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**Research Article**

# Variation in Above Ground Tree Biomass and Soil Organic Carbon Across Different Tree Stands

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**Abstract**

Above Ground Tree Biomass (AGTB) and Soil Organic Carbon (SOC) in forests contribute significantly to improving soil health and mitigating climate change through long-term carbon sequestration. Quantities of carbon sequestered, however, vary among tree species compositions. Hence, this study assessed AGTB and SOC across three tree species stands-*Alnus nepalensis*, *Pinus roxburghii*, and *Neolitsea cuipala*-in the protected Gokarna Rajnikunj Forest of central Nepal. Results showed that *Pinus* stands had the highest AGTB (1,050.94 ± 522.95 t ha$^{-1}$), while *Alnus* stands recorded the highest SOC stock (248.97 ± 70.20 t ha$^{-1}$), despite having comparatively lower biomass. Soil properties, particularly pH and moisture content, varied significantly among species and influenced SOC accumulation. Notably, SOC levels in this forest exceeded those reported in comparable ecosystems. These findings highlight the importance of species-specific forest management strategies and support the integration of soil carbon considerations into broader conservation and climate policy frameworks to maximize carbon sequestration, biodiversity, and ecosystem resilience.

## Introduction

Forests play a vital role in the global carbon cycle by sequestrating carbon in Aboveground Biomass (AGB), Belowground Biomass (BGB), and Soil Organic Carbon (SOC) (Bohara et al., 2021). AGB refers to the total mass of living plant material above the soil surface. Through photosynthesis, forest vegetation absorbs atmospheric carbon dioxide and stores it in plant tissues, resulting in the accumulation of carbon in the form of biomass. Equally important is SOC-the primary component of Soil Organic Matter (SOM)-which accumulates through litterfall, root turnover, and the decomposition of organic residues (Guan et al., 2025). However, the AGB has been more extensively studied than SOC (Ma et al., 2024), likely due to the latter's complex dynamics, greater temporal and spatial variability, labor-intensive assessment methods, and its relatively limited contribution to short term forest productivity (Malla et al., 2023). Estimation of carbon stock and their variation in different pool is crucial to devise the conservation measures that enhance the climate change mitigation potential of an ecosystem (Imran et al., 2025).

Aboveground biomass (AGB) is a key indicator of forest ecosystem health, productivity, and carbon storage capacity (Simmavong et al., 2024). Globally, AGB has been found to vary with latitude (Hu et al., 2016). Several factors influence AGB, including climate, topography, soil properties, biological characteristics, stand age, land use, and disturbances (Ding & Jang, 2021). In addition to global-scale research, national-level studies have explored AGB variation in different regions of Nepal. For instance, AGB has been assessed in the Chure region using Sentinel-2 imagery (Khanal & Boer, 2023), in the Terai forests using airborne LiDAR and forest inventory data (KC et al., 2024), and in the mid-hills using UAV imagery (Upadhyaya et al., 2023). However, studies specifically examining AGB in relation to monospecific vegetation stands remain limited, highlighting a gap in current research.

SOC is recognized as equally important due to its critical role in maintaining soil health and functionality (Kham-balkar et al., 2021). It influences nutrient availability through its cation exchange capacity (CEC), enhances moisture retention, reduces leaching of harmful chemicals, promotes soil aggregation, and supports microbial and faunal biodiversity (Ciric et al., 2023). As the largest terrestrial carbon reservoir, SOC plays a central role in global carbon cycling-storing more carbon in the top 30 cm of soil than in the atmosphere and all vegetation combined (Georgiou, 2022). Effective forest management can enhance carbon storage, particularly in the form of Soil Organic Carbon (SOC) (Lal, 2005). Thus, maintaining SOC is essential not only for ecosystem health but also for climate regulation.

Multiple environmental and pedological factors influence SOC levels (Wang et al., 2024). These include climate, vegetation type, land use, topography, hydrology, fire regimes, soil texture, structure, pH, mineralogy, and bulk density (Andreetta et al., 2023). Forest soils hold approximately 44% of the 861 gigatons of carbon stored globally in forests (Pan et al., 2011). The carbon stock of forest soil varies with factors such as altitude, aspect, slope, and vegetation composition (Patton et al., 2019). Additionally, anthropogenic influences-such as tillage, fertilization, residue management, and land degradation-further shape SOC dynamics (Pu et al., 2024).

Globally, SOC concentrations are highest in high-latitude and high-altitude biomes like boreal forests, whereas tropical forests exhibit lower levels (Gachchhadar et al., 2022). In Nepal, SOC stock tends to increase with elevation, with higher values in coniferous and mixed forests compared to lowland broadleaf forests-likely due to cooler temperatures, lower decomposition rates, and reduced disturbances (Malla & Neupane, 2024). SOC also varies significantly with soil depth, generally declining beyond 40–60 cm (Rahman et al., 2022). For example, in Kenyan montane forests, SOC in the top 0–20 cm layer ranges from 109 to 151 Mg C/ha, decreasing sharply with depth (Rotich, 2025). Emerging evidence suggests that many plants possess deeper secondary root layers extending over a meter, potentially increasing carbon storage in subsoil layers often overlooked in conventional sampling (Lu et al., 2025).

Given that AGTB and SOC not only contribute to climate mitigation but also support climate adaptation, understanding their dynamics at a local scale is essential. Such insights are crucial for sustainable forest management, evidence-based policymaking, and leveraging climate finance for vulnerable countries and communities (Ruiting et al., 2025). However, many landscape-level studies overlook fine-scale AGTB and SOC variations influenced by site-specific factors (Malla et al., 2022). This study, therefore, aims to analyze AGTB and SOC under different tree stands within the Gokarna Rajnikunj forest, focusing on tree stands of *Alnus nepalensis*, *Pinus roxburghii*, and *Neolitsea cuipala*, to better understand localized carbon storage dynamics and inform forest management strategies.

## Materials and methods

### Study area

The study was conducted in the Gokarna Rajnikunj Forest, a nationally protected forest located in the mid-hill physiographic zone of the Bagmati province, Nepal (Figure 1). Situated in Ward No. 15 of Gokarneshwar Municipality, Kathmandu District, the forest is one of the oldest and most effectively conserved and managed protected forests in the Kathmandu Valley. Covering an area of 186 hectares, the site lies between latitudes 27°43’09.33” N and 27°40’19.05” N, and longitudes 85°23’03.27” E and 85°24’18.5” E, at an elevation of approximately 1300 meters above sea level.

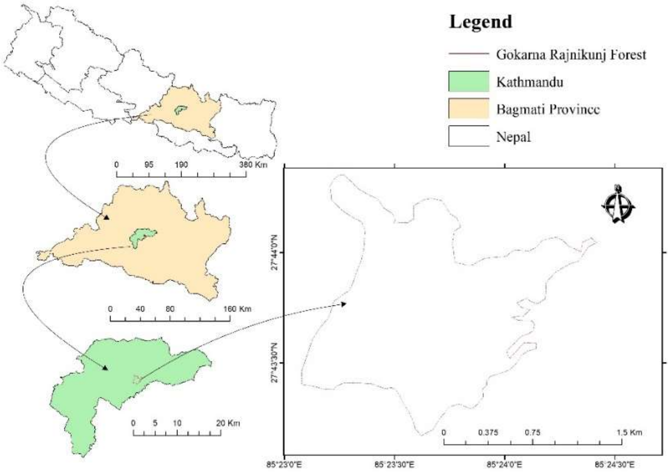

**Figure 1: Map of Nepal showing Kathmandu district and Gokarna Rajnikunj Forest**

### Description of Selected Tree Species

**a) *Alnus nepalensis* (D. Don)**

*Alnus nepalensis*, commonly known as Alder, belongs to the family Betulaceae. It is a pioneer, deciduous, and gregarious tree species native to the middle hills of Nepal. Naturally found at elevations ranging from 1000 to 2500 meters, it can also be cultivated as low as 300 meters (FRA, 2000). It typically grows in moist environments such as along riverbanks and ravines, but it also colonizes gravelly and unstable lands exposed by landslides and areas adjacent to cultivated fields (Jackson, 1994). *Alnus nepalensis* is a fast-growing species that can reach heights of up to 22 meters (Jiang, 2008). It has the unique ability to fix atmospheric nitrogen through a symbiotic association with *Frankia*, a nitrogen-fixing bacterium that forms root nodules (Khan et al., 2007).

**b) *Pinus roxburghii* (Sarg.)**

*Pinus roxburghii*, locally known as *Khote Salla*, is a member of the Pinaceae family (Farjon, 2010). It is an evergreen, coniferous, and fast-growing tree species. It can attain a height of over 50 meters and a trunk diameter of up to 1 meter (Wu & Raven, 1999). In Nepal, it typically grows between 900 and 1950 meters in elevation (Arya et al., 2000). This species is well adapted to dry hills and has significant ecological and economic value.

**c) *Neolitsea cuipala* (D. Don, Kosterm.)**

*Neolitsea cuipala*, locally known as *Kalche*, belongs to the Lauraceae family (Manandhar & Manandhar, 2002). It is a large, evergreen tree that can grow up to 20 meters tall, with leaves up to 15 cm long and hairy on the underside. This species is primarily distributed in the eastern and central regions of Nepal, occurring at elevations between 900 and 2100 meters (Manandhar & Manandhar, 2002). *Neolitsea cuipala* is a light-demanding and fast-growing species. It regenerates readily from seeds and has a strong coppicing ability, making it valuable for reforestation and forest management efforts (Huy et al., 2010).

### Vegetation measurement:

Monospecific stands of the three selected tree species were identified, and sampling was conducted with 10 x10 m quadrats. Since these stands were distributed across different parts of the forest, it was not feasible to assess the development history of all three species during the study period. Consequently, although stand development history is recognized as an important factor influencing various ecological parameters, it was beyond the scope of this study.

Due to the spatial distribution of the monospecific patches, the distance between quadrats ranged from a minimum of 30 m to over several hundred meters. Within each quadrat, individual trees were measured, and corresponding soil samples were collected following the methodology of Subedi et al. (2010). A total of 20 samples were collected from both the *Alnus nepalensis* and *Pinus roxburghii* plots, and 21 samples from the *Neolitsea cuipala* plots, resulting in a total of 61 samples.

For each tree within the plots, diameter at breast height (DBH) was measured using a diameter tape, and tree height was recorded using a Silva clinometer.

### Soil Measurement:

Each 10x10m quadrat was sub-divided into four 5x5m sections, and soil samples were collected from the mid-point of each subsection. At each of these four points, soil was extracted to a depth of 8.2 inches (21 cm) using a galvanized steel soil auger with a tapered, sharp cutting edge for efficient core extraction (Jobbágy & Jackson, 2000). The four samples from each quadrat were mixed to form a composite sample, which was then transferred into labeled soil sampling bags following standard procedures outlined in Subedi et al. (2010).

The aboveground pole biomass was estimated using the biomass model developed by Chave et al. (2005), based on the prevailing climate and forest stand type, following the recommended guidelines.

### Vegetation data analysis:

The following biomass model, based on climate and forest stand type, was used to estimate aboveground pole biomass in accordance with the guidelines provided by Chave et al. (2005).

$$AGTB = 0.0509 \times \rho D^2 H$$

Where,

AGTB = Above ground tree biomass (t $ha^{-1}$)
$\rho$ = Wood specific gravity ($g/cm^3$)
D = Diameter of the tree at breast height (cm) and
H = Height of the tree (m)

Wood specific gravity values were obtained from *Manual of Wood Densities for Tropical Tree Species* (Brown et al., 1982). The biomass stock density ($kg/m^2$) was calculated by summing the individual tree biomasses within a sample plot and dividing by the plot area. This value was then converted to tonnes per hectare ($tha^{-1}$) by multiplying by 10, following the Forest Carbon Measurement Guideline (2067).

### Soil Analysis:

Soil pH was measured using the suspension method at a 1:5 soil-to-water ratio with a digital pH meter (McLean, 1982). Soil moisture content (MC%) was calculated using the following equation:

$$MC\% = [(W_2 - W_3) / (W_3 - W_1)] \times 100$$

Where:

$W_1$ = weight of the empty tin
$W_2$ = weight of the moist soil + tin
$W_3$ = weight of the oven-dried soil + tin

Soil bulk density was determined from soil core samples following the method of Blake and Hartge (1986). The bulk density was calculated using the formula:

$$\text{Bulk density (gcm}^{-3}\text{)} = \text{Oven-dry weight of soil (g)} / \text{Volume of soil (cm}^{3}\text{)}$$

Soil organic carbon (SOC) concentration was determined using the Walkley and Black method (Walkley & Black, 1934). SOC stock (tha$^{-1}$) was estimated using the formula:

$$\text{SOC (tha}^{-1}\text{)} = \text{Organic carbon content (\%)} \times \text{Bulk density (g/cm}^{3}\text{)} \times \text{Soil depth (cm)}$$

### Statistical analysis:

Descriptive analyses were performed for the measured parameters including AGTB, SOC, Soil Moisture, Bulk density and Soil pH. Pearson's correlation test was conducted to assess relationships among these variables. Group-wise normality was assessed using the Shapiro-Wilk test, and the homogeneity of variances was evaluated using Levene's test. Although the data were normally distributed, the assumption of equal variances was violated. Therefore, analysis of variance (ANOVA) with Welch's correction was applied. Post hoc comparisons were conducted using the Games-Howell test. All statistical analyses were performed using JASP (version 0.95.0.0; JASP Team, 2024), and figures were generated in R (R Core Team, 2025).

### Results:

Descriptive statistics for tree biomass and soil properties across three forest stands-*Alnus*, *Neolitsea*, and *Pinus*-in the Gokarna Rajnikunj forest revealed distinct patterns in aboveground biomass distribution. The mean aboveground tree biomass was highest in *Pinus* stands (1,050.94 ± 522.95 tha$^{-1}$), followed by *Neolitsea* (236.16 ± 130.05 tha$^{-1}$) and *Alnus* (76.99 ± 37.23 tha$^{-1}$).

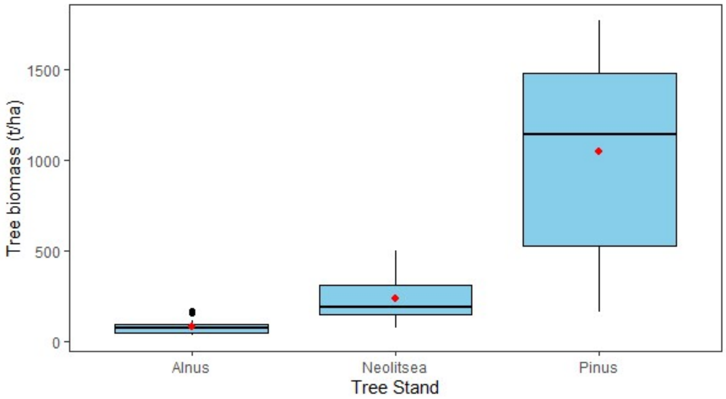

**Figure 2: Box and Whisker plots showing above ground tree biomass of the studies species**

There was a statistically significant difference in above-ground biomass among the three tree species studied ($p < 0.05$). Subsequent pairwise comparisons revealed that above-ground biomass differed significantly between all species pairs ($p < 0.05$).

In contrast to aboveground biomass, soil organic carbon (SOC) was found to be highest under *Alnus* (248.97 ± 70.20 t ha$^{-1}$), followed by *Neolitsea* (214.92 ± 64.88 t ha$^{-1}$) and *Pinus* (180.09 ± 32.14 t ha$^{-1}$) forest stands.

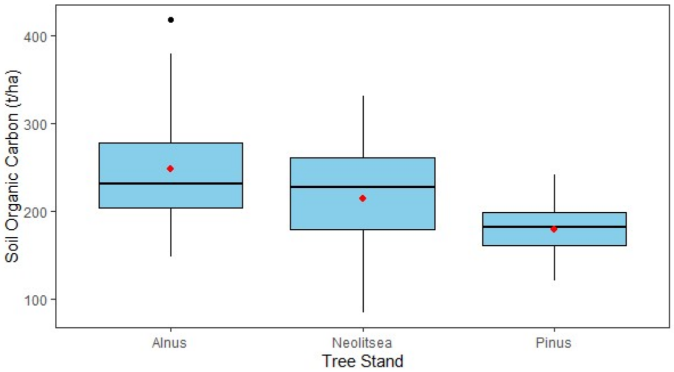

**Figure 3: Box and Whisker plots showing SOC across the soil of studied tree stands**

Soil organic carbon (SOC) differed significantly among the stands of the three tree species ($p < 0.05$). Pairwise comparisons indicated a significant difference in SOC between *Alnus* and *Pinus* stands ($p < 0.05$), while no significant differences were observed between the other species pairs ($p > 0.05$).

Soil pH was found to be most acidic under *Alnus* stands (6.56 ± 0.23), moderately acidic under *Pinus* (6.67 ± 0.21), and near-neutral to slightly alkaline under *Neolitsea* (7.43 ± 0.20). Soil pH differed significantly among the tree stands ($p < 0.001$). Pairwise comparisons showed that the *Neolitsea* stand had significantly different soil pH compared to both the *Alnus* and *Pinus* stands ($p < 0.001$ for both). No significant difference in soil pH was observed between the *Alnus* and *Pinus* stands ($p = 0.269$).

Soil bulk density values were similar across all forest types, with *Pinus* exhibiting the mean value (2.41 ± 0.18 gcm$^{-3}$), followed by *Neolitsea* (2.34 ± 0.21 gcm$^{-3}$) and *Alnus* (2.32 ± 0.13 gcm$^{-3}$). There were no statistically significant differences in soil bulk density among the three tree stands ($p > 0.05$).

Soil moisture content varied notably, with the highest mean observed in *Neolitsea* stands (6.52 ± 1.68%), followed by *Pinus* (4.70 s± 1.93%) and *Alnus* (3.54 ± 2.16%). Soil moisture content differed significantly among the tree stands ($p < 0.05$). Pairwise comparisons showed significant differences between the *Neolitsea* and *Pinus* stands ($p = 0.008$), and between the *Alnus* and *Neolitsea* stands ($p < 0.001$). No significant difference was observed between the *Alnus* and *Pinus* stands ($p = 0.187$).

**Table 1: Descriptive statistics of the studied parameters**

| | | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| Tree biomass | *Alnus* | 76.997 | 37.232 | 30.870 | 165.980 |
| | *Neolitsea* | 236.155 | 130.046 | 70.190 | 499.310 |
| | *Pinus* | 1,050.936 | 522.948 | 160.220 | 1,773.810 |
| SOC tha$^{-1}$ | *Alnus* | 248.970 | 70.197 | 148.070 | 418.750 |
| | *Neolitsea* | 214.923 | 64.884 | 84.670 | 331.530 |
| | *Pinus* | 180.093 | 32.141 | 121.020 | 242.170 |
| Soil pH | *Alnus* | 6.563 | 0.229 | 6.210 | 6.950 |
| | *Neolitsea* | 7.427 | 0.196 | 7.090 | 7.840 |
| | *Pinus* | 6.672 | 0.205 | 6.110 | 6.920 |
| Bulk density | *Alnus* | 2.315 | 0.127 | 2.060 | 2.550 |
| | *Neolitsea* | 2.338 | 0.211 | 2.050 | 2.830 |
| | *Pinus* | 2.406 | 0.179 | 2.090 | 2.720 |
| Soil moisture | *Alnus* | 3.544 | 2.155 | 0.090 | 6.850 |
| | *Neolitsea* | 6.519 | 1.682 | 3.250 | 9.980 |
| | *Pinus* | 4.702 | 1.929 | 1.990 | 8.460 |

These results indicate that forest type influences both biomass accumulation and soil characteristics, with *Pinus* associated with higher biomass, while *Alnus* supports greater SOC stocks.

The correlation analysis revealed generally weak and statistically insignificant relationships among most variables. Tree biomass showed a weak negative correlation with soil organic carbon (SOC; $r = -0.252$, $p = 0.052$), which was marginally non-significant. Similarly, weak and non-significant correlations were observed between tree biomass and soil pH ($r = -0.156$, $p = 0.235$), bulk density ($r = 0.161$, $p = 0.218$), and soil moisture ($r = 0.031$, $p = 0.816$). SOC also showed negligible correlations with soil pH ($r = -0.063$, $p = 0.632$), bulk density ($r = 0.054$, $p = 0.681$), and soil moisture ($r = -0.142$, $p = 0.280$). Notably, a moderate and statistically significant positive correlation was found between soil pH and soil moisture ($r = 0.444$, $p < 0.001$), indicating a potential interaction between these two soil properties (Table 2).

**Table 2: Results of Pearson's correlation test between the measured variables**

| Variable | | Tree Biomass | SOC tha$^{-1}$ | Soil pH | Bulk Density | Soil Moisture |
|---|---|---|---|---|---|---|
| 1. Tree Biomass | Pearson's r | — | | | | |
| | p-value | — | | | | |
| 2. SOC tha$^{-1}$ | Pearson's r | -0.252 | — | | | |
| | p-value | .052 | — | | | |
| 3. Soil pH | Pearson's r | -0.156 | -0.063 | — | | |
| | p-value | .235 | .632 | — | | |
| 4. Bulk Density | Pearson's r | 0.161 | 0.054 | -0.029 | — | |
| | p-value | .218 | .681 | .826 | — | |
| 5. Soil Moisture | Pearson's r | 0.031 | -0.142 | 0.444 | -0.061 | — |
| | p-value | .816 | .280 | < .001 | .645 | — |

Aboveground biomass did not significantly predict soil organic carbon (SOC) across the three forest stands ($p = 0.052$), indicating that variations in biomass explain little of the variation in SOC among the studied plots.

## Discussion:

The biomass value for *Pinus* appears substantially higher than those observed in the other forest types. This result also exceeds the aboveground biomass values previously reported for *Pinus* trees and *Pinus*-dominated forests in Kathmandu, Makawanpur, and other mid-hill regions of Nepal (Sharma et al., 2020; Pariyar et al., 2019; DFRS, 2015). One possible explanation is that monospecific stands of *Pinus*, as found in Gokarna (Pariyar et al., 2019), tend to accumulate greater biomass compared to mixed forests. Additionally, the long history of forest protection likely contributes to this high biomass. Gokarna Forest has been under continuous protection for approximately 500 years (Ranjit, 2017) and was officially designated as a royal hunting reserve in 1862 AD (Gokarneshwor Municipality, n.d.). This extended period of minimal disturbance may have enabled trees to reach larger sizes and accumulate more biomass over time. Few published studies specifically report the aboveground biomass of *Neolitsea*. Shrestha et al. (2016), in their study of the Bajrabarahi Sacred Grove in Kathmandu, reported an aboveground biomass of 84.59 t ha$^{-1}$, which is considerably lower than the value observed in our study. This supports our earlier explanation that the long-term conservation status of the Gokarna Rajnikunj forest may have contributed to greater biomass accumulation. Furthermore, Dhakal et al. (2017) conducted a study in the same forest-Gokarna Rajnikunj-where *Neolitsea* was the dominant species and reported a significantly higher aboveground biomass value of 457.44 t ha$^{-1}$. This difference is likely due to the inclusion of other co-occurring species, such as *Schima wallichii* which sequesters more carbon comparatively (Dhakal et al., 2017), in their estimation, which may have inflated the total biomass. For *Alnus*, the present findings are comparable to those reported by Dahal and Kafle (2013), though lower than values recorded in a study conducted in Sikkim, India (Limboo et al., 2025). These differences could be attributed to a range of factors, including geographical, ecological, climatic, soil-related, management, and socioeconomic conditions that influence tree growth and biomass accumulation across regions.

A study by Dahal and Kafle (2013) conducted in an *Alnus* forest in Kathmandu reported considerably lower SOC values: 19.78 t ha$^{-1}$ in the 0–10 cm soil layer and 10.61 t ha$^{-1}$ in the 10–20 cm layer. There are limited studies specifically reporting SOC in *Neolitsea* forests. For *Pinus* forests, Wagle (2023) documented SOC values ranging from 25.45 t ha$^{-1}$ to 130.24 t ha$^{-1}$ in the forests of Kathmandu and Shivapuri–Nagarjun. Overall, the SOC values observed in this study are notably higher than those reported in previous research. This can likely be attributed to the protected status of the Gokarna Rajnikunj forest, where litter collection is restricted and burning of forest litter is prohibited. The visible accumulation of undecomposed litter on the forest floor indicates long-term organic matter input, contributing to increased soil carbon storage. Additionally, the presence of broad-leaved, soft-wooded species such as *Alnus* enhances the rate of litterfall, decomposition, and subsequent organic matter incorporation into the soil (Ranabhat et al., 2009). It is also well established that soil organic carbon tends to increase with forest age and successional development (Kafle, 2024; Joshi & Garkoti, 2021a). Therefore, the intact and undisturbed condition of the forest over time has likely played a significant role in maintaining the high SOC levels observed across all three tree stands.

The acidic to moderately acidic nature of soils under *Pinus* and *Alnus* forests has also been reported by various researchers (Kumar & Pandey, 2022; Sharma et al., 2002). In *Pinus* stands, the slow decomposition of needle litter rich in resins and organic acids tends to acidify the soil over time (Gupta et al., 2024). Similarly, in *Alnus* forests, the high quantity of litterfall can lead to increased production of organic acids during decomposition, which may contribute to a decrease in soil pH (Joshi & Garkoti, 2021b). Additionally, factors such as high uptake and low return of base cations (e.g., $Ca^{2+}$, $Mg^{2+}$), leaching losses, and the nature of parent material can also influence soil acidity. In contrast, the absence of such acidifying processes in *Neolitsea* stands may explain the higher, near-neutral to slightly alkaline soil pH observed in those areas. Additionally, the relatively higher soil moisture content in *Neolitsea* forests may have contributed to this pH pattern by diluting soil acids, enhancing buffering capacity, and reducing the leaching of base cations, collectively leading to a less acidic soil environment. However, further dedicated research is needed to fully understand and confirm the mechanisms underlying this relationship.

The positive correlation observed between soil moisture and soil pH suggests that wetter soils tend to be less acidic. This may be due to increased soil moisture promoting anaerobic conditions, which enhance denitrification processes that consume protons ($H^+$), thereby increasing the soil pH (Bian, 2022; Saaban et al., 2018; Zárate-Valdez et al., 2006). However, despite this trend, the soils in *Alnus* and *Pinus* stands remained acidic, suggesting that other factors may be overriding the buffering effect of soil moisture. In overall, the results suggest limited direct linear relationships between tree biomass and the measured soil parameters, with the exception of a significant association between soil pH and moisture content.

The significant variation in soil pH among the tree stands may be attributed to the acidifying tendencies of *Pinus* and *Alnus*, both of which are known to lower soil pH. Notably, *Pinus roxburghii* thrives in moderately acidic soils (South, 2017), while *Neolitsea* was observed growing in slightly alkaline conditions. The reason behind *Neolitsea cuipala*'s preference for such soil conditions remains unclear and warrants further investigation through species-specific ecological studies.

The lack of significant difference in soil moisture between *Alnus* and *Pinus* stands can be explained by their litter dynamics (Sharafatmandrad et al., 2010). *Alnus*, being a broad-leaved and soft-wooded species, sheds substantial amounts of leaf litter, which, when left to decompose, contributes to the organic horizon, enhances soil porosity, and acts as a mulch, thereby improving moisture retention (Danish et al., 2020). Similarly, *Pinus* needles decompose more slowly and provide a mulching effect under undisturbed conditions, aiding in moisture conservation. Furthermore, Kim et al. (2023) observed that Korean pine needles, owing to their smaller physical size and lower porosity, formed a denser surface layer that effectively retained more rainfall and moisture. A similar mechanism may be applicable to *Pinus roxburghii*, as both species possess relatively small needles. In the studied Gokarna Rajnikunj Forest, the long-term accumulation of *Pinus roxburghii* needles may have contributed to increased soil moisture retention, despite the species typically being associated with moisture-limited environments. Interestingly, *Neolitsea* stands exhibited significantly higher soil moisture, though a definitive ecological explanation for this remains unclear. This difference may underlie the significant contrasts in soil moisture observed between *Neolitsea* and the other two species.

The significant variation in aboveground biomass among *Pinus*, *Neolitsea*, and *Alnus* likely reflects their distinct ecological traits.

In the context of the Gokarna Rajnikunj Forest, where monospecific stands are under long-term protection, aboveground biomass alone does not reliably predict SOC. This implies that other factors-such as litter quality, decomposition rates, root biomass, and microclimatic conditions-may play a more influential role in determining SOC levels.

## Conclusion:

This study demonstrates that tree species significantly influence both aboveground biomass and soil organic carbon levels. While *Pinus roxburghii* stands stored the highest biomass, *Alnus nepalensis* supported the greatest SOC stocks, highlighting species-specific contributions to carbon storage. Variation in soil properties such as pH and moisture further illustrate how tree-soil interactions shape ecosystem processes. with *Neolitsea cuipala* associated with near-neutral pH and higher moisture levels. Importantly, the forest's long-term protection and minimal disturbance have likely enhanced carbon accumulation both above and below ground. These results emphasize the substantial potential of forest soils and biomass-especially under appropriate species and sustained management-to optimize forest ecosystems as long-term carbon sinks ultimately supporting global climate change mitigation efforts over time.

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## CRediT Author Statement

**AS**: Conceptualization, Methodology, Investigation, Resources, Data Curation, Project administration, Writing- Original Draft, Writing- Review & Editing; **YDG**: Conceptualization, Supervision, Writing- Review & Editing; **SA**: Conceptualization, Supervision, Writing-Review & Editing; **NN**: Writing- Original Draft, Writing-Review & Editing, Visualization

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