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Forest Floor Biomass in Relation with Soil Attributes under Pinus roxburghii Sarg. Plantation, North-East India

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Abstract

This study evaluated forest floor biomass dynamics and soil physico-chemical properties under a Pinus roxburghii plantation in Lumami, Nagaland, to understand ecosystem functioning and nutrient cycling. Forest floor biomass was quantified using 1 m^2 quadrats at monthly intervals, and soil samples were collected from three depths across autumn and spring seasons. Total forest floor biomass was estimated at ~12.6 t ha^{-1}, dominated by woody litter, followed by partially decomposed and fresh litter fractions, while herbaceous biomass was negligible. Seasonal patterns indicated higher litter accumulation during post-monsoon and summer, reflecting the balance between litterfall and decomposition. Soil properties showed clear vertical and seasonal gradients. Soils were acidic, with pH increasing with depth, while soil organic carbon was concentrated in the surface layer and declined downward. Moisture content was higher during autumn, and bulk density remained low, indicating favourable soil structure. The soils were predominantly sandy loam. The results demonstrate a strong coupling between forest floor biomass and soil properties, influencing nutrient cycling and carbon storage. However, the dominance of recalcitrant litter and surface-localized carbon suggests slower nutrient turnover and increased sensitivity to disturbance. These findings highlight the need to integrate litter and soil carbon pools in assessing the sustainability of pine plantation ecosystems.

Keywords: *Forest floor biomass; Soil properties; Pinus roxburghii; Soil organic carbon; Litter dynamics; Nagaland*

INTRODUCTION

Forest ecosystems function as dynamic systems where vegetation, soil, and microbial processes interact to regulate productivity, nutrient cycling, and carbon sequestration [1]. Among these, coniferous species such as *Pinus roxburghii* dominate large areas of subtropical and temperate regions and play a significant role in biomass accumulation and ecosystem functioning [2]. These systems are particularly important in hilly landscapes, where they influence soil stability, hydrology, and long-term carbon storage [1, 3]. Biomass, defined as the total quantity of living and dead organic matter, is a fundamental ecological parameter used to assess ecosystem productivity and energy flow [4]. It integrates both structural and functional aspects of ecosystems and is widely used in estimating carbon stocks and nutrient dynamics. Biomass distribution within forest ecosystems varies across components such as stem, branch, foliage, and roots, and is strongly influenced by stand age, species composition, and environmental conditions. Studies across different forest systems have demonstrated that biomass accumulation generally increases with plantation age and varies significantly along ecological gradients [5, 6]. Furthermore, component-wise allocation typically shows dominance of stem biomass followed by roots, branches, and foliage, reflecting structural prioritization in tree growth [7]. The forest floor, comprising litter, woody debris, and partially decomposed organic matter, represents a critical interface between vegetation and soil.

It acts as a temporary reservoir of nutrients and plays a key role in regulating decomposition processes, soil moisture, and nutrient cycling [8]. Litterfall and its subsequent decomposition provide essential inputs for soil organic matter formation and influence overall ecosystem productivity. The accumulation and turnover of forest floor biomass are governed by climatic factors, litter quality, and microbial activity, leading to spatial and temporal heterogeneity in nutrient cycling processes [9].

Soil serves as both a medium for plant growth and a major sink for carbon storage, particularly in the form of soil organic carbon (SOC). Soil properties such as texture, bulk density, porosity, moisture content, and pH determine root development, microbial activity, and nutrient availability. Previous studies have shown that soil properties under forest plantations are significantly modified by vegetation type and litter inputs [10], while soil pH in forest ecosystems typically ranges from acidic to slightly acidic conditions and may vary with depth [11].

The interaction between forest floor biomass and soil properties forms a critical feedback mechanism controlling ecosystem functioning. Litter decomposition contributes to soil organic matter, enhances aggregation, and supports microbial processes, while soil conditions regulate decomposition rates and biomass turnover. Studies have demonstrated a strong relationship between vegetation characteristics and soil carbon storage, indicating that changes in forest structure can significantly influence soil properties and carbon dynamics [12]. Despite extensive research on biomass and soil properties in various forest ecosystems, there remains a lack of site-specific studies focusing on pine plantation systems in Northeast India, particularly in Nagaland. The region is characterized by complex terrain, high rainfall variability, and evolving land-use patterns, which may significantly influence ecosystem processes. However, quantitative data on forest floor biomass and associated soil physico-chemical characteristics in these systems remain limited. Therefore, the present study was undertaken with an objective of estimating the forest floor biomass across different components and analyze few selected parameters of soil in the study area.

MATERIALS AND METHODS

Study Area

The study site was selected in a pine (*Pinus roxburghii Sarg.*) plantation located at Lumami, Akluto sub-division, Zunheboto district (Fig.1), Nagaland, India (26°18′–27°27′ N; 94°15′–94°40′ E). The region is a humid, and possesses a subtropical monsoon climate with an average temperature ranging from 27–32°C. Altitude varies between 600 and 2400 m above mean sea level. The climate can be broadly categorized into post-monsoon (October–December), winter (January–February), and pre-monsoon/summer (March–April) periods. The selected plantation was approximately 15 years old and represents a typical pine-dominated system of the region.

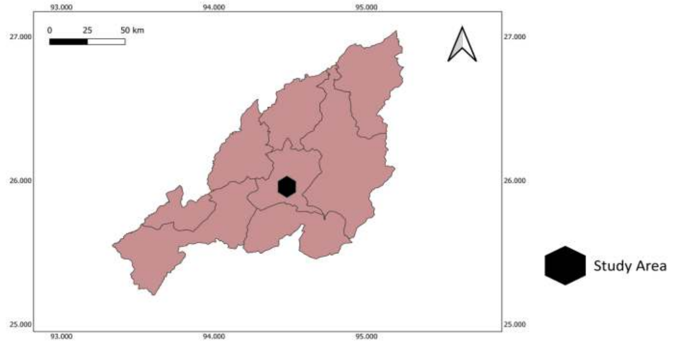

Fig. 1: The study area map of pine plantation in Lumami, Zunheboto, Nagaland (QGIS 3.44.5)

Estimation of Forest Floor Biomass

Forest floor biomass was quantified using five randomly placed quadrats (1 m × 1 m) at monthly intervals from October, 2017 to April, 2018. Within each quadrat, all aboveground herbaceous biomass was first harvested. The remaining forest floor material was categorized into: (i) fresh pine leaf litter, (ii) partially decomposed pine litter, (iii) woody pine litter (twigs, bark, cones, and branches), and (iv) herbaceous components (above and belowground). All collected samples were oven-dried at 105°C to constant weight and expressed on a dry weight basis (g m^{-2}).

Soil Sampling and Analysis

Soil samples were collected from the study site during autumn and spring seasons at three depth intervals: 0–10 cm, 10–20 cm, and 20–30 cm. Samples were air-dried, ground, and sieved prior to laboratory analysis. Soil temperature was measured in situ at depths of 0–10 cm, 10–20 cm, and 20–30 cm using a soil thermometer. Soil pH was determined using a digital pH meter in a 1:10 soil–water suspension. Bulk density was determined using the core sampler method [13]. Soil moisture content was determined gravimetrically by oven-drying fresh soil samples at 105°C for 48 hours. SOC was estimated using the Walkley and Black [14]. Soil texture was determined using the International Pipette method [15] to estimate the relative proportions of sand, silt and clay. Particle density was determined by the volume displacement method, and soil porosity was calculated using bulk density and particle density values:

$$P = (1 - Pb/Pd),$$

where P is porosity, Pb is bulk density, and Pd is particle density.

RESULTS AND DISCUSSION

Fresh Pine Leaf Litter

Fresh leaf litter of pine showed marked temporal variation, ranging from 1.41 ± 0.27 to 12.58 ± 3.21 g m^{-2}, with peak accumulation observed during March and minimum during November (Fig. 2). The higher values during late winter–early summer reflect increased litterfall associated with phenological cycles of *P. roxburghii*, while lower values indicate reduced litter input during early post-monsoon periods [16].

Partially Decomposed Pine Leaf Litter

Partially decomposed pine leaf litter of pine ranged from 12.06 ± 2.12 to 15.80 ± 1.99 g m^{-2}, with a total accumulation of 97.54 g m^{-2} (Fig. 3). Maximum accumulation during October and minimum during February indicate a dynamic balance between litter input and decomposition processes. Higher values during post-monsoon may be attributed to carry-over of fresh litter inputs, while subsequent decline reflects enhanced decomposition rates. Similar trends have been reported in Himalayan forest systems, where decomposition dynamics are closely linked to seasonal climatic variability [17, 18].

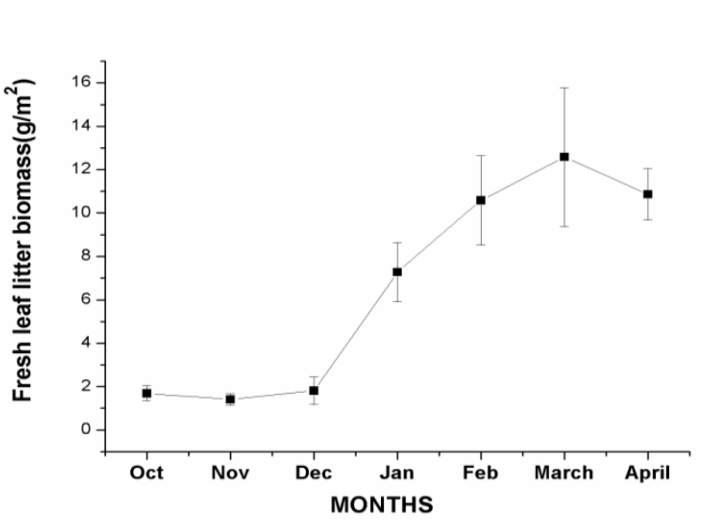

Fig. 2: Monthly variation in biomass of fresh pine leaf litter

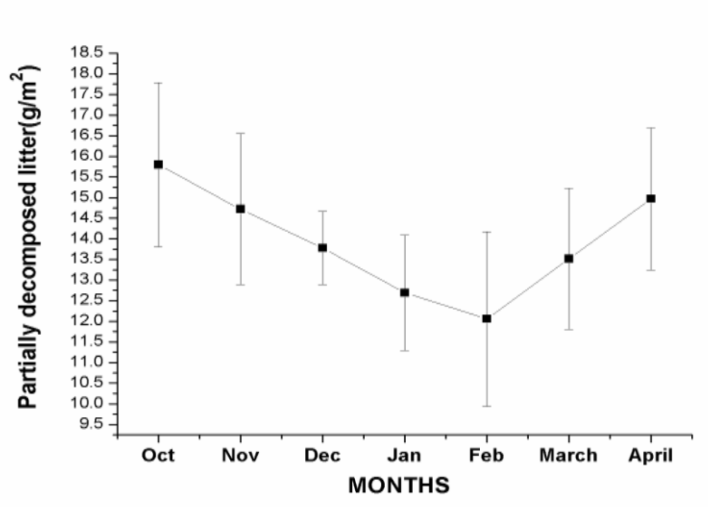

Fig. 3: Monthly variation in biomass of partially decomposed pine leaf litter

Woody Pine Litter

Woody pine litter constituted the dominant biomass component, ranging from 20.19 ± 10.36 to 45.20 ± 4.63 g m^{-2}, with a total contribution of 224.24 g m^{-2} (Fig. 4). Peak values during March suggest increased accumulation of recalcitrant materials such as twigs, bark, and cones. The dominance of woody litter reflects slower decomposition rates due to lignified structure, consistent with earlier observations in coniferous forest ecosystems [19].

Above Ground Herbaceous Biomass

Aboveground herbaceous biomass ranged from 2.15 ± 0.84 to 5.73 ± 0.87 g m^{-2}, with maximum values during October and minimum during January (Fig. 5). Seasonal variation indicates strong dependence on favourable moisture and temperature conditions during post-monsoon periods, while reduced winter growth limits biomass accumulation [20].

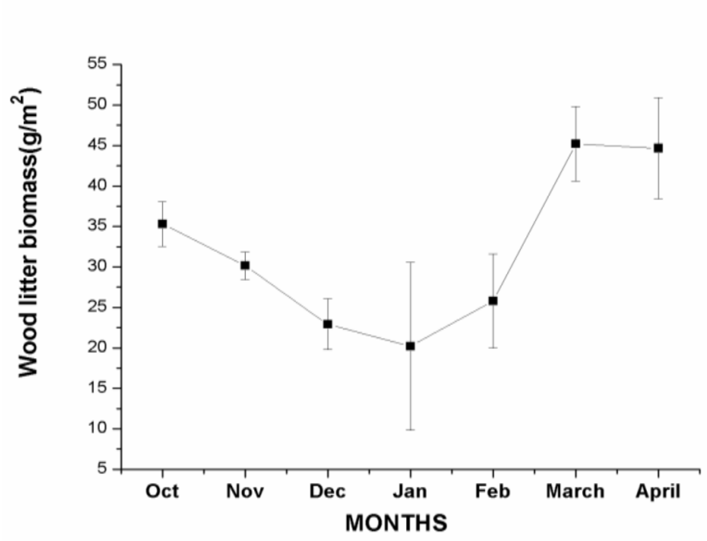

Fig.4: Monthly variation in biomass of woody pine litter

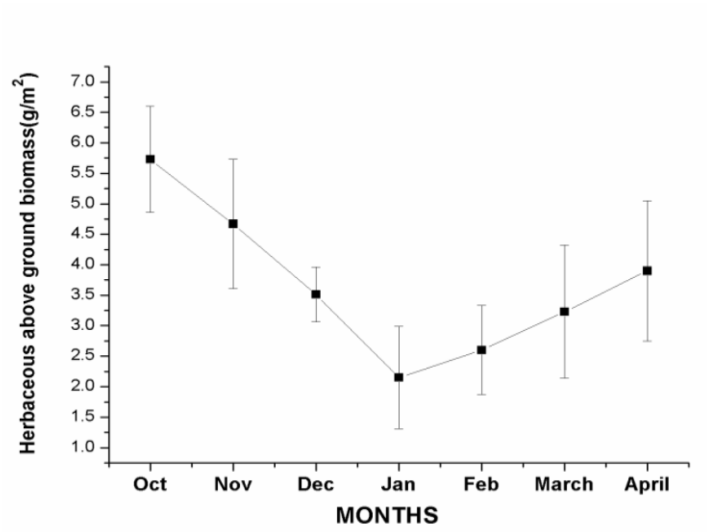

Fig.5: Monthly variation in biomass of understorey herbaceous above ground biomass under pine plantation

Below Ground Herbaceous Biomass

Belowground herbaceous biomass ranged from 0.83 ± 0.34 to 3.11 ± 0.81 g m^{-2}, with highest values in October and lowest in January (Fig. 6). The relatively low contribution of herbaceous biomass compared to litter components reflects limited understory development under dense pine canopy conditions [21].

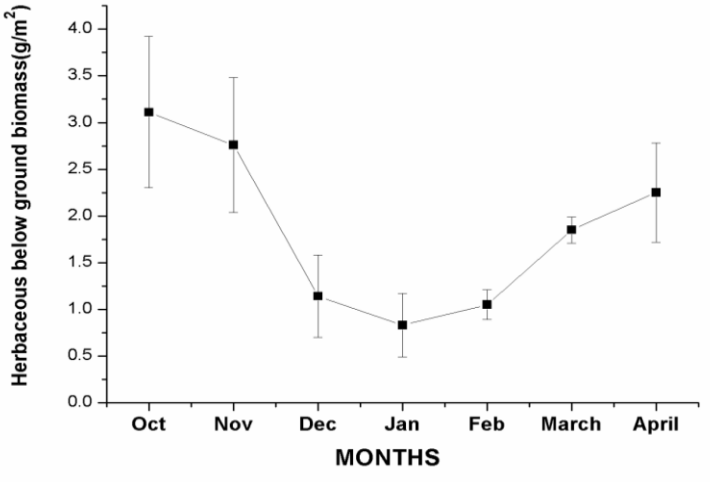

Fig. 6: Monthly variation in biomass of herbaceous below ground under pine plantation

Total Forest Floor Biomass and Litter Components Contribution

Forest floor biomass was recorded at 406.77 g m^{-2}. Among all litter components, woody litter contributed the highest proportion, followed by partially decomposed pine leaf litter, fresh pine leaf litter and herbaceous components. The dominance of woody pine litter indicates slower decomposition and accumulation of recalcitrant organic matter under pine systems. The estimated forest floor biomass (12.6 t ha^{-1}) falls within the range reported for subtropical Himalayan forests but is lower than other typical temperate systems. This intermediate status reflects climatic conditions that allow moderate microbial activity without extreme limitations or acceleration of decomposition processes.

Seasonal Variation in Soil Physico-Chemical Properties

Bulk density ranged from 0.63 to 0.91 g cm^{-3}, with higher values recorded during the spring season and lower values during autumn. The overall low bulk density indicates relatively porous soil conditions typical of forest ecosystems, which favour root penetration and microbial activity. Soil pH showed a consistent increase with depth (20–30 cm) across both seasons. During autumn, pH ranged from 4.97 to 5.25, while in spring it ranged from 4.10 to 5.15 (Fig. 7), indicating acidic soil conditions under the pine plantation. This acidity may be attributed to the decomposition of organic matter, which releases organic acids and lowers soil pH [22]. The observed increase in pH with depth is consistent with typical forest soil profiles. SOC was highest in the surface layer (0–10 cm), with values of 2.76% in autumn and 2.57% in spring (Fig. 8). The maximum SOC was recorded during autumn (2.76%), while lower values were observed during spring (2.25%), with an overall mean of 2.49%. The higher SOC during autumn may be associated with favourable moisture conditions and enhanced litter input and decomposition [23]. A clear decline in SOC with depth was observed, reflecting reduced organic matter inputs and lower biological activity in subsurface layers [24].

Soil temperature exhibited seasonal variation, with slightly higher values during spring (20.3°C) compared to autumn (19.8°C). Temperature decreased with increasing soil depth, likely due to reduced influence of atmospheric conditions and higher thermal stability in deeper layers. Soil moisture content was higher during autumn (29.09%) and lower during spring (20.86%), with an average of 25.31% (Fig. 9). Moisture content was consistently higher in the surface layer (0–10 cm) and decreased with depth. The higher surface moisture can be attributed to the presence of litter cover, which reduces evaporation and enhances water retention, as well as the influence of soil texture [25]. Particle density increased with soil depth, reflecting decreasing organic matter content in deeper layers. Since organic matter has a lower density than mineral particles, soils with higher organic content exhibit lower particle density, whereas deeper layers with reduced organic inputs show higher values [26]. Soil porosity ranged from 39% to 69%, with maximum values observed during autumn and minimum during spring (Fig. 10). Porosity increased with soil depth, likely due to reduced compaction compared to the surface layer. The inverse relationship between bulk density and porosity was evident, where lower bulk density corresponded to higher porosity, indicating better soil structure and aeration. Percentage of sand (89%) was higher during autumn followed by clay (8%) and silt (3%) **(**Fig.11a**)** and also during spring, percentage of sand (85%) was higher followed by silt(9%) and clay(6%) (Fig.11b) indicating the texture of soil in pine plantation site was sandy loam. Soils with sandy textures are reported to have a higher bulk density than soils with fine clay textured soil [27].

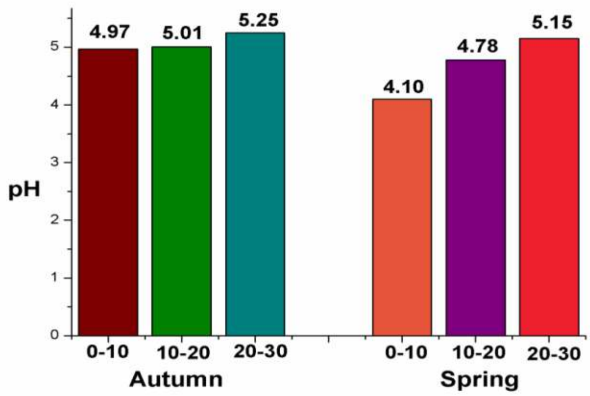

Fig. 7: Seasonal variation in soil p^H of pine plantation

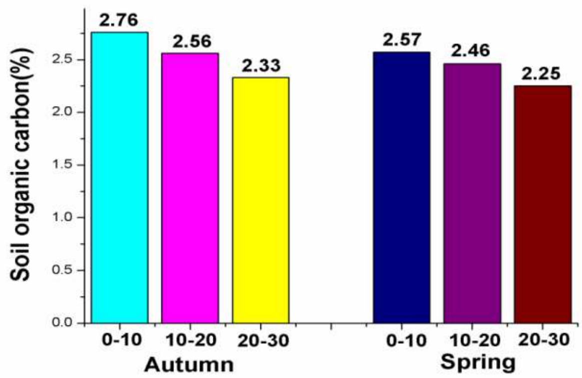

Fig. 8: Seasonal variation in soil organic carbon of pine plantation

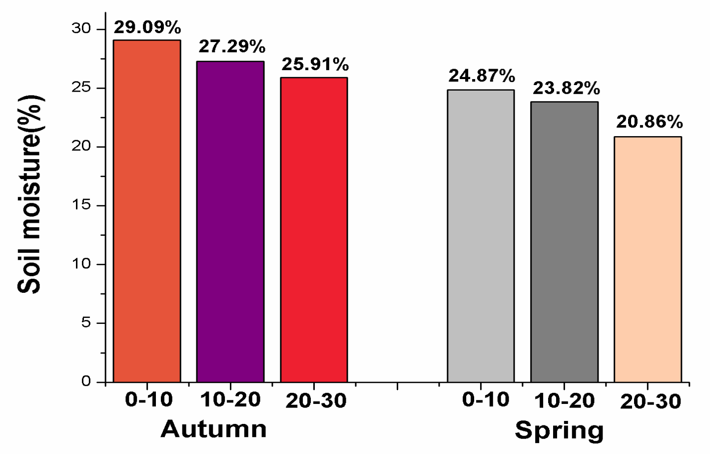

Fig. 9: Seasonal variation in soil moisture content of pine plantation

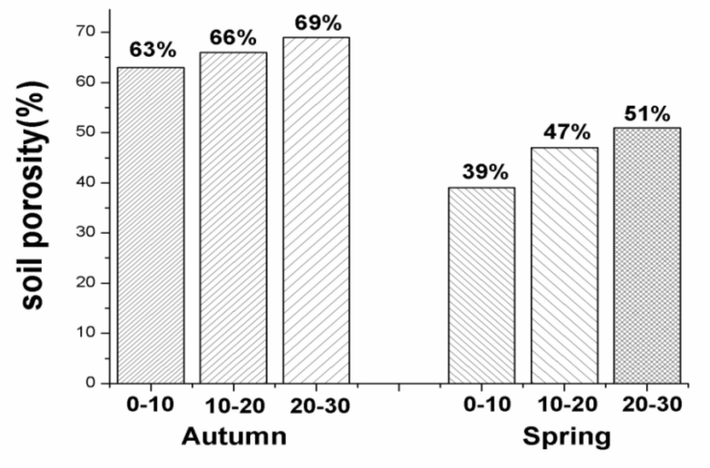

Fig. 10: Seasonal variation in soil porosity of pine plantation

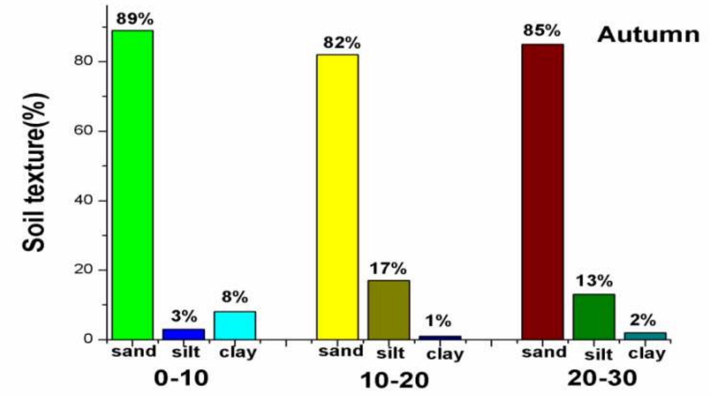

Fig. 11(a): Variation of soil texture autumn in pine plantation

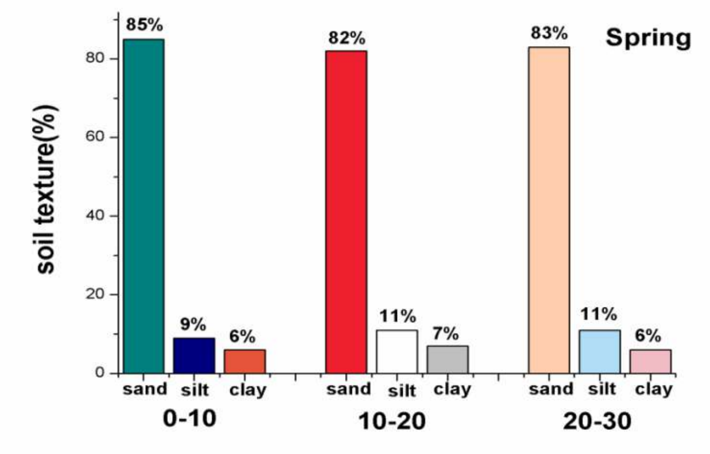

Fig. 11(b): Variation of soil texture spring in pine plantation

CONCLUSION

The present study estimated that forest floor biomass under pine plantation was moderate (406.77 g m^{-2}; ~12.6 t ha^{-1}) and dominated by woody pine litter, indicating slower decomposition due to lignified material. Herbaceous biomass contributed minimally, reflecting limited understory development. Seasonal variation in biomass components highlights a dynamic balance between litter input and decomposition driven by climatic and phenological factors. Soil properties showed clear vertical and seasonal patterns. The soil was consistently acidic (4.10–5.25), typical of pine ecosystems. SOC and moisture were higher in the surface layer and decreased with depth, emphasizing the importance of litter inputs in maintaining soil fertility. Low bulk density and higher porosity indicate a favourable soil structure for root growth and microbial activity. The study demonstrates a strong linkage between litterfall dynamics and soil properties, forming a feedback system that regulates nutrient cycling and carbon storage. However, the concentration of SOC in surface layers makes the system vulnerable to disturbance, particularly under fire-prone pine conditions. Overall, the pine plantation represents a moderately productive system with active litter–soil interactions, but slower nutrient turnover due to dominance of recalcitrant litter.

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