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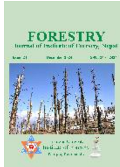

Influence of Forest Management Regimes and Soil Depth on Some Selected Soil Properties

Asmit Neupane[1*], Anisha Dhakal[1], Praju Khatiwada[2], Bashundhara Acharya[3] and Ashma Dahal[2]

[1] *Institute of Forestry, Pokhara Campus, Tribhuvan University, Pokhara, Nepal*

[2] *Kathmandu Forestry College, Kathmandu, Nepal*

[3] *School of Forestry and Natural Resource Management, Institute of Forestry, Tribhuvan University, Kathmandu, Nepal*

KEYWORDS

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ABSTRACT

Forest management activities and soil depth can significantly impact soil characteristics and carbon sequestration. This study assessed variations in soil pH, Soil Organic Carbon (SOC) %, and Available Nitrogen across different community-based forest management (CBFM) regimes and soil depths in the Mahottari district of Nepal. The results indicated significant differences among management regimes for all three soil parameters ($p < 0.05$). Soil pH ranged from 5.6 ± 0.2 in Leasehold Forest (LF) to 6.4 ± 0.1 in Religious Forest (RF), showing a decreasing trend from LF to Community Forest (CF), Collaborative Forest Management (CBM), and RF, with no consistent depth-related trend ($p = 0.12$ for depth interaction). SOC % varied significantly, declining from 2.6 ± 0.3% in CF to 1.8 ± 0.2% in RF and 1.5 ± 0.1% in LF ($p < 0.001$), with a consistent decrease across depths. Similarly, Available Nitrogen showed a linear decline across regimes, from 230 ± 15 mg/kg in CF to 140 ± 10 mg/kg in LF ($p < 0.01$), with depth also influencing nitrogen availability ($p < 0.05$). These findings suggest that while soil pH remains relatively stable with depth, SOC % and Available Nitrogen are highly sensitive to both management regime and soil depth. The study recommends targeted forest management practices to enhance soil organic carbon stocks and improve soil fertility across CBFM regimes.

INTRODUCTION

Soil is a dynamic system composed of organic matter, mineral nutrients, air, water, and living organisms, shaped by environmental factors like climate, parent material, topography, organisms, and time (Sitaula et al., 2004). The unique properties of soil arise from varying proportions of organic and mineral components and their responses to different environmental conditions (Nortcliff et al., 2011). Analyzing the vertical distribution of soil organic carbon

*Corresponding author
Email: asmitneupane111@gmail.com
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(SOC) and key nutrients such as nitrogen (N), phosphorus (P), and potassium (K), across different land uses can provide valuable insights into the current state of SOC and nutrient pools (Kirby, 1985). Typically, surface horizons are rich in organic materials derived from plant and animal residues (Nortcliff et al., 2011). The vertical distribution of soil nutrients is influenced by processes such as leaching, weathering, atmospheric deposition, and biological cycling (Trudgill & Coles, 1988). While leaching can move nutrients downward, biological cycling brings them back to the surface, where they are absorbed by plants and recycled through litter fall (Kirby, 1985; Trudgill & Coles, 1988; Stark, 1994).

Vegetation is crucial in soil formation (Chapman & Reiss, 1992). Plant tissues, both aboveground litter and belowground root detritus, are the primary sources of soil organic matter, significantly affecting soil properties like pH, texture, water-holding capacity (WHC), and nutrient availability (Johnston, 1986). Organic matter is vital for soil fertility, providing energy and building materials for microorganisms (Brady, 1984; Allison, 1973). Nutrient availability varies among ecosystems, leading to differences in plant community structure and productivity (Binkley & Vitousek, 1989; Chapin et al., 1986).

Effective land management and planning are essential for restoring soil quality and ensuring sustainable productivity, as soil quality is closely linked to land use and management practices (Oyetola & Philip, 2014). Various forest management practices, such as community forest management, pro-poor leasehold forest management, collaborative forest management, and buffer zone management, actively involve local communities in planning, implementation, and benefit-sharing (Government of Nepal (GoN), 2016). Community-based forest management is widely recognized as a creative and effective approach to managing forest resources (Acharya, 2002). Forest management activities can significantly impact soil characteristics and carbon sequestration (Johnson & Curtis, 2001). By selecting tree species that influence litter composition, root depth, and thinning regimes, forest management can affect the decomposition and quality of forest floor.

While much attention has been given to the aboveground dynamics of forest ecosystems, the role of forest management in altering belowground soil properties and processes remains underexplored, particularly across soil depths. The choice of management regime directly impacts the quantity and quality of organic matter inputs into the soil and the subsequent decomposition and nutrient cycling processes (Jandl et al., 2002). For example, Community Forests (CF) often incorporate diverse tree species, fostering higher organic matter inputs and microbial activity, whereas Leasehold Forests (LF) prioritize specific species for economic benefits, potentially reducing soil nutrient inputs over time (GoN, 2016). Soil depth further modulates these impacts, as surface layers are primarily influenced by organic matter decomposition and nutrient recycling, while deeper layers reflect leaching, root exudates, and mineral weathering processes (Stark, 1994).

In Nepal, vegetation zones reflect significant variations in soil properties (Bhatta, 1981). The Terai region, characterized by alluvial soils deposited by rivers, supports dense Sal forests and other valuable timber species. However, these forests are threatened by indiscriminate cutting, recurrent fires, and uncontrolled grazing. Globally, more than 50% of soils are highly weathered, leached, and nutrient-poor, making nutrient conservation critical (Sanchez, 1976; Kibret et al., 2023). Soil degradation often results from a lack of nutrient inputs. Restoring degraded soils by reestablishing native forest types can help rebuild soil carbon pools. Modern research explains that forest restoration generates healthy soil and climate-reducing effects by storing more carbon in the environment (Dangwal et al., 2022; Sharma et al., 2020). This can be achieved naturally, supported by anthropogenic nitrogen deposition and climate change, or through interventions like under-planting, liming, and fertilization (Jandl et al., 2002).

Researchers have demonstrated that soil pH, SOC, and nitrogen availability are highly sensitive to forest management practices and vary across soil depths (Johnson & Curtis, 2001). For instance, surface layers in managed forests generally show higher SOC concentrations due to litter deposition, whereas deeper layers often experience reduced SOC and nutrient availability due to limited organic matter inputs and greater mineralization rates (Nortcliff et al., 2011). These findings underscore the importance of integrating soil depth into forest management strategies to enhance productivity and carbon sequestration.

Soil nutrients like nitrogen, phosphorus, and potassium, along with organic and inorganic materials, micronutrients, and water, are essential for plant growth (Tale & Ingole, 2015). Understanding soil physical and chemical properties is crucial for effective soil and crop management and guiding soil research (Wasiullah et al., 2010). Information on soil properties, especially soil depth, is vital for sustainable forest management. Quantifying soil organic carbon helps assess productivity, sustainability, health, and carbon sequestration potential (Vashum et al., 2016). A deeper understanding of soil chemical processes is essential for developing better resource management strategies and managing terrestrial ecosystems at regional and global scales (Tale & Ingole, 2015).

This study aims to assess the influence of forest management regimes and soil depth on selected soil properties in different community-based forest management regimes in Mahottari District, Nepal. The research examines two main relationships regarding forest management practices and soil conditions: (i) forest regimes substantially impact soil pH and potential nutrient levels, including SOC and nitrogen availability, and (ii) deep soil layers directly affect SOC levels together with nitrogen content while showing reduced influence on soil pH values. By examining the interplay between forest management and soil depth, the research provides critical insights into optimizing soil nutrient dynamics and supporting sustainable forest management.

MATERIALS AND METHODS

Study area

The study was conducted in the Mahottari district of Madhesh Pradesh (Figur 1). Geographically, the study area ranges from 26°54'6.84" to 27°08'46.90" latitude and 85°47'42.67" to 85°56'42.97" longitude. It has an altitudinal range of 300 to 1000 meters above mean sea level with an area coverage of 1,00,200 hectares. The physiography is divided into plain Terai in the south and Bhabar and Chure in the North. The district's climate varies from tropical to sub-tropical to lower temperate with hot summer and cold and dry winters. The average annual precipitation of the district is found to be 1841.1 ml, with 80 % of the rain falling in the monsoon (Lillesø et al., 2005). The district has a forest area of 22,246 ha where forest management activities have been carried out by adopting different forest management modalities. Temperature across the district spans from 10°C during winter to 40°C in summer (DHM, 2021). Soil fertility is greatly influenced by climate-controlled soil moisture retention and organic matter decomposition (Lal, 2020). Different seasonal patterns of temperature and precipitation hold essential impacts on soil microbial behavior as well as nutrient recycling and plant development processes, thus influencing the quality of soil structure and fertility (Singh et al., 2022). The region's varied topography, land types, parent materials, and management interventions create diverse environmental conditions that shape the soil's physical and chemical characteristics. According to MoFE (2020), the main types of soil found in the study site consist of sandy loam dominant in the Terai plains alongside loamy soils prominent in the Bhabar region, and shallow rocky soils located in the Chure hills. These variations in soil texture influence water-holding capacity, erosion susceptibility, and nutrient availability across different forest management regimes (FAO, 2019). Sandy loam soils in the Terai region drain quickly but yet retain fewer nutrients, whereas loamy soils in the Bhabar region combine appropriate soil aeration with soil fertility (Sharma & Bhattarai, 2021).

The research sites and their locations were selected according to three main criteria, which included different forest management approaches, ecological diversity, and site accessibility (Poudyal et al., 2023). Four forest management groups were chosen for the study due to their widespread legal recognition in Nepal, according to MoFE (2020). These forests include Community Forest (CF) as well as Collaborative Forest Management (CBM), Religious Forest (RF), and Leasehold Forest (LF) because they have distinct governance practices along with management approaches that affect soil characteristics in different ways (Gautam & Mandal, 2013). The research included these management systems because they displayed diverse levels of management practices in conjunction with different forest compositions and soil protection measures (Labadie et al., 2024). The four forest regimes—RF, LF, CF, and CBM—dominated the study area, thus enabling researchers to evaluate properly forest management effects on soil attributes (MoFE, 2020). The four distinct CBFM regimes were Sita Community Forest, Gadanta Collaborative Forest, Tuteshornath Religious Forest, and Ratukhola Leasehold Forest. These regimes represent diverse forest types, management interventions, and management durations. Sita Community Forest is dominated by a natural mixed broadleaf forest with *Shorea robusta* (Sal) as the primary species. Management interventions in this regime include regular silvicultural operations such as thinning, pruning, and controlled grazing, which have been implemented for over 15 years. The forest is located in the fertile plains of the Terai, with gentle slopes and alluvial soils enriched by organic matter from adjacent agricultural lands.

Gadanta Collaborative Forest is also a natural mixed broadleaf forest dominated by *Shorea robusta*, with sustainable forest management practices introduced about 10 years ago. Collaborative efforts focus on sustainable harvesting, fire prevention, and active community participation. This regime is situated in gently undulating terrain within the transition zone between the Bhabar and Chure ranges, characterized by fluvial and colluvial deposits that result in moderate soil fertility.

Tuteshornath Religious Forest is a dense mixed broadleaf forest with *Shorea robusta* as the dominant species, interspersed with sacred groves. Managed for over 20 years, the regime emphasizes conservation and religious preservation with minimal silvicultural interventions. Located in the Chure range, this forest lies on steep slopes with shallow soils derived from shale and sandstone parent materials. The area's religious significance has historically guided management practices.

Ratukhola Leasehold Forest differs from other regimes, consisting of plantation forests dominated by *Emblica officinalis* (Amla) and *Acacia catechu* (Khair). Leasehold forest management practices began about 12 years ago, aiming to restore degraded lands, control soil erosion, and support livelihoods for economically disadvantaged groups. Situated in the foothills of the Chure range, this regime features eroded, gravelly soils originating from Chure-derived rivers.

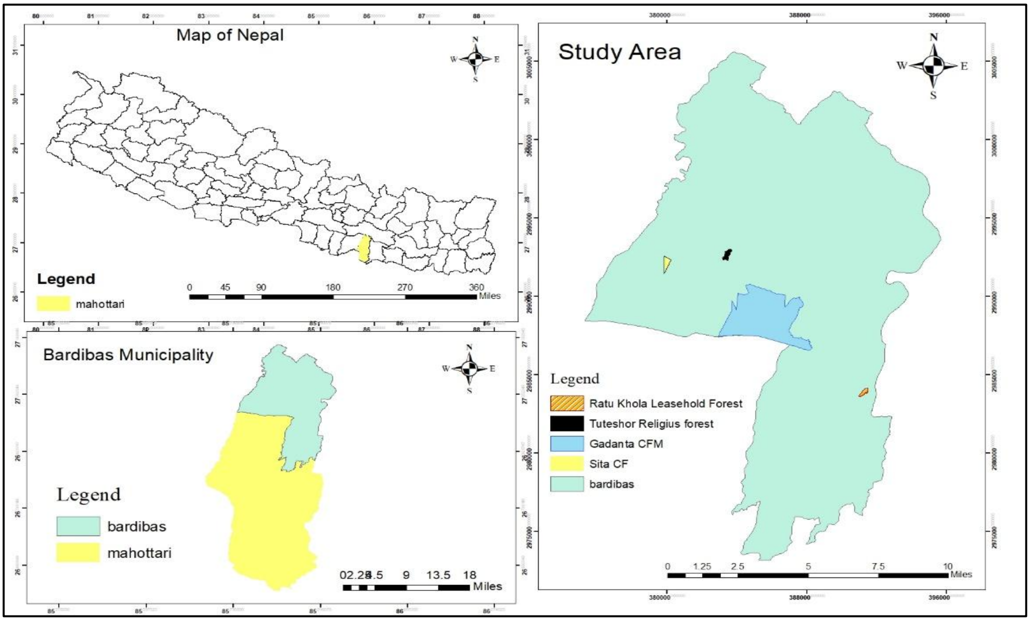

Figure 1: Location map of the study area.

Data collection

Soil sampling: Soil sampling was conducted using stratified random sampling method across the four community-based forest management regimes. The selection process used stratified random sampling, which delivered unbiased information related to soil properties throughout management zones and soil depth layers (Jones et al., 2021). We randomly selected testing locations within each forest type while keeping away from sites affected by human disturbances like trails and settlements, according to Dahal et al (2015). The sampling method minimized the risk of selecting identical locations twice, and it maintained results that were representative of all study areas. To account for vertical soil variation, samples were collected from three depths: 0-15 cm, 15-30 cm, and 30-45 cm. The systematic analysis considered every forest management system as an individual experimental segment. We employed GIS-based spatial analysis to produce random points that were distributed across sampling grids to guarantee unbiased site selection. Proportional sampling distribution from the various forest types was achieved through this method, which minimized the risk of concentration patterns in specific regions (Dangwal et al., 2022). The sampling was performed using a soil corer (15 cm height and 7 cm diameter), resulting in a total of 36 composite soil samples. The sample distribution included 9 samples each from Sita Community Forest and Tuteshornath Religious Forest, 15 samples from Gadanta Collaborative Forest, and 3 samples from Ratukhola Leasehold Forest. The variation in sample size was determined by the differing forest sizes and management areas within each regime, ensuring representative sampling. GPS coordinates of the sample plots were recorded for spatial referencing.

The soil sampling was designed to capture the impact of differing management interventions, such as selective harvesting, grazing control, and plantation activities, on soil properties. While initial soil conditions were assumed to vary due to diverse physiography and management histories, all comparisons were conducted within the scope of observed management impacts rather than initial soil homogeneity.

Figure 2: Data collection using soil corer (Source: Author)

Soil sample analysis: Soil samples were analyzed for pH, soil organic carbon (SOC), and available nitrogen (N) using standard methodologies. For pH, the suspension method was employed as outlined by Sharma & Bhattarai (2020). SOC was determined following the Walkley-Black method (Walkley & Black, 1934), while available nitrogen was calculated indirectly from SOC using established empirical formulas (Subba Rao, 1982). Depending upon the pH values, the type of soil reactions is given in Table 1.

Table 1: Soil pH rating table

pH range	Soil reaction rating
<4	Extremely acidic
4-5	Strongly acidic
5-6	Moderately acidic
6-7	Slightly acidic
7	Neutral
7-8	Moderately alkaline
>8.5	Strongly alkaline

Source: Sharma & Bhattarai (2020)

Data analysis

Data from laboratory analysis were processed using Microsoft Excel. Descriptive statistics were applied to calculate mean values and standard deviations for each parameter. Analysis of Variance (ANOVA) was performed to evaluate the significance of differences in pH, SOC, and available nitrogen across the four forest management regimes and three soil depths. An α-value of 0.05 was used to determine statistical significance, and F-values and p-values were reported to identify significant interactions. Before conducting ANOVA, data were tested for normality using the Shapiro-Wilk test. The results indicated that soil pH, SOC %, and available nitrogen met the assumptions of normality ($p > 0.05$), justifying the use of parametric statistical tests (Ghasemi & Zahediasl, 2012; Kim, 2015).

RESULTS AND DISCUSSION

Soil properties under different forest management regimes and soil depth

Soil pH, SOC% and Available nitrogen content in all types of CBFMS within three soil horizons are displayed in Table 2. All values are the mean values of each replication.

Soil pH: Soil samples collected from all the sites were found to have variation in soil pH ranging from strongly acidic to nearly neutral, referring to the soil pH interpretation chart in Figure 3 (Soil Management Directorate, 2018). The mean pH of soil of all depths was found to be highest under leasehold forest, 7.167 (nearly neutral), and lowest under religious forest 5.67 (moderately acidic), whereas, the mean pH of collaborative and community forest fell under 5.902 (moderately acidic) to 6.2355 (slightly acidic).

Table 2: Soil properties according to management regimes and soil depth

Forest management regime	Depth(cm)	pH	Soil Organic Carbon (SOC %)	Av. Nitrogen (kg\ha)
Community Forest	0-15	6.28	0.9736	560
	15-30	6.31	0.7468	540
	30-45	6.11	0.5872	377.3
	Mean	6.23	0.7692	492.4
Collaborative Forest	0-15	6.124	0.7004	414.4
	15-30	5.823	0.6603	408.8
	30-45	5.76	0.6212	395.4
	Mean	5.90	0.6606	406.2
Religious Forest	0-15	5.48	0.8008	451
	15-30	5.78	0.5818	377
	30-45	5.75	0.4041	238.33
	Mean	5.67	0.5956	355.44
Leasehold forest	0-15	7.2	0.486	272
	15-30	7.13	0.1489	83
	30-45	7.17	0.189	105
	Mean	7.167	0.2746	153.33

The results in Figure 4 showed a decreasing trend in soil pH from Leasehold Forests (LF) to Community Forests (CF), Collaborative Forest Management (CBM), and Religious Forests (RF). This suggests that management practices in Leasehold Forests, which experience higher human activity and potential nutrient depletion, might result in soil acidification.

Sludge management techniques only partially determine soil acidity, but other important factors, such as precipitation levels, along with altitude and ambient temperatures, remain essential. Base cation leaching through precipitation exceeds at high rainfall levels, which increases acidity in soils, but alkaline conditions develop with reduced precipitation due to limited leaching (Bünemann et al., 2018). The range of elevation in a landscape creates different drainage paths, which indirectly modifies organic matter storage and, consequently, soil pH values. The decomposition process of microorganisms within organic matter releases both acid and base compounds, which subsequently affect soil pH values. The inconsistent relationship between pH and depth ($p = 0.9$) implies that surface interventions, along with environmental elements, influence soil acidity more than depth alone, according to Wiesmeier et al. (2019). On the other hand, Community Forests (CF), which are generally less disturbed, tend to maintain a more neutral to slightly alkaline pH, likely due to better organic matter management and fire control. However, the absence of a consistent pattern of pH change with increasing soil depth was noted, suggesting that the influence of depth on soil pH might be overshadowed by surface-level management practices or external environmental factors. Further exploration of specific soil amendments or vegetation types in each management regime could provide more clarity on this observation in Figure 4. The pH range in the present study was in line with the values reported by Sigdel (1994) in Chitwan National Park (5.90-6.42), by Karki (1999) in Koshi Tappu Wildlife Reserve (6.4-7.1), or by Singh & Singh (1985) in *S. robusta* dominant central Himalaya forests (6.7-6.8). This may be due to local environmental factors such as aspect, rainfall, and vegetation composition (Paudel & Sah, 2003). Litter decomposition, together with nutrient cycling in National Parks, remains unaffected by human activities because these parks experience minimal human disturbance. Managed forests receive different levels of human management because owners practice selective forestry techniques combined with controlled grazing programs and controlled fire operations (FAO, 2019). The research activities analyzed pH variations by modifying organic decomposition and decomposition rates, thus helping explain the data discrepancies with protected area results (Ziter & MacDougall, 2021).

The highest soil pH in the leasehold forest could be due to the leasehold forest being a degraded flooded riverine area converted into a leasehold forest. According to Budke et al. (2008), riverine forests were slightly alkaline because of occasional floods, given that forest soil had a higher pH. Soils with higher pH generally had poorer capacity for regeneration (Suoheimo, 1995). Good Sal regeneration areas had low pH in soils (Bhatnagar, 1965). The finding of higher acidity in the sites was consistent with other observations (Banerjee et al., 1986; Singh et al., 1987). The lower pH may be due to the higher number of Sal trees and their saplings (Bhatnagar, 1965) and the accumulation of leaf litter as well. In our findings, higher values of soil pH were observed at 15-30 cm depth than at other depths for community and religious forests. The cause may be attributed to the removal of basic cations from the surface horizons by leaching, causing a rise in basic cations along the soil depth from the top to the bottom of the soil profile since basic cations and pH often have a strong and favorable association (Fetene & Amera, 2018). Research conducted by Osujieke et al. (2017) showed a decrease in pH with soil depth in an irregular pattern, which was only seen in collaborative forests in this research. It could be due to greater inputs of organic matter through the above-ground litter.

Single-factor ANOVA for pH between different forest management regimes showed that the differences in the soil pH were statistically significant in all four forest management regimes ($p = 0.01$). The differences among the soil pH values at all depths in the study area were statistically insignificant, as observed in the single-factor ANOVA ($p = 0.9$). The study conducted by Gautam & Chettri (2020) showed that the vertical differences among the soil pH were statistically insignificant in all three different forest regimes; however, the differences among the soil pH values at all depths in the three different forest regimes were statistically significant, which is similar to our result. Similarly, Tiwari et al. (2006) showed the result in which pH, SOC, and Nitrogen varied significantly with land use.

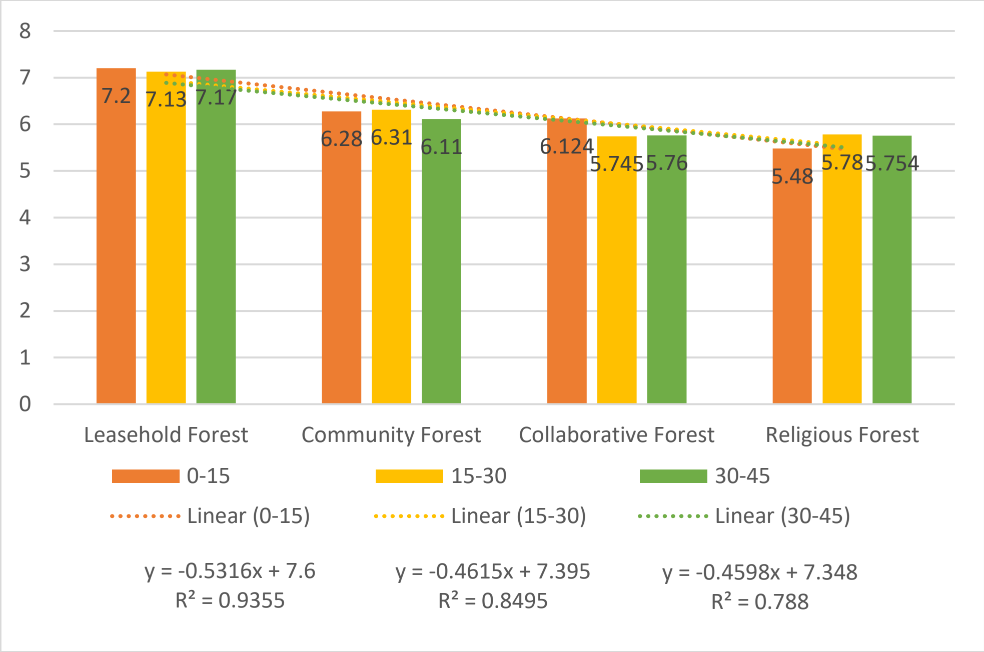

Figure 3: pH under different depth according at different management regimes

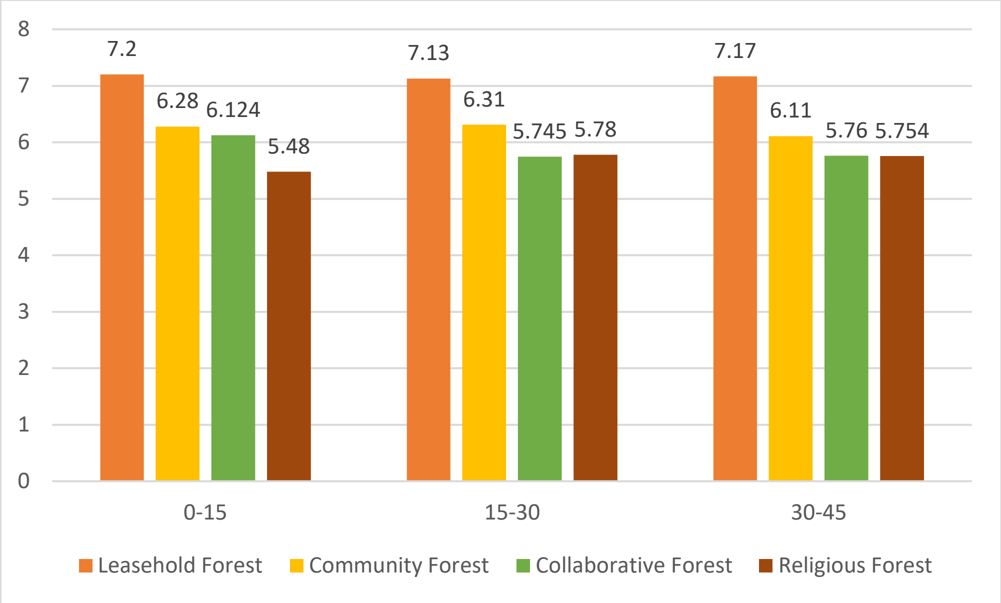

Figure 4: pH of soil under different management regimes at different depths

Soil organic Carbon (SOC) %: SOC had been found highest under Community Forest in all depths and lowest under Leasehold Forest (Figure 5). However, the SOC values in the study area were consistently lower than the typical threshold of 1% often found in forest soils. According to the NARC (2013) soil fertility rating chart, all SOC values, including the highest (0.9736%), fell within the very low range for SOC%. This is in contrast to the 1.8-4% SOC values reported from forests in Riyale (Shrestha, 1996), and within the 0.23-1.8% range reported for Chitwan National Park by Sigdel (1994).

The observed low SOC values, particularly across all management regimes, can be attributed to a combination of factors such as poor organic matter input, climatic conditions, and land use practices. Despite the Community Forest (CF) regime having the highest SOC levels, the values remain lower than typically expected in forest ecosystems. One possible explanation is the relatively short duration of management practices in the study area and high rates of soil erosion due to the topography, which may hinder SOC accumulation (Shrestha, 1996). Leasehold forests, on the other hand, often experience more intensive land use pressures, such as grazing and cutting, leading to reduced SOC. Moreover, the overall tropical climate, characterized by high temperatures and rapid decomposition rates, could result in the faster breakdown of organic matter, thereby limiting SOC accumulation (Barbhuiya et al., 2008).

The study concluded that CF had the highest SOC composition, followed by CBM, RF, and LF, which could be attributed to comparatively fewer illegal anthropogenic activities, fire prevention by proper fire line management, and comparatively more decomposition of litter, which could have led to more SOC% in CF. There was a gradual decrease in SOC with increasing soil depth, as observed by Barbhuiya et al. (2008) in the tropical rainforest ecosystem of Assam, India. A similar result was observed in our study as well. It could be due to greater inputs of organic matter through the above-ground litter, animal feces, and other plant detritus (Tamhane et al., 1964; Fetene & Amera, 2018).

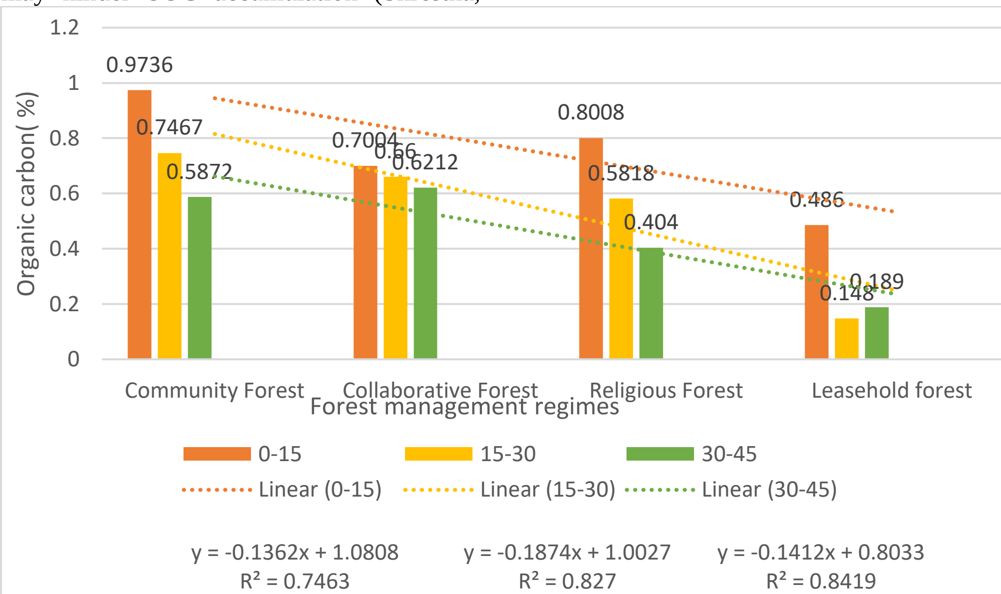

Figure 5: SOC % under different depths at different management regimes

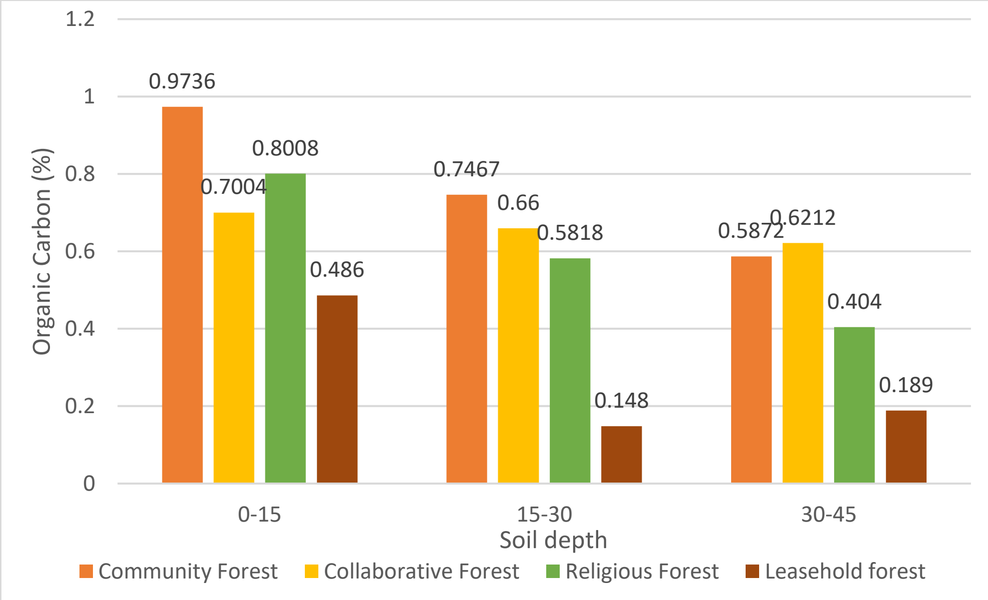

Figure 6: SOC% % under different management regimes at different depths.

Single-factor ANOVA revealed that the differences in SOC% among the forest management regimes were statistically significant ($p = 0.01$), as were the differences in SOC across the different soil depths ($p = 0.02$). This supports the hypothesis that management practices have a measurable impact on SOC levels and highlights the influence of soil depth on organic carbon content. In line with the findings of Gautam & Mandal (2013) and Gautam & Chettri (2020), the study showed a significant statistical relationship between SOC and soil depth, with a typical decrease in SOC with increasing depth, particularly in CF and CBM regimes. This is consistent with the literature, where the surface soil tends to have higher SOC due to greater organic matter inputs from litter fall, root turnover, and above-ground biomass (Fetene & Amera, 2018).

Available Nitrogen (Kg\hac): Mean Prolific Nitrogen was found to be highest under the community forest and lowest under the leasehold forest (Figure 7). In the study, the mean value was found to be from 153.33-492.4 kg/ha under different management regimes and soil depths (Figure 8). It was higher than the value (41.01-87.79 kg/ha) reported in two Sal forests in the hills of Kavreplanchowk (Pant, 1997), research conducted in *S. robusta* forest in Chitrepani (86.40-262.8 kg/ha) (Shrestha, 1997), and (329.57-399 kg/ha) in Koshi Tappu Wildlife Reserve (Karki, 1999).

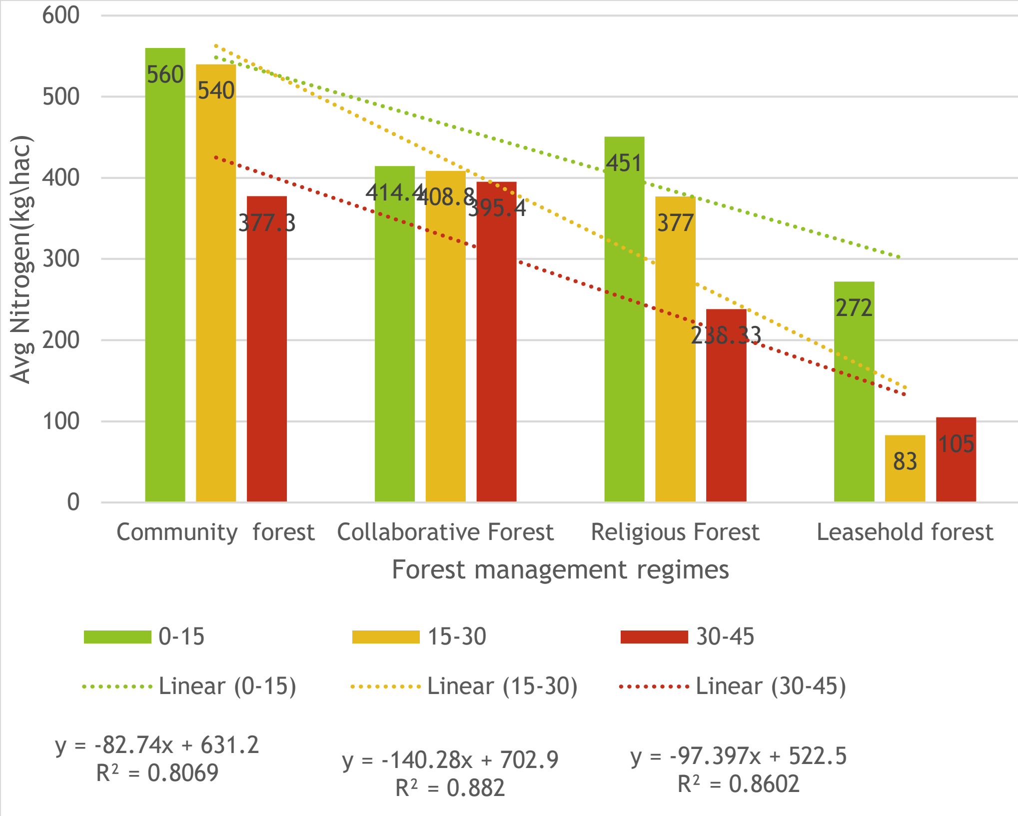

Figure 7: Av Nitrogen under different depths at different management regimes

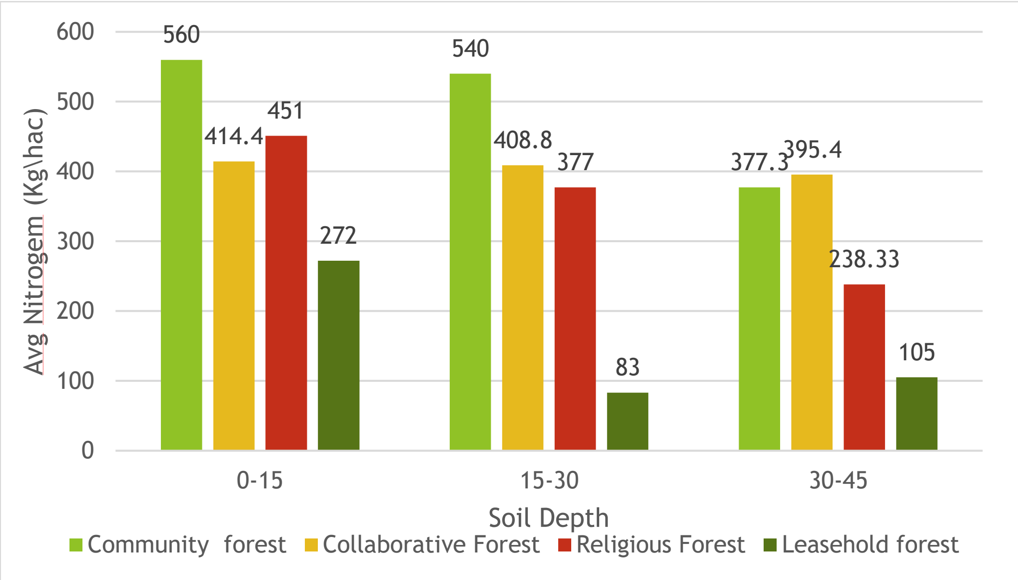

Figure 8: Available Nitrogen under different management regimes at different depths.

Of all the CBFM, Av nitrogen was found to be highest under CF and lowest under LF. This could be attributed to the natural strains, tree species composition, and management practices adopted in those forests. Also, Sandy soil was deficient in nitrogen (Sah, 1997), which could also be the reason for the lower nitrogen content in LF. Nitrogen content was found to be the highest in topsoil, which coincides with our findings (Adugna & Abegaz, 2015). The maximum nitrogen content was found on the topsoil of CF (560 kg/ha), while the lowest was on the topsoil of LF (272 kg/ha). It is probably due to the loss of organic matter by the mineralization process. Available nitrogen decreased linearly from CF, CBM, RF, and LF. The nitrogen content measurements in Leasehold Forests at 30-45 cm depth exceed those at 15-30 cm depth, which indicates probable nitrogen accumulation because of soil texture combined with previous land-use effects. Based on the study by Van Meter et al. (2020), the coarse nature of these soils impeded nitrogen seepage into deeper areas, thus resulting in its storage at lower depths. The combination of previous agricultural activities and seasonal flooding seems to have led to increased nitrogen levels at lower soil depths. Further research is needed to validate these observations and identify underlying mechanisms (Wang et al., 2023).

The differences among the available values at all management regimes were statistically significant in the ANOVA test for Av. Nitrogen between different forest management regimes (p = 0.003). Similarly, single-factor ANOVA for Av. Nitrogen between different soil depths, the differences among the Available nitrogen values at all depths in the study area were statistically insignificant (p = 0.1400924). Nitrogen also showed the trend of decrease in value with an increase in depth in all the management regimes except for leasehold forest. Av. nitrogen in the soil decreased depth-wise, similar to the result by Gautam & Mandal (2013). Different studies conducted in the eastern and northwestern highlands of Ethiopia also found a decreasing trend of nitrogen content with increasing soil depth (Yimer et al., 2007). However, no significant difference at different depths was observed in our study.

The properties of soils differ between management practices because of the effects of variations in the pattern of litter deposition and decomposition speed, together with disturbance levels. Riparian forests of Community type contain the highest stocks of SOC and nitrogen because they receive repetitive organic matter inputs without extensive soil disturbances (Gurung et al., 2015). Soil values were lowest in Leasehold Forests because they experienced historical degradation alongside reduced drop-off of organic material. The SOC measures in Collaborative and Religious Forests fell between the highest and lowest values, which corresponded to their different management levels. Forest interventions positively influence SOC content and nitrogen concentration (p = 0.01) and nitrogen content (p = 0.003), according to studies about soil fertility maintenance (Lal, 2020).

CONCLUSION

This study examined the variations in soil pH, Soil Organic Carbon (SOC) %, and Available Nitrogen across different community-based forest management (CBFM) regimes and soil depths in the Mahottari district of Nepal. It was found that Community Forests achieved the highest values of soil organic carbon and nitrogen, while Leasehold Forests recorded the lowest values based on research data. The research showed that soil pH decreased from LF to CF, then to CBM and RF, yet depth did not impact the pattern (p = 0.9). Statistical significance occurred between SOC% and soil depth changes throughout all examined management practices (p = 0.02). The soil nitrogen availability was reduced between CF and LF zones, but did not produce significant depth-derived statistical relationships (p = 0.14). Former land management practices combined with restrictive conditions of leaching might explain why LF soils contain elevated nitrogen concentrations between 30 and 45 cm.

Soil management programs must be developed in order to enhance productivity and carbon absorption levels based on these laboratory findings. The study demonstrates that forest managers should combine correct organic matter applications with fire protection and sustainable livestock management in addition to responsible logging operations to enhance soil productivity and the room for carbon storage in Leasehold Forests. The study produces practical knowledge regarding changes in soil composition caused by forest management, yet it requires an understanding of certain limitations. Inadequate persistent climate data regarding precipitation and temperature probably affected soil property analysis. The observed research outcomes potentially received influence from historical changes in land use and site disturbance patterns. Future studies should monitor soil nutrient patterns by following different management methods with extended observations of microorganism behavior, climate conditions, and soil water flow to understand completely the state of soil health within communal forest practices.

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ANNEX

Single-factor ANOVA for pH between different forest management regimes.

Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	5.801	3	1.933	4.426	0.01	2.90
Within Groups	13.979	32	0.436			
Total	19.781	35				

Single-factor ANOVA for soil pH at different depths.

Source of Variation	SS	Df	MS	F	P-value	F critical
Between Groups	0.120	2	0.060	0.100	0.90	3.28
Within Groups	19.661	33	0.595			
Total	19.781	35				

Single-factor ANOVA for Soil Organic Carbon% % between different forest management regimes.

Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	5.801	3	1.933	4.426	0.01	2.90
Within Groups	13.979	32	0.436			
Total	19.781	35				

Single factor ANOVA for Soil Organic Carbon% between different soil depths.

Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	0.392	2	0.196	4.217	0.02	3.28
Within Groups	1.535	33	0.046			
Total	1.927	35				

Single-factor ANOVA for Av Nitrogen between different forest management regimes.

Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	276594.488	3	92198.163	5.604	0.003	2.90
Within Groups	526409.511	32	16450.297			
Total	803004	35				

Single factor ANOVA for Av Nitrogen between different soil depths.

Source of Variation	SS	Df	MS	F	P-value	F critical
Between Groups	90175.17	2	45087.58	2.087304	0.140	3.28
Within Groups	712828.8	33	21600.87			
Total	803004	35				