cultivated and grassland soils.

Table 4: Soil pH in different land uses

Land use	pH	SD	SE	Min	Max	P value
Forest	6.29	0.24	0.14	5.57	6.01	p=0.11
Agroforest	6.5	0.49	0.28	6.3	7.06	

Total Nitrogen (TN)

TN was found higher in agroforestry land (0.21%) than in forest (0.08%). However, there was found non-significant difference (p=0.12) in between two land uses. (Table 2). TN exists in organic forms and inorganic (or mineral) forms such as plant available ammonium ($NH^{4+)}$) and nitrate (NO^{3-}). The majority of TN is bound in soil organic matter. Thus, calculating TN gives the concept of both organic and inorganic nitrogen status. TN availability under agroforestry systems was higher which might be due to high organic inputs from the multi-story system with Nitrogen fixing species, fodders and vegetables as well as use of inorganic fertilizer. The lower amount of TN in forest was due to lower organic matter content due to use of leaf litter as mulch by users and poor and degraded condition of forest. The result is also consistent with Singh *et al.* (1997) who found agroforestry as a better land use option than forestry and agriculture in moderately alkali soils. The soil conditions were much improved in terms of the buildup of soil organic matter, TN, TP, and TK when trees were associated with agricultural crops. Also, it has been reported that the organic/inorganic amendments or their combination application has significantly increased TN in agroforestry (Abbasi & Thair, 2012).

Table 5: Total Nitrogen (%)

Land use	TN %	SD	SE	Min	Max	P value
Forest	0.08	0.007	0.004	0.07	0.08	p=0.12
Agroforest	0.21	0.11	0.06	0.11	0.34	

Available Phosphorus (AP)

AP was found comparatively higher in agroforestry land 37.21 ppm than forest 7.42 ppm (Table 2). Low levels of AP from forest soil might be due to the forest vegetation itself with large biomass which uptake and immobilize phosphorus in plant biomass and causing depletion on soil (Tilahun, 2007). Phosphorus movement is heavily influenced by soil properties and land management practices such as cropping and tillage. The application of organic and inorganic fertilizers might be the reason of increasing AP in agroforestry. The result i.e., higher amount of AP in agroforestry land might be due the use of poultry manure along with wheat straw residue, Urea (UN) and DAP which seems to be justified in light of results made by Bhatt (2013) who found AP significantly higher in improved agroforestry than in forest. The ANOVA test shows that there was no significant difference of AP (p= 0.08) between both land use type at 5% level of significance (Table 2).

Table 6: Available phosphorous (ppm)

Land use	AP	SD	SE	Min	Max	P value
Forest	7.42	4.93	2.85	2.77	12.6	p=0.08
Agroforest	37.21	22.18	12.80	15.07	59.43	

Available Potassium (AK)

AK was found higher in agroforestry land 152.22 ppm than forest 108.8 ppm value (Table 2). The higher availability of AK of agroforestry might be because of application of ash by burning of crop stubbles and leaf litters after crop harvest. Chauhan *et al.* (2014) also reported higher amount of AK in agroforestry than in forest, pastures, cultivated lands which might be due to recycling of nutrients. The damaged fruits, crops and shed leaves were mixed with soil and undergo recycling to release potassium. However, lower amount of AK in forest might be due to poor vegetation management which caused leaching of potassium. The ANOVA test shows that there was no significant difference of AK (p=0.45) between both land use type at 5% level of significance (Table 2).

Table 7: Statistics of Available Potassium

Land use	Mean AK	SD	SE	Min	Max	P value
Forest	108.8	78.92	45.56	42.62	196.15	p=0.45
Agroforest	152.22	45.01	25.99	113.3	201.52	

Carbon/Nitrogen ratio (C: N ratio)

C: N ratio was found higher in forest (7.45) than in agroforestry land (3.76) respectively. One-way ANOVA at 5% level of significance revealed that there is significant different between land use system (p=0.0031) as represented in Table 2. The ratio was found smaller in agroforestry land as compared to forest which might be due to higher mineralization, presence of nitrogen fixing plants, use of farmyard manures and fertilizers and oxidation of organic matter. Bayala *et al.* (2018) found low C: N ratio in alley cropping as compared to mulched land and Parkland with trees which might indicate the quality of organic matter which is in principle from nitrogen fixing species (Palm and Sanchez, 1991) and also found lower C: N ratio in alley cropping which was associated with higher mineralization of biomass. Puget and Lal (2005) reported higher C: N ratio in forest soil as compared to grassland which might reflect variations in qualities of organic residues entering the soil organic matter pool and presence of contrasting vegetation.

CONCLUSION

Soil properties like pH, TN, AP, P, and SOC were found higher in agroforestry land whereas these properties didn't differ significantly among both land uses. Bulk density and C: N ratio were found higher in forest. However, BD doesn't vary significantly but C: N ratio varies significantly among forest and agroforestry. Regular tillage, use of organic manures and fertilizers and good management in agroforestry practices increases the condition of soil rather than poor, degraded and unmanaged forest. So, regular silviculture based management of forest is necessary for increasing soil quality in *Shorea* forest.

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Authors' Contributions

Ms. Yamuna Paudel: Experimentation, data processing and analysis and prepare manuscript
Dr. Gandhiv Kafle: Project and experiment design, guide to implementation, regular monitoring, providing necessary guidelines for research.

Conflicts of Interest

The authors declare that the authors do not have any competing interests.

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