Physicochemical Properties of Soils from Grasslands and Forests in Two Protected Areas Across Temperate and Subtropical Zones of Nepal

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ABSTRACT

Soil is the largest carbon reservoir, contains soil organic carbon (SOC) influenced by soil properties that is vital for soil fertility and carbon management. This study assessed physicochemical properties in grasslands and forests within the Annapurna Conservation Area (ACA) and Shivapuri Nagarjun National Park (SNNP) across temperate and subtropical zones. The soil temperature was lower and soil moisture was higher in the temperate ACA grassland, compared to sub-tropical SNNP, and in forests compared to the grasslands. Soil electrical conductivity was higher in ACA grasslands than forests, but lower in grassland than forests in SNNP, and overall lower in ACA than in SNNP. Both soil pH and bulk density were higher in grasslands than forests at ACA and SNNP, with a sandy loam soil texture across sites. Soil organic carbon (SOC) and organic matter were higher in ACA than SNNP, with ACA grasslands and SNNP forests showed the highest values. Soil properties differed significantly between grasslands and forests, with soil parameters varying across land uses and climate zones. Most soil characteristics apart SOC being more pronounced in temperate zone than in subtropical one. Hence, grassland and forest soils are key carbon sinks, and these soils require proper management, assessment and conservation.

Keywords: Soil properties, Land use type, Grassland, Forest, Temperate and subtropical zone

1. INTRODUCTION

Soil is the largest carbon reservoir in the terrestrial carbon cycle, holding nearly three times more carbon than all of Earth's vegetation combined (Sheikh et al. 2009). Carbon is stored in soil through contributions from aboveground organic biomass and root inputs (Beniston et al. 2014). Understanding how soil organic carbon (SOC) is distributed within the soil profile is vital for assessing soil fertility, health, carbon stock, and management practices, as this distribution varies across different vegetation types and land uses (Kopittke et al. 2022; Feeney et al. 2024). Research has shown significant variations in soil physicochemical parameters across different land use systems (Tellen et al. 2018).

The soil physicochemical properties like soil organic carbon (Shapkota et al. 2021), soil organic matter (Mayer et al. 2020), soil temperature and soil moisture (Tang et al. 2022), soil bulk density and pH (Zhang et al. 2018), soil texture (Iranmanesh and Sadeghi 2019) and electrical conductivity (Win et al. 2025) are the most recognized key factors influencing soil quality, vegetation growth, productivity, and carbon storage and sequestration, that might vary with seasonal variations, land use changes and ecological zones. More than 75% of SOC in the top meter of soil is directly influenced by human land use (Harden et al. 2018). The primary source of organic matter in soil comes from dead plant material (litter) derived from both above and below ground tissues (Mayer et al. 2020). Soil texture is one of the regulating elements that affects carbon sequestration and storage (Iranmanesh and Sadeghi 2019). The SOC levels in sandy soils are frequently low, and are considered to have a low capacity for sequestering SOC (Adhikari et al. 2017).

Nepal's grasslands cover 1.75 million hectares, providing crucial services like water filtration, biodiversity preservation, and soil erosion control (Shrestha et al. 2016). According to estimates, 0.2-0.8 Gt CO_2 per year can be absorbed in grassland soils by 2030 if management practices are altered (Ghosh et al. 2014). At the same time forests are believed to store the largest amount of carbon in terrestrial ecosystems (Bonan et al. 2008). The SOC concentration in the forest soil was significantly greater than that of other land uses (Alidoust et al. 2018). There are an estimated 726 million ha of forest in protected areas worldwide (FAO 2020).

There are currently more than one trillion tons of carbon stored in the world's forests and soils (Oli et al. 2009). Forests contain significant amounts of SOC, which must be preserved to prevent climate change (Ali et al. 2020). The SOC sequestration is influenced by temperature, soil, tree species, management practices, and litter composition (Lal et al. 2005). Accurate estimates of SOC decomposition and carbon emissions are vital for carbon modeling and decision-making (Zhong et al. 2017, Dhital et al. 2019, 2022b). Forest and grassland soils store significant carbon (Meena et al. 2018), and forests impact carbon storage capacity (Subashree et al. 2019). Protected areas store 0.5 Pg of carbon annually, but this is expected to decrease by 2100 due to climate change (Melillo et al. 2016). Land use changes may convert 5.6 million km² of protected areas (Panchal et al. 2022).

Measuring soil parameters helps predict the long-term effects of land use and climate changes (Bhutia et al. 2021). Plant remains contribute most carbon inputs to ecosystems (Paustian et al. 2019). Soils in cold, high-altitude areas store significant belowground carbon but are sensitive to climate change (Pan et al. 2011, Dhital et al. 2022a). Estimating key soil property like SOC can be enhanced using climate proxies like elevation, land use, soil practices, and vegetation (Wiesmeier et al. 2019). This study aimed to examine the various soil physicochemical properties, including temperature, moisture content, electrical conductivity, pH, bulk density, texture, organic carbon and organic matter of the soil, in the different land use types such as grasslands and forests of the temperate and subtropical zones within the Annapurna Conservation Area (ACA) and Shivapuri Nagarjun National Park (SNNP) in protected areas of Nepal.

2. MATERIAL AND METHODS

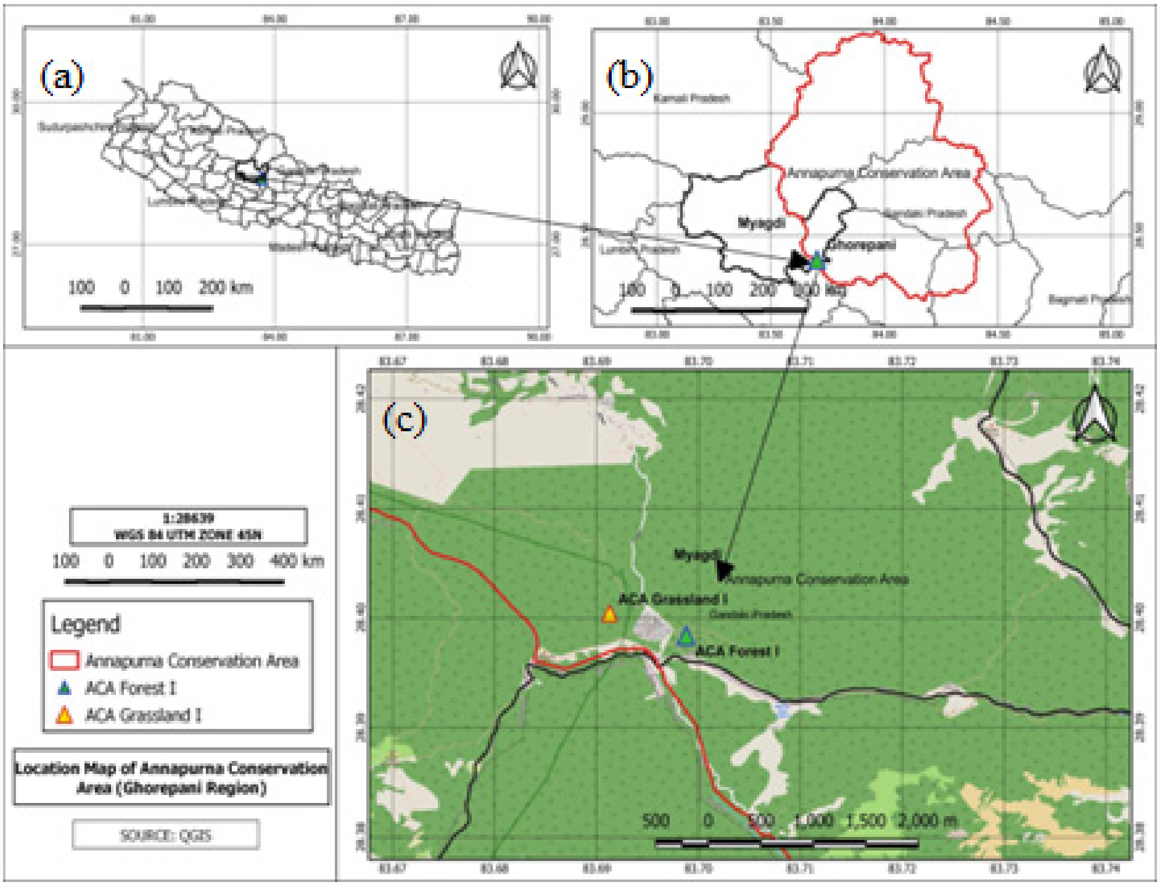
2.1 Study Site

2.1.1 Grassland (ACA Grassland 1) and forest (ACA Forest 1) site of the Annapurna Conservation Area

The temperate grassland site (ACA Grassland 1) and forest site (ACA Forest 1) of size 100m×100m in the Annapurna Conservation Area (ACA) was selected for this study which is located in the Ghorepani area. The grassland site is situated at an elevation of 2900 m asl (Figure 1i). Sampling points were chosen within the coordinates 28°24'211.1" N latitude and 83°41'752" E longitude. The plant species like *Potentila fulgens*, *Rumex nepalensis, Hemiphragma heterophyllum* etc., were dominated in the ACA grassland 1. The grassland was surrounded by Rhododendron (*Rhododendron arboreum*) forests and moderately grazed with minimal human disturbance. The forest site is located at the coordinates between 28°24'5.41" N latitude and 83°42'11.9" E longitude. It is situated at an altitude of 2870 m asl (Figure 1i). The forest is primarily dominated by Rhododendron (*Rhododendron arboreum*) trees, with a few *Acer spp.* also present in the forest. It is a deciduous temperate forest, free from human disturbances as it is located in a protected area.

The Ghorepani area falls within the temperate climatic zone, with the average annual temperature over the past ten years (2013–2022) reaching a maximum of 20.4°C and a minimum of 12.13°C. Air temperature consistently increased above 20°C from June to August, while temperature dropped below 12°C from December to February. Over the period, total annual precipitation of the study site was recorded 2557.56 mm, with the highest rainfall recorded in July (666.98 mm) Likewise (Figure 2a).

(i)



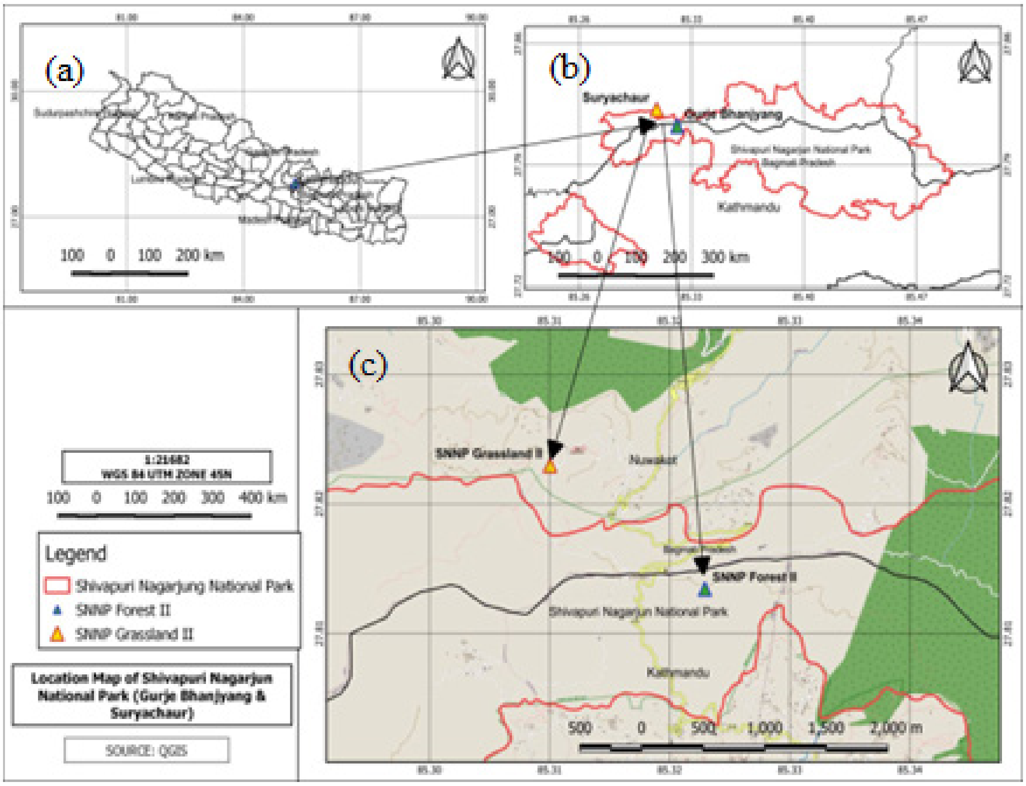


Fig 1: *Location map of (i) (a) Annapurna Conservation Area (ACA) in Nepal (b) Ghorepani in ACA (c) Grassland I and forest I in Ghorepani and (ii) (a) Shivapuri-Nagarjun National Park (SNNP) in Nepal (b) Study site in SNNP (c) grassland II and forest II in the study site*

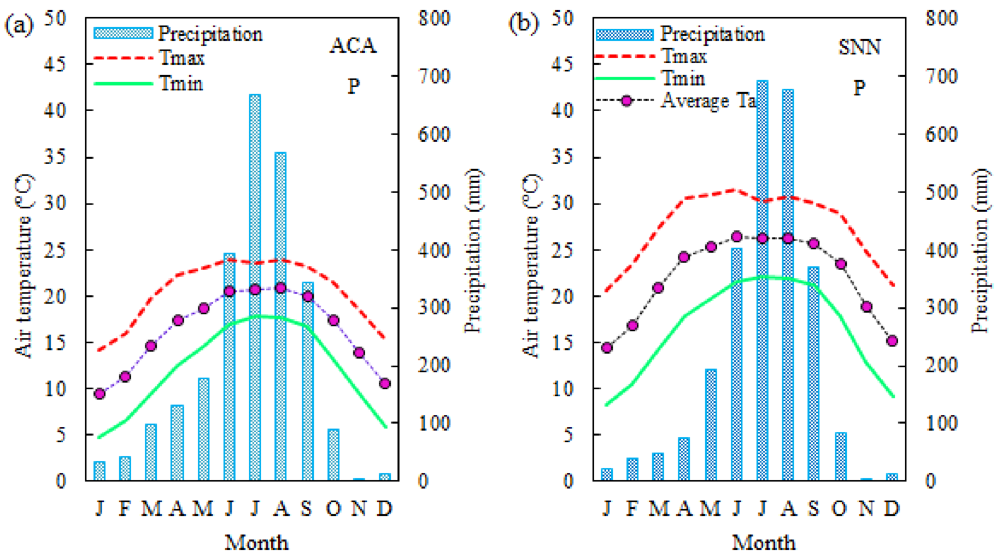


Fig 2: *Monthly average ten years mean (from 2013 to 2022) precipitation, and maximum and minimum air temperatures of (a) Ghorepani in ACA and (b) Kakani in SNNP (Source: Department of Hydrology and Meteorology, Government of Nepal, Kathmandu, Nepal)*

2.1.2 Grassland (SNNP Grassland 2) and forest (SNNP Forest II) site of Shivapuri Nagarjun National Park

The sub-tropical grassland (SNNP Grassland 2) and forest (SNNP Forest II) of sampling plot size 100m×100m in the Shivapuri Nararjun National Park (SNNP) was selected for this study. The grassland lies within 27°48′48″ to 27°49′17″N latitude and 85°18′31″ to 85°19′17″E longitude in the Suryachaur area. The altitude was 1979 m asl (Figure 1ii). The plant species like *Ageratina adenophora*, *Artemisia vulgaris*, *Melastoma malabathricum* etc., are dominated in the SNNP grassland II. The area was over grazed and frequent human disturbances was observed. The forest is located in the Gurje bhanjyang area of the Shivapuri-Nararjun National Park (SNNP), with the coordinates 27°48′48″N latitude to 85°19′20″E longitude and lies at 1882 m asl altitude (Figure 1ii). The forest is dominated with *Pinus roxburghii*, *Castanopsis indica* and *Schima wallichii*, etc. It is a mixed forest with minimal human disturbance.

The study site in the Shivapuri-Nagarjun National Park (SNNP) area falls within the sub-tropical climatic zone, with the average annual temperatures over the past ten years (2013–2022) reaching a maximum of 27.5°C and a minimum of 16.4°C. Air temperatures from June to August increased above 26°C and dropped below 15°C from December to February. The total of annual precipitation over the period of ten years in this study site was recorded as 2612.2 mm, with the highest rainfall recorded in July at 690.6 mm in average (Figure 2b).

2.2 Methods of Data Collection

2.2.1 Sampling design

The study area was categorised into grasslands and forest sites within the Annapurna Conservation Area (ACA) in the Temperate zone and the Shivapuri-Nagarjun National Park (SNNP) in the Subtropical zone of Nepal. The study area of size 70m×70m were selected in the ACA Grassland I, ACA Forest I, SNNP Grassland II and SNNP Forest II within the grasslands and forests in each site for sample collection and measurements. The sampling and measurements were conducted in pre-monsoon season, from March to May in the year 2023.

2.2.2 Soil sample collection

A total of 15 random sampling points were selected from 15 subplots in the study area of ACA Grassland I, ACA Forest I, SNNP Grassland II and SNNP Forest II for soil sample collection to make sure every part of the site was included, and precise data collection and representation. Samples were taken from a depth of 15 cm at each site using a stratified random sampling approach. The sample was taken with a sampler volume 117.75 cm^3 (a metallic cylinder with a diameter of 5 cm and a height of 6 cm). Zip lock polythene bags were used to collect the soil sample. The geographical coordinates and elevations of the sampling sites were recorded using the GPS (global positioning system). For bulk density analysis, soil samples were taken up to 15 cm depth. Additionally, 300 gm soil samples were collected for soil properties analysis. At the sampling locations, soil temperature was measured. The collected soil samples were carried to the laboratory at the Nepal Academy of Science and Technology (NAST) immediately after collection and were then processed for the necessary laboratory analysis for the measurements of moisture content, electrical conductivity (EC), pH, bulk density (BD), texture, organic carbon (SOC) and organic matter (OM) of the soil.

2.2.3 Soil temperature measurement

The soil temperature at a depth of 5 cm from the study sites in the grasslands and forests of ACA and SNNP was recorded using a digital lab stem thermometer (MEXTECH Multi-Stem Thermometer, ST9283B, India) during the soil sample collection period.

2.2.4 Moisture content (MC) measurement

A total of 50 g fresh soil sample was weighed and kept at 100°C in an oven for 48h in order to determine its moisture content. The oven-dried soil sample was left for 24 hrs to cool down and weighed. The same steps were followed for all soil samples to determine the moisture content.

The percent of moisture content was calculated by using formula:

$$\% \text{ of Moisture content} = \frac{W1-W2}{W1} X\ 100$$

Where,

W1 = Initial weight of sample

W2 = Final (air dry) weight of sample

2.2.5 Soil electrical conductivity (EC) measurement

A digital conductivity meter was used to measure soil EC. The 20 gm of soil was taken in a beaker and 40 ml of distilled water was added and it was vigorously stirred. Then, left for an hour with continuous stirring. The electrode of the EC meter was dipped into the beaker, and the obtained value was noted. After determination of each sample, electrode was rinsed with distilled water (Smith and Doran 1997).

2.2.6 Soil pH measurement

Using a digital pH meter, the soil pH was determined. At first, a beaker was taken and 20 g soil sample was placed in the beaker. Then 40 ml of distilled water was poured ointo the sample. Further, the mixture was gently stirred for 5 minutes with a clean glass rod, and was left for 30 minutes to allow the suspension to settle. Then, a pH meter was calibrated before the measurement using buffer solution. The electrode was then placed into the beaker to get a pH reading.

2.2.7 Bulk density (BD) measurement

Bulk density (BD) of soil was determined by using the core method (Blake and Hartge,1986). The soil sample of volume 117.7 g cm^{-3} was sampled from the study sites and at the laboratory of NAST and oven dried at 105°C for 24 hours. The BD was estimated by:

$$\text{Bulk Density (BD)} = \frac{\text{Weight of oven dried soil}}{\text{Volume of Core Sampler (V)}}$$

Where, V is the volume of core sampler auger in cm^3

Volume of core sampler was calculated by using formula:

$$\text{Volume (V)} = h \times \Pi r^2$$

Where, V is the volume of the soil in the core sampler in cm^3,

'h 'is the height of the core sampler in cm and,

'r 'is the radius of the core sampler in cm

2.2.8 Soil texture measurement

The soil texture of the sample was determined by using hydrometer (Pradhan et al. 1996). A 50 g of soil was transferred to 1000 ml jar and 100 ml of sodium hexametaphosphate was added. To that suspension on 250 ml of distilled water was added, stirred well and left overnight. Day after, water was added to the solution up to 1000ml, cork was placed and shaked well. The mixture was then left for sediment action for 40 seconds. After 40 seconds, initial reading was observed, was left for 3 hours for particles settlement and the final reading was taken. Lastly, blank (without soil sample) reading was taken. The temperature of the solution was also noted using a thermometer.

The soil texture was calculated using a formula,

(Silt+ clay) %= Hydrometer reading at 40 second + 0.3 * (t-20°C)

Clay %= Reading after 3 hours + 0.3 * (t-20°C)

Sand %= 100 − (Silt + clay) %

Silt %= (Silt + clay) % − Clay %

According to obtained proportions of sand, silt and clay, soil textural classes of the samples were calculated.

2.2.9 Soil organic carbon (SOC) measurement

Soil organic carbon (SOC) was determined by titrimetric method (Walkley and Black 1934). A total of 0.25 g of the soil was taken in a dried 500 ml conical flask, to which 10 ml of normal potassium dichromate (1N $K_2Cr_2O_7$) was added. Then, 20 ml of sulphuric acid (H_2SO_4) was added and was gently stirred. The mixture was left for half an hour. During this time, the potassium dichromate oxidizes the organic carbon present in the soil. After 30 minutes, 100 ml of distilled water was added to dilute the suspension of the flask and cooled. Then, 10 ml of phosphoric acid and 1 ml of diphenylamine indicator were added. After that, the sample was titrated with 0.5N ferrous ammonium sulphate (FAS) to notice the endpoint. At the endpoint, the colour turned into brilliant green. Further, for blank sample, same amount of chemical was used in the process. The blank titration was run without the soil and the endpoint was noted. The soil organic carbon content (SOC%) was calculated using the formula:

$$\frac{\text{(Blank reading − Titration reading)} \times N \times 0.003 \times 100}{\text{Weight of soil (g)}}$$

Here,

N= Normality of ferrous ammonium sulphate

0.003 is a factor to convert the amount of dichromate into organic carbon.

The carbon stock of soil was calculated as,

SOC Stock= ρ × d × %C

Where,

SOC = Soil organic carbon stock per unit area (t ha^{-1})

ρ = Soil bulk density (g cm^{-3})

d = The total depth at which the sample was taken (cm) and

%C = SOC (%)

2.2.10 Soil organic matter (SOM) measurement

The soil organic matter (SOM) was estimated by multiplying the soil organic carbon content by a conversion factor of 1.724, since SOM is typically considered to contain about 58% organic carbon on average i.e. 100% (SOM)/58% (SOC) (Douglas 2010).

Then,

Soil organic matter (%) = Total soil organic carbon % × 1.724

2.3 Statistical Analysis

The mean values and standard errors of soil physicochemical parameters were calculated for both land use types in temperate and subtropical climates. A t-test and correlation analysis were conducted using Microsoft Excel (version 2013) and R (version 4.3.2) to compare soil property differences ($p<0.05$) and correlate MC, EC, pH, BD, SOC, and OM.

3. RESULTS

3.1 Soil Temperature

In the Annapurna Conservation Area (ACA), the average soil temperature at a 5 cm depth was recorded at 9.9°C in ACA grassland I (n=15), while in ACA forest I, it was 5.2°C. Similarly, in the Shivapuri-Nagarjun National Park (SNNP), the soil temperature at a 5 cm depth was measured at 21.5°C in SNNP grassland II and 15.1°C in SNNP forest II. The soil temperatures across the different land use types showed statistically significant ($p<0.05$) variation (Figure 3a).

3.2 Soil Moisture Content (MC)

The soil moisture content in the ACA grassland I and forest I were measured at 20.7% and 22.3%, respectively. Similarly, the average soil moisture content (n=15) in the SNNP grassland II and forest II were 20.1% and 18.5%, respectively. This indicates that the grassland and forest in the temperate climatic zone in ACA had higher soil moisture content compared to the subtropical zone (Figure 3b). However, the differences in soil moisture content between these two climatic zones were not statistically significant ($P>0.05$, i.e., 0.33 in grassland and 0.56 in forest).

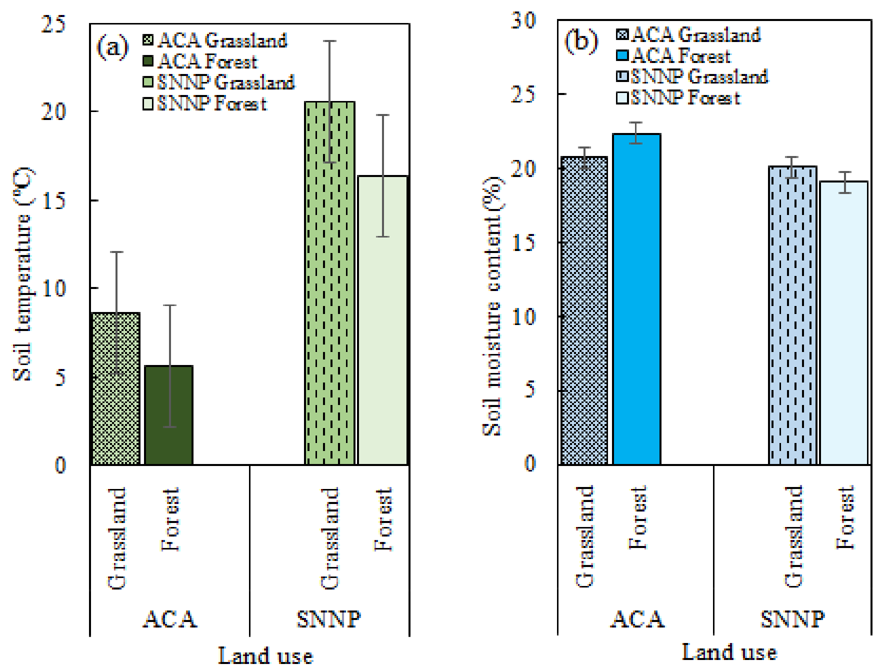


***Fig 3:** (a) Soil temperature and (b) soil moisture content variations in two land use types; grasslands and forests in ACA and SNNP; Error bar-Standard error*

3.3 Soil Electrical Conductivity (EC)

The average (n=15) soil electrical conductivity (EC) of ACA grassland I was 296 µs cm^{-3}, while that of the forest was 260 µs cm^{-3}, indicating that the grassland soil had a higher EC than the forest. In contrast, the average EC of SNNP grassland II was 270 µs cm^{-3}, whereas the forest had a higher EC of 358 µs cm^{-3} (Figure 4a), meaning the grassland soil had a lower EC compared to the forest. Statistical analysis of the EC values showed no significant difference between the land use types ($P>0.05$).

3.4 Soil pH

The average pH of ACA grassland I was 6.35 (n=15), which is nearly neutral and indicates a weakly acidic soil pH. In contrast, the pH of ACA forest I soil was 4.86, which is acidic. The mean pH of SNNP grassland II was 6.31, also nearly neutral, while the pH of SNNP forest II soil was 4.7, indicating acidity (Figure 4b) . Both the ACA and SNNP forest soils were found to be acidic, while the grasslands were nearly neutral. Statistically significant differences in soil pH were observed between the different land use types ($p<0.05$).

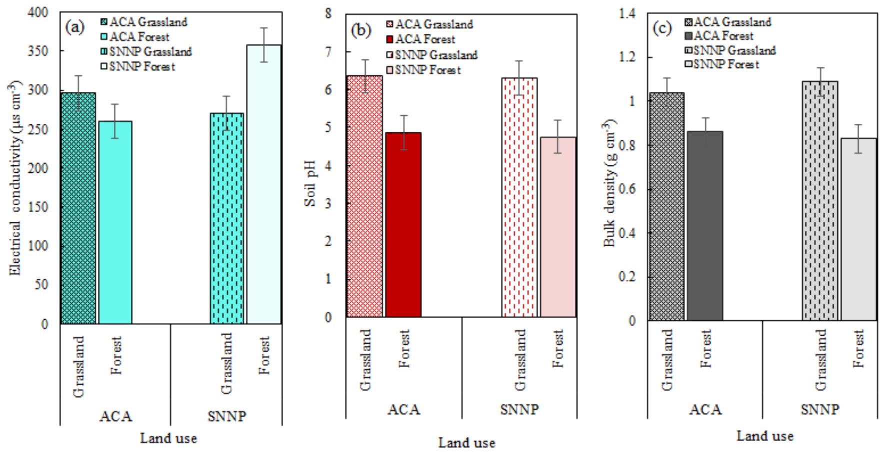


***Fig 4:** (a) Soil electrical conductivity (µs cm^{-3}) (b) soil pH and (c) bulk density (g cm^{-3}) variations in two land use types in ACA and SNNP; Error bar-Standard error*

3.5 Soil Bulk Density (BD)

The average bulk density of the ACA grassland I was 1.04 g cm^{-3} (n=15), while the forest I had a BD of 0.86 g cm^{-3}. In the SNNP, average BD was 1.09 g cm^{-3} in grassland II and 0.83 g cm^{-3} in forest II (Figure 4c). The findings indicated that the grasslands at both study sites had a higher BD compared to the forest sites. Significant variations ($p<0.05$) in BD were observed between different land use types within the same climatic zone.

3.6 Soil Texture

In both ACA and SNNP, forest soils (n=15) had a greater average clay percentage than grassland soils, with values of 16.4% and 11.7% for forests, and 13.9% and 9.0% for grasslands, respectively.

However, the clay percentage was higher in the ACA than the SNNP in both forests and grasslands (Figure 5a). The clay percentage was statistically not varied ($p>0.05$) in grassland and forest of the ACA, while it was significantly varied ($p<0.05$) in SNNP sites. The sand percentage in grassland soils was higher than in forest soils for both the Annapurna Conservation Area (ACA) and Shivapuri-Nagarjun National Park (SNNP), with values of 72.9% and 78.6% for grasslands, and 65.5% and 74.9% for forests, respectively. Thus, it shows that the soil under forests have less sand percent (Figure 5b). The statistical calculation justified for significant variation in sand percentage between land use type in both climatic zones ($p<0.05$). The silt percentage in ACA and SNNP grasslands have less silt percentage was (13.2% and 12.4%), than the respective forests was (18.1% and 13.4%) (Figure 5c). The statistical calculation revealed that there was significant ($p<0.05$) variation between grassland and forest of ACA, whereas no significant variation ($p>0.05$) in grassland and forest of SNNP region. The overall estimation of the soil texture on the basis of the soil particle sizes the study sites among grasslands and forests indicated that all of the soils have sandy loam texture, characterized by high percentage of sand (greater than 50% in all cases), moderate to low percentages of clay (between 8-17%) and moderate amounts of silt (12-18%) (Table 1).

Table 1: Soil particle size distribution and texture in two land use types in the Annapurna Conservation Area (ACA) and Shivapuri-Nagarjun National Park (SNNP)

Particle size distribution				
Land use type	**Clay %**	**Sand %**	**Silt %**	**Texture**
ACA Grassland	13.9 ±3.46	72.9 ±7.67	13.2 ±4.59	Sandy loam
ACA Forest	16.38 ±3.49	65.49 ±6.46	18.13 ±3.31	Sandy loam
SNNP Grassland	8.97 ±2.46	78.63 ±3.44	12.4 ±1.76	Sandy loam
SNNP Forest	11.7 ±2.83	74.9 ±4.27	13.4 ±2.41	Sandy loam

± indicates Standard error (SE)

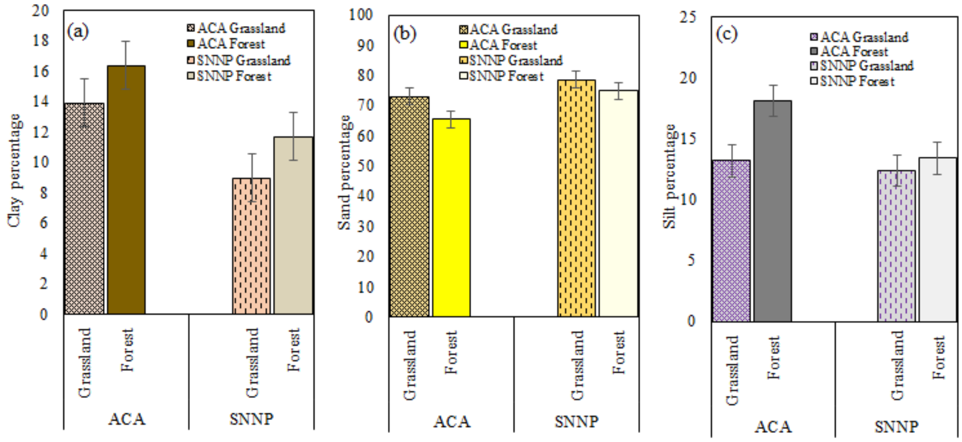


Fig 5: *(a) Clay, (b) sand and (c) silt percentage (%) variations in the grasslands and forests of ACA) and (SNNP); Error bar-Standard error*

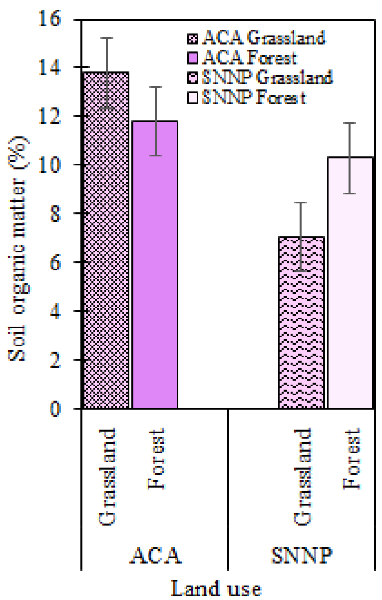


Fig 6: *Soil organic matter variation in two land use types in ACA and SNNP; Error bar-Standard Error*

3.7 Soil Organic Matter (SOM)

The soil under ACA grassland I had an average (n=15) organic matter content of 13.8%, while the forest I soil contained 11.3%, which was comparatively lowered than the grassland I. In the SNNP region, the grassland II soil had an average organic matter content of 6.1%, while the forest II soil had 10.1%, showing a higher organic matter content in the forest compared to the grassland. Statistical analysis revealed significant differences ($p<0.05$) in soil organic matter across the various land use types in these study sites.

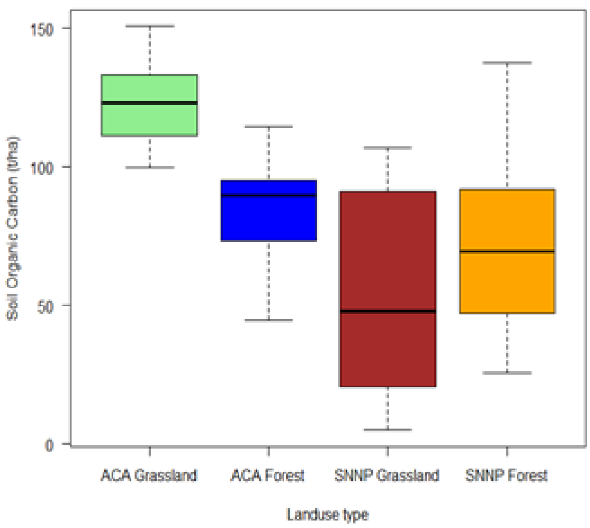


***Fig 7:** Soil organic carbon (SOC, t ha^{-1}) variations in the grasslands and forests of ACA and SNNP; Error bar-Standard error*

3.8 Soil Organic Carbon (SOC)

This study found that the average soil organic carbon (SOC) in ACA grassland I across all sampling sites (n=15) was 123.2 t ha^{-1}, which was the highest value recorded among both climatic zones. In comparison, the SOC in the ACA forest I soil was 84.6 t ha^{-1}. The lowest SOC value was observed in the SNNP grassland II, with an average of 55.5 t ha^{-1}, while the forest II site in the SNNP region had 71.7 t ha^{-1} (Figure 6). Statistical analysis revealed that there were significant differences ($p<0.05$) in SOC levels between the two land use types i.e. grassland and forest across both climatic zones.

3.9 Correlations between the soil physicochemical properties

Correlation between various physicochemical properties of soil was analysed in the grasslands and forests of the two climatic zones in the Annapurna Conservation Area (ACA) and the Shivapuri-Nagarjun National Park (SNNP). In the ACA grassland I, pH, Electrical conductivity (EC), organic matter (OM), and moisture content (MC) all showed negative correlations with bulk density (BD) (r = -0.16, -0.29, -0.74, and -0.59, respectively), indicating if BD increases, these properties decrease, and vice versa. However, SOC showed no significant correlation with BD (r = 0.01).

All other soil properties, except BD, were positively correlated with each other. In the ACA forest, soil pH and EC exhibited positive correlations with OM and MC, while pH showed a negative correlation with EC, SOC, and BD. The EC had a significant ($p<0.05$) negative correlation with SOC (r = -0.57). The SOC was negatively correlated with both MC and BD (r = -0.23, -0.15), and OM also had negative correlations with MC% and BD (r = -0.22, -0.31) (Table 2).

Table 2: Correlation between soil properties in the grassland and forest of the ACA

Soil properties	pH	EC	SOC	OM	MC	BD
Grassland						
pH	1					
EC	0.22	1				
SOC	0.06	0.26	1			
OM%	0.21	0.38**	0.65**	1		
MC%	0.13	0.41**	0.23	0.61**	1	
BD	-0.17	-0.29	0.01	-0.74**	-0.59**	1
Forest						
pH	1					
EC	-0.13	1				
SOC	-0.06	-0.57	1			
OM %	0.10	0.12	0.09	1		
MC %	0.38	0.31	-0.23	-0.23	1	
BD	0.38	0.22	-0.15	-0.32	0.19	1

**Significant at P<0.05

Table 3: Correlation between soil properties in the grassland and forest of the SNNP

Soil properties	pH	EC	SOC	OM %	MC %	BD
Grassland						
pH	1					
EC	0.23	1				
SOC	0.25	0.37	1			
OM %	0.23	0.43	0.99	1		
MC %	0.23	-0.24	0.17	0.19	1	
BD	0.18	-0.50	-0.48	-0.55	-0.38	1
Forest						
pH	1					
EC	-0.55	1				
SOC	-0.29	0.26	1			
OM %	-0.32	0.4	0.93	1		
MC %	-0.56	0.56	0.21	0.39	1	
BD	0.23	-0.38	0.12	-0.22	-0.57	1

**Significant at $P<0.05$

In the SNNP grassland I, EC, SOC, OM, and MC were all negatively and significantly ($p<0.05$) correlated with BD (r = -0.50, -0.48, -0.55, -0.38), while pH showed a positive correlation with BD (r = 0.18). The correlation between EC and MC was negative but insignificant ($p>0.05$, r = -0.23). In the SNNP forest II, pH had a negative correlation with EC, SOC, OM, and MC (r = -0.55, -0.29, -0.32 and -0.56). Additionally, EC showed positive and significant ($p<0.05$) correlations with OM and MC (r = 0.40 and 0.56). Other soil properties were positively correlated with each other, with SOC and OM showing a strong positive and significant ($p<0.05$) correlation (Table 3).

4. DISCUSSION

The variations in soil and air temperature beneath the canopy and in open areas were strongly associated with solar radiation and the changes in solar energy and heat passing through the soil surface (Onwuka et al. 2018). In the hot season, area with less canopy absorbed heat and this supported for greater temperature in grassland area. Further, according to Morecroft et al. (1998), at two sites in the deciduous forest, it was found that forest soil temperature didn't rise above 20°C and this outcome supported for lower soil temperature of both forest areas of our study compared to the grassland of the similar zone. However, the soil temperature in the ACA region of the temperate zone is lower in both land use types i.e. grassland and forest compared to the sub-tropical zone of this study (Figure 3a). The presence of the tree canopy causes forest soil to experience more stable temperatures compared to the fluctuating temperatures in grassland soil (Lozano-Parra et al. 2018), which results in differing vegetation responses to soil temperature variations in the forest and grassland ecosystems (Luis et al. 2021).

Precipitation increases soil moisture and decreases soil temperature (Shi et al. 2011). This result supported higher moisture (Fig. 3b) and lower temperature (Fig. 3a) in ACA grassland and forest, compared to the subtropical zone. Forest soil moisture varies with vegetation density and rainfall; for example, Bangladesh's forest moisture ranged from 5 to 18% (Islam et al. 2016). In this study, ACA grassland (20.7%) and SNNP grassland (20.1%) had similar moisture, while ACA forest (22.3%) had higher moisture than SNNP forest (19.0%) (Fig. 3b), which was less dense and more disturbed. Zhou et al. (2019) found low average soil moisture in forests with significant temporal variation, but more moisture was present in forests with increased rainfall compared to grasslands. Ghosh et al. (2020) reported, moisture content ranging from 3.41 to 28% in temperate forest soil at Jaldapara National Park, similar to our study, where soil moisture in the ACA temperate forest ranged from 13.14 to 26.32%.

Soil electrical conductivity (EC) indicates salt content and the availability of water and nutrients for plants. A decline in EC with lower soil temperature and increase with higher organic matter (OM) content was observed in forests (Dar et al. 2018). In this study, ACA forest had lower EC (260 $\mu s\ cm^{-3}$) in the temperate zone, while SNNP forest had higher EC (358 $\mu s\ cm^{-3}$) in the subtropical region (Fig. 4a) which may be because of higher soil temperature and lower OM content. The study by Chaneton and Lavado (1996) found that salinization was higher in grazed grasslands. In our study, the ACA grassland I (296 $\mu s\ cm^{-3}$) in the temperate zone had higher EC, likely due to seasonal grazing, which may have contributed to the increased EC in the area. In contrast, the SNNP grassland II (270 $\mu s\ cm^{-3}$) had lower EC, possibly because of less grazing, disturbance, and more open vegetation.

Grassland soils are generally neutral to slightly alkaline, but in this study, both ACA (6.4) and SNNP (6.3) grasslands had weakly acidic pH. Forest soils had more acidic pH (4.9 in ACA, 4.8 in SNNP) of this study (Fig. 4b) comply with the findings from Shrestha et al. (2020)

and Sigdel et al. (2015). Generally, decomposition of organic matter in forests contributes to this acidity. The optimal pH for soil nutrient availability and microbial activity is close to 7 (McCauley et al., 2009).

A soil's bulk density (BD) is an unpredictable attribute that changes depending on the soil's structural characteristics. In this study, the mean BD was found to be higher in ACA grassland I (1.04 g cm^{-3}) and SNNP grassland (1.09 g cm^{-3}) compared to the forests in ACA (0.86 g cm^{-3}) and SNNP (0.83 g cm^{-3}) (Fig. 4c). The higher BD in grassland than the forest, which were 1.29 and 1.23 g cm^{-3}, respectively were reported by Shrestha et al. (2020) observed in the grasslands of this study and most prominent in the SNNP grassland. The BD increases with availability of nutrients (Chaudhari et al. 2013), grazing intensity together (Hamza and Anderson, 2005) and vegetation. The average high BD (1.2 g cm^{-3}) reported by Muche et al. (2015), under grassland soil is in harmony with the BD value of SNNP grassland II with average value of 1.09 cm^{-3}. This could be due to lower litter deposition, which caused soil particles to be strongly packed together.

Soil textures in grasslands and forests can vary based on factors such as climate, parent material, plant types, and soil-forming processes (Tellen et al. 2018, Bhutia et al. 2021). Differences in precipitation, landscape position, and zone variations play significant roles in shaping soil texture (Meij et al. 2020, Sun et al. 2021, Sheshnitsan et al. 2024). Grassland soils feature a mix of clay and loam and offer better water retention, while forest soils develop finer textures due to organic matter accumulation. In this study, ACA grassland and forest soils had higher clay content (13.9% and 16.4%) than SNNP soils (11.7% and 9%), leading to higher water retention and poor drainage, which supports higher moisture content and nutrient levels. ACA soils were more clayey than those in the subtropical zone. However, ACA grassland (72.9%) and forest (65.5%) had lower sand content than SNNP grassland (78.6%) and forest (74.9%), indicating better drainage and lower nutrients in SNNP soils. The silt content was higher in ACA grassland (13.2%) and forest (18.2%) compared to SNNP grassland (12.4%) and forest (13.4%), showing moderate drainage and nutrient content in the ACA region (Fig. 5). Kumar et al. (2022) found significant differences in sand, silt, and clay percentages along the elevational gradient, with the lowest sand content between 3360 to 3540 m asl, supporting the lower sand proportion in the temperate zone of this study. Soil texture in grasslands and forests of ACA and SNNP was sandy loam (Table 1). A similar sandy loam texture was observed in temperate forests at varying altitudes in Uttarakhand, India (Rawat et al. 2021).

Soil organic matter (OM) is an important soil characteristic. The OM, such as animal manures and compost, can be added to the soil. As per the obtained result, grassland I of ACA had the higher percentage of OM (13.8%) than the other sites in different land use and zones (Fig. 6). A significant portion of grasslands are composed of herbaceous plants, which includes grasses and contribute OM to the soil. According to Mason and Zanner (2005) animal manures and roots are the principal sources of OM inputs for grassland soils, whereas plant litter makes up a very small portion, thus supporting for higher OM in ACA grassland I (Figure 6). Antony et al. (2022), stated that topsoil and subsoil of the forests were substantially higher in the mineral-free particulate matter proportion, and supported for higher OM percentage in both forests (11.9% in ACA, 10.3% in SNNP). As a consequence of the decomposition of leaf litter, forests obtain a higher intake of OM, which significantly assists in the accumulation of organic matter than those under grassland. The intensity and frequency of grazing have a substantial impact on OM build-up. Overgrazing inhibits OM formation, which could explain why the SNNP grassland (7.0%) has low OM availability. Moderate grazing, on the other hand, promotes root growth and increases organic input, contributing in more OM in ACA grassland I.

Soil organic carbon (SOC) is an essential component of terrestrial ecosystems, contributing significantly to carbon sequestration and general soil health. The amount of SOC was found higher in grassland I (123.3 t ha^{-1}) and forest I (84.6 t ha^{-1}) of ACA. Similar result was obtained in a study conducted by Gupta et al. (2013), where SOC pool was estimated in the grasslands occurring between the wide altitudinal range, found that 142.14 t ha^{-1} was observed in the altitudinal range of 2501and 4200m asl and 97.80 t ha^{-1} between 150 and 2000 m asl, and concluded that temperate climate favours organic carbon accumulation in the soil (Fig. 7). Dondini et al. (2023) stated that the highest SOC stocks were discovered in temperate areas with slow rates of decomposition and high productivity of grasslands. The soil carbon increases from tropical to boreal climates, with temperate forests retaining up to 100 Mg C ha^{-1} or more (Lal 2013). Our study showed similar results, with SNNP forest in the subtropical zone storing more SOC (71.72 t ha^{-1}) than grassland (55.5 t ha^{-1}). Ghimire et al. (2018) found higher SOC (110 t ha^{-1}) in forests, noting that SOC varies with land use. Moderate temperatures in temperate zones reduced microbial activity, but vegetation adds more organic matter to the soil. A study by Cai et al. (2016) showed higher MOC/TSOC ratios in temperate forest and grassland soils compared to subtropical areas, emphasizing that soil texture, type, climate, and land use are key factors for SOC storage.

5. CONCLUSION

The study found significant variation in soil properties between grassland and forest across land use and climatic zones. In ACA temperate grassland, most soil properties were higher than in the forest, except for soil moisture and clay/silt percentages. In SNNP subtropical climate, grasslands had higher soil temperature, moisture, pH, bulk density, and sand content. ACA grassland stored more SOC, while SNNP forest had higher SOC than the grassland. Grasslands showed lower SOC storage due to frequent disturbances. In ACA grassland, SOC positively correlated with bulk density (BD), while in the forest, it had a negative correlation. In SNNP grassland, SOC, organic matter (OM), and moisture content (MC) negatively correlated with BD, while in the forest, MC, OM, and SOC were positively correlated. SOC sequestration was higher in the temperate zone. The study emphasized the importance of grassland and forest soils in SOC storage and the need for effective soil management, including grazing control, soil quality assessment, ecosystem research, protective laws, and public awareness.

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REFERENCES

Adhikari, K. and A. E. Hartemink, 2017. Soil organic carbon increases under intensive agriculture in the Central Sands, Wisconsin, USA. Geoderma Regional, 10:115-125. DOI: 10.1016/j.geodrs.2017.07.003

Ali, A., M. I. Ashra., S. Gulzar, M. Akmal and B. Ahmad, 2020. Estimation of soil carbon pools in the forests of Khyber Pakhtunkhwa Province, Pakistan. Journal of Forestry Research, 31:2313-2321. DOI: 10.1007/s11676-019-01059-9

Alidoust, E., Afyuni, M., Hajabbasi, M. A., and Mosaddeghi, M. R, 2018. Soil carbon sequestration potential as affected by soil physical and climatic factors under different land uses in a semiarid region. Catena, 171:62-71. DOI: 10.1016/j.catena.2018.07.005

Antony, D., C. D. Collins, J. M. Clark and T. Sizmur, 2022. Soil organic matter storage in temperate lowland arable, grassland and woodland topsoil and subsoil. Soil Use and Management, 38(4):1532-1546. DOI: 10.1111/sum.12801

Beniston, J. W., S. T. DuPont, J. D. Glover, R. Lal and J. A. Dungait, 2014. Soil organic carbon dynamics 75 years after land-use change in perennial grassland and annual wheat agricultural systems. Biogeochemistry, 120:37-49. DOI: 10.1007/s10533-014-9980-3

Bhattacharyya, T., D. K. Pal, P. Chandran, S. K. Ray, C. Mandal and B. Telpande, 2008. Soil carbon storage capacity as a tool to prioritize areas for carbon sequestration. Current science, 482-494.

Bhutia, P. L., B. Gupta, R. P. Yadav, A. K. Gupta, K. G. Bhutia and P. Rai, 2021. Soil physico-chemical and biological properties as affected by vegetation systems and elevation in western Himalayas. Range Management and Agroforestry, 42(1):86-94.

Binkley, D., F. Singer, M. Kaye and R. Rochelle, 2003. Influence of elk grazing on soil properties in Rocky Mountain National Park. Forest Ecology and Management, 185(3):239-247. DOI: 10.1016/S0378-1127(03)00162-2

Blake, G. R. and K. H. Hartege, 1986. Bulk density. In: Physical and mineralogical methods of agronomy, methods of soil Analysis (2nd ed., pp. 425-442). Maidson, ASA; SSSA. Monographs. DOI: 10.2136/sssabookser5.1.2ed.c13

Bonan, G. B., 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science, 320(5882):1444-1449. DOI: 10.1126/science.1155121 PMID: 18556546

Cai, A., W. Feng, W. Zhang and M. Xu, 2016. Climate, soil texture, and soil types affect the contributions of fine-fraction-stabilized carbon to total soil organic carbon in different land uses across China. Journal of Environmental Management, 172:2-9. DOI: 10.1016/j.jenvman.2016.02.009 PMID: 26905446

Chaneton, E. J. and R. S. Lavado, 1996. Soil nutrients and salinity after long-term grazing exclusion in a flooding Pampa grassland. Journal of Range Management, 49(2):182-187. DOI: 10.2307/4002692

Chaudhari, P. R., D. V. Ahire, V. D. Ahire, M. Chkravarty and S. Maity, 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. International Journal of Scientific and Research Publications, 3(2):1-8.

Dar, Z. A., Q. Humaira, M. S. Ahmad, B. Bilal and A. Amin, 2018. Assessment of physico-chemical parameters of forest soil of Hirpora Wildlife Sanctuary,Kashmir. International Journal of Advance Research in Science and Engineering, 7(4): 46-56.

Dhital D, S. Prajapati, S. R. Maharjan and H. Koizumi, 2019. Soil carbon dioxide emission: soil respiration measurement in temperate grassland, Nepal. Journal of Environmental Protection, 10(2):289-314. DOI: 10.4236/jep.2019.102017

Dhital D, P. Manandhar, B. Gosain and J. Sijapati, 2022a. Soil respiration variations in temperate Rhododendron (*Rhododendron arboreum*) forest of Annapurna Conservation Area (ACA) in Nepal. International Journal of Forestry Research, 1-14. DOI: 10.1155/2022/1677084

Dhital D, R. Manandhar, P. Manandhar and S. R. Maharjan, 2022b. Soil CO2 efflux dynamics and its relationship with the environmental variables in a sub-tropical mixed forest. Open Journal of Forestry, 12(3):312-336. DOI: 10.4236/ojf.2022.123017

Dondini, M., M. Martin, C. De Camillis, A. Uwizeye, J. F. Soussana, T. Robinson and H. Steinfeld, 2023. Global assessment of soil carbon in grasslands: From current stock estimates to sequestration potential, vol. 187. Rome, Food and Agriculture Organization of the United Nations FAO.

Douglas W. Pribyl, 2010. A critical review of the conventional SOC to SOM conversion factor, Geoderma, 156(3-4):75-83. DOI: 10.1016/j.geoderma.2010.02.003

Feeney C. J., L. Bentley, D. D. Rosa, P. Panagos, B. A. Emmett, A. Thomas, D. A. Robinson, 2024. Benchmarking soil organic carbon (SOC) concentration provides more robust soil health assessment than the SOC/clay ratio at European scale. Science of The Total Environment, 951:175642. DOI: 10.1016/j.scitotenv.2024.175642 PMID: 39163941

Food and Agriculture Organization (FAO) of the United Nations, 2020. Global forest resources assessment (pp. 1-186), Rome.

Ghosh, C., M. Mukherjee and K. Biswas, 2020. Physico-chemical Properties of Soil of Jaldapara National Park in West Bengal, India. International Journal of Advanced Research in Biological Sciences, 7(6):141-150.

Ghosh, P. K., and S. K. Mahanta, 2014. Carbon sequestration in grassland systems. Range Management and Agroforestry, 35(2):173-181.

Ghimire, P., B. Bhatta, B. Pokhrel, G. Kafle and P. Paudel, 2018. Soil organic carbon stocks under different land uses in Chure region of Makawanpur district, Nepal. SAARC Journal of Agriculture, 16(2):13-23. DOI: 10.3329/sja.v16i2.40255

Gupta, M. K. and S. D. Sharma, 2013. Sequestered organic carbon status in the soils under grassland in Uttarakhand State, India. Applied Ecology and Environmental Sciences, 1(1):7-9. DOI: 10.12691/aees-1-1-2

Hamza, M. A. and W. K. Anderson, 2005. Soil compaction in cropping systems: A review of the nature, causes and possible solutions. Soil and Tillage Research, 82(2):21-145. DOI: 10.1016/j.still.2004.08.009

Harden, J. W., G. Hugelius, A. Ahlström, J. C. Blankinship, B. Bond-Lamberty, C. R. Lawrence and L. E. Nave, 2018. Networking our science to characterize the state, vulnerabilities, and management opportunities of soil organic matter. Global Change Biology, 24(2):e705-e718. DOI: 10.1111/gcb.13896 PMID: 28981192

Iranmanesh M. and H. Sadeghi, 2019. Effects of soil texture and nitrogen on ability of carbon sequestration in different organs of two *Tamarix* species as a good choice for carbon stock in dry lands. Ecological Engineering, 139:105577. DOI: 10.1016/j.ecoleng.2019.08.007

Islam, M., S. H. Salim, M. H. Kawsar and M. Rahman, 2016. The effect of soil moisture content and forest canopy openness on the regeneration of Dipterocarpus turbinatus CF Gaertn (Dipterocarpaceae) in a protected forest area of Bangladesh. Tropical Ecology, 57(3):455-464.

Kopittke, P. M., A. A. Berhe, Y. Carrillo, T. R. Cavagnaro, D. Chen, Q. L. Chen, et al., 2022. Ensuring planetary survival: the centrality of organic carbon in balancing the multifunctional nature of soils. Critical Reviews in Environmental Science and Technology, 52(23): 4308-4324. DOI: 10.1080/10643389.2021.2024484

Kumar, D., D. R. Bhardwaj, P. Sharma, Bharti, N. Sankhyan, N. Al-Ansari and N. T. Linh, 2022. Population dynamics of juniperus macropoda bossier forest ecosystem in relation to soil physicochemical characteristics in the cold desert of north-western Himalaya. Forests, 13(10):624. DOI: 10.3390/f13101624

Lal, R., 2005. Forest soils and carbon sequestration. Forest ecology and management, 220(1-3):242-258. DOI: 10.1016/j.foreco.2005.08.015

Lal, R. 2013. Soil carbon management and climate change. Carbon Management, 4(4):439-462. DOI: 10.4155/cmt.13.31

Lozano-Parra, J., M. Pulido, C. Lozano-Fondón and S. Schnabel, 2018. How do soil moisture and vegetation covers influence soil temperature in drylands of mediterranean regions? Water, 10:12-747. DOI: 10.3390/w10121747

Luis, M. R., M. D. Hidalgo Galvez, J. Cambrolle, M. T. Dominguez and I. M. Perez-Ramos, 2021. How will forecasted warming and drought affect soil respiration in savannah ecosystems? The role of tree canopy and grazing legacy. Agricultural and Forest Meteorology, 304:305-108425. DOI: 10.1016/j.agrformet.2021.108425

Mason, J. A. and C. W. Zanner, 2005. Grassland soils. Encyclopedia of Soils in the Environment, 138-145. DOI: 10.1016/B0-12-348530-4/00028-X

Mayer, M., C. F. Prescott, W. E. Abaker, L. Augusto, L. Cécillon, G. W. Ferreira and L. Vesterdal, 2020. Tamm Review: Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis. Forest Ecology and Management, 466:118127. DOI: 10.1016/j.foreco.2020.118127

McCauley, A., C. Jones and J. Jacobsen, 2009. Soil pH and organic matter. Nutrient management module, 8(2):1-12.

Melillo, J. M., X. Lu, D. W. Kicklighter, J. M. Reilly, Y. Cai and A. P. Sokolov, 2016. Protected areas' role in climate-change mitigation. Ambio, 45:133-145. DOI: 10.1007/s13280-015-0693-1 PMID: 26474765 PMCID: PMC4752559

Meena, V. S., T. Mondal, B. M. Pandey, A. Mukherjee, R. P. Yadav, M. Choudhary and A. Pattanayak, 2018. Land use changes: Strategies to improve soil carbon and nitrogen storage pattern in the mid-Himalaya ecosystem, India. Geoderma, 321:69-78. DOI: 10.1016/j.geoderma.2018.02.002

Morecroft, M. D., M. E. Taylor and H. R. Oliver, 1998. Air and soil microclimates of deciduous woodland compared to an open site. Agricultural and Forest Meteorology, 90(1-2):141-156. DOI: 10.1016/S0168-1923(97)00070-1

Muche, M., A. Kokeb and E. Molla, 2015. Assessing the physicochemical properties of soil under different land use types. Journal of Environmental and Analytical Toxicology, 5(5):1-5.

National Research Council, 1993. Soil and water quality: An agenda for agriculture. National Academies Press.

Oli, B. N. and K. Shrestha, 2009. Carbon status in forests of Nepal: An overview. Journal of Forest and Livelihood, 8(1):62-66.

Onwuka, B. and B. Mang, 2018. Effects of soil temperature on some soil properties and plant growth. Journal of Agricultural Science, 8(1):34-37. DOI: 10.15406/apar.2018.08.00288

Pan, Y., R. A. Birdsey, J. Fang, R. Houghton, P. E. Kauppi, W. A. Kurz and D. Hayes, 2011. A large and persistent carbon sink in the world's forests. Science, 333(6045):988-993. DOI: 10.1126/science.1201609 PMID: 21764754

Panchal, P., C. Preece, J. Peñuelas and J. Giri, 2022. Soil carbon sequestration by root exudates. Trends in Plant Science, 27(8):749-757. DOI: 10.1016/j.tplants.2022.04.009 PMID: 35606255

Paustian, K., H. P. Collins and E. A. Paul, 2019. Management controls on soil carbon. Soil organic matter in temperate agroecosystems, pp. 15-49. CRC Press DOI: 10.1201/9780367811693-2

Pradhan, S. B., 1996. Soil and plant analysis manual. Nepal Agricultural Research Council (NARC).

Rawat, V., A. S. Bagri, H. Singh, P. Tiwari and J. Krishan, 2021. Altitudinal variation in soil physico-chemical properties of a Western Himalayan Forest, Uttarakhand, India. Journal of Mountain Research, 16(3):111-119. DOI: 10.51220/jmr.v16i3.12

Shapkota, J. and G. Kafle, 2021. Variation in Soil Organic Carbon under Different Forest Types in Shivapuri Nagarjun National Park, Nepal. Scientifica, 2021. DOI: 10.1155/2021/1382687 PMID: 34777893 PMCID: PMC8580687

Sheikh, M. A., M. Kumar and R. W. Bussmann, 2009. Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. Carbon Balance and Management, 4:1-6. DOI: 10.1186/1750-0680-4-6 PMID: 19706175 PMCID: PMC2745406

Sheshnitsan, S., G. Odnoralov, E. Tikhonova, N. Gorbunova, T. Sheshnitsan, O. C. Murariu and G. Caruso, 2024. Influence of Soil Texture on Carbon Stocks in Deciduous and Coniferous Forest Biomass in the Forest-Steppe Zone of Oka-Don Plain. Soil Systems, 8:4-118. DOI: 10.3390/soilsystems8040118

Shi, W. Y., R. Tateno, J. G. Zhang, Y. L. Wang, N. Yamanaka and S. Du, 2011. Response of soil respiration to precipitation during the dry season in two typical forest stands in the forest-grassland transition zone of the Loess Plateau. Agricultural and Forest Meteorology, 151(7):854-863. DOI: 10.1016/j.agrformet.2011.02.003

Shrestha, K, 2016. Variation in soil organic carbon within highland grasslands of Langtang National Park, Nepal. International Journal of Environment, 5(3):57-65. DOI: 10.3126/ije.v5i3.15704

Shrestha, S. and G. Kafle, 2020. Variation of selected physicochemical and hydrological properties of soils in different tropical land use systems of Nepal. Applied and Environmental Soil Science, 2020(1):8877643. DOI: 10.1155/2020/8877643

Sigdel, S. R., D. Rupakheti, U. Baral, L. Tripathee, R. Aryal, S. Dhital and P. Sharma, 2015. Physico-chemical characteristics of soil along an altitudinal gradient at southern aspect of Shivapuri Nagarjun National Park, Central Nepal. International Research Journal of Earth Sciences, 3(2):1-6.

Smith, J. L., and J. W. Doran, 1997. Measurement and Use of pH and Electrical Conductivity for Soil Quality Analysis. In Methods for Assessing Soil Quality, pp. 169-185. John Wiley & Sons, Ltd. DOI: 10.2136/sssaspecpub49.c10

Subashree, K., J. A. Dar and S. Sundarapandian, 2019. Variation in soil organic carbon stock with forest type in tropical forests of Kanyakumari Wildlife Sanctuary, Western Ghats, India. Environmental Monitoring and Assessment, 191:1-16. DOI: 10.1007/s10661-019-7881-6 PMID: 31664599

Sun, S., G. Zhang, T. He, S. Song and X. Chu, 2021. Effects of landscape positions and landscape types on soil properties and chlorophyll content of citrus in a sloping orchard in the three gorges reservoir area, China. Sustainability, 13:8-4288. DOI: 10.3390/su13084288

Tang M., W. Li, X. Gao, P. Wu, H. Li, Q. Ling and C. Zhang, 2022. Land use affects the response of soil moisture and soil temperature to environmental factors in the loess hilly region of China. PeerJ 10:e13736. DOI: 10.7717/peerj.13736 PMID: 35855431 PMCID: PMC9288829

Tellen, V. A. and B. P. K. Yerima, 2018. Effects of land use change on soil physicochemical properties in selected areas in the North West region of Cameroon. Environmental Systems Research, 7:1-29. DOI: 10.1186/s40068-018-0106-0 van der Meij, W. M., A. J. A. M. Temme, J. Wallinga and M. Sommer, 2020. Modeling soil and landscape evolution - the effect of rainfall and land-use change on soil and landscape patterns, Soil, 6:337-358. DOI: 10.5194/soil-6-337-2020

Walkley, A. and I. A. Black, 1934. An Examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. Soil Science, 63:251-263. DOI: 10.1097/00010694-194704000-00001

Wiesmeier, M., L. Urbanski, E. Hobley, B. Lang, M. von Lützow, E. Marin-Spiotta and I. Kögel-Knabner, 2019. Soil organic carbon storage as a key function of soils-A review of drivers and indicators at various scales. Geoderma, 333:149-162. DOI: 10.1016/j.geoderma.2018.07.026

Zhang, X., J. F. Adamowski, R. C. Deo, X. Xu, G. Zhu and J. Cao, 2018. Effects of Afforestation on Soil Bulk Density and pH in the Loess Plateau, China. Water, 10(12):1710. DOI: 10.3390/w10121710

Zhong, X. L., J. T. Li, X. J. Li, Y. C. Ye, S. S. Liu, P. D. Hallett and M. Naveed, 2017. Physical protection by soil aggregates stabilizes soil organic carbon under simulated N deposition in a subtropical forest of China. Geoderma, 285:323-332. DOI: 10.1016/j.geoderma.2016.09.026

Zhou, Q., Z. Sun, X. Liu, X. Wei, Z. Peng, C. Yue and Y. Luo, 2019. Temporal soil moisture variations in different vegetation cover types in karst areas of southwest China: A plot scale case study. Water, 11(7):1423. DOI: 10.3390/w11071423