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FOREST FLOORS TO FARMLANDS: UNVEILING DEPTH-WISE DYNAMICS OF VERY LABILE CARBON IN NORTH-WESTERN HIMALAYAS

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ABSTRACT

The present study was carried out at Faculty of Agriculture, SKUAST-Kashmir during the year 2024 to evaluate the distribution of Very Labile Carbon (VLC) at two soil depths (0–20 cm and 20–40 cm across agricultural, horticultural, and forest land uses. The results of the study revealed that VLC consistently decreased with depth for all land uses, with agricultural soils showing the highest decrease (mean decrease: 2.86 mg/g). At both levels, forest soils held the maximum VLC (D1: 7.73 mg/g; D2: 7.10 mg/g), indicating improved carbon stability and little vertical loss. The general carbon retention pattern followed the trend of Forest > Agriculture > Horticulture. In contrast to agricultural soils, which showed greater variability (14.41–24.91%), forest soils had the lowest coefficient of variation (<9%), suggesting a consistent distribution of carbon. Forest systems also had the lowest standard error (SE), demonstrating data's dependability. These results were corroborated by box plot analysis, which revealed that forest soils had shorter interquartile ranges and higher median VLC values, especially at D1, suggesting stable carbon dynamics. On the other hand, agriculture showed wider dispersion, particularly in the subterranean strata. These results highlight the importance of land use and soil depth in determining the distribution of Very labile carbon, and imply that switching to forest systems could improve vertical carbon cycling and topsoil carbon sequestration.

Key words**:** Carbon sequestration**,** Forest soils, Land use, Soil depth, Very labile carbon

Introduction

The global carbon cycle is receiving more scientific and public attention because of concerns about rising atmospheric carbon dioxide levels. The global C cycle is significantly influenced by the pedosphere (Lal, 2018). The terrestrial ecosystem, in which the soil is a major component, contributes significantly to the current atmospheric C pool. Soil organic matter is an essential part of terrestrial ecosystems, and its content and dance have a significant impact on systemic activities (Ding *et al.*, 2022). Soil fertility and ecosystem function are significantly influenced by the build-up and turnover of soil organic matter (SOM), which also establishes whether soils serve as sources or sinks of carbon in the global carbon cycle (Dhaliwal *et al.*, 2019). Carbon dynamics plays a major role in the global carbon cycle and are crucial for the sustainability of industrial systems (Chen *et al.*, 2020). The dynamics of terrestrial C pools are directly affected by the type and character of land use systems.

By changing land cover and land use, anthropogenic activities have drastically changed global C pools and fluxes (Mandal *et al.*, 2022). The carbon cycle has changed as a result of the conversion of forested areas to different land uses and production systems (da silva *et al.*, 2025). However, the agricultural production system determines how quickly C is removed from soil (Omonode & Kladivko, 2025). Soil organic C stores have been declining owing to land disturbances and global warming (Mariappan, *et al.*, 2023). Appropriate land use plans can reduce the greenhouse effect and facilitate the storage of carbon in the soil. According to (Gupta *et al.*, 2025) the soils under temperate conditions are primarily coarse to medium in texture, have low levels of organic carbon and accessible nutrients, are stony on the surface, and have a very low capacity to hold water. Due to drastic climatic fluctuations, the productivity of soils is not only low but also extremely variable. Soil erosion is the primary cause of low productivity, because most nutrients are washed away with the soil. Additionally, soil carbon leaves the local C, further reducing soil fertility.

Varying land use can significantly affect soil carbon storage, both by preventing soil erosion and adding carbon. Very labile carbon (VLC), which represent the most readily decomposable segment of soil organic carbon, serves as a sensitive indicator of soil quality and ecosystem disturbance. Recent research across various land-use systems consistently highlights that natural forests support significantly higher VLC than cultivated or plantation lands, which is attributed to continuous organic inputs and minimal disturbance (Mishra *et al.*, 2020). In the temperate Himalayas, specifically in the Kashmir region, VLC concentrations were highest under natural forest cover compared to grassland, maize-converted fields, and paddy systems, thereby underscoring the influence of land-use practices on the distribution of this active carbon pool (Kumar *et al.*, 2022). These findings indicate that assessing VLC across land uses is essential for evaluating soil resilience and guiding sustainable land management, particularly in sensitive temperate environments such as those of the Kashmir Valley.

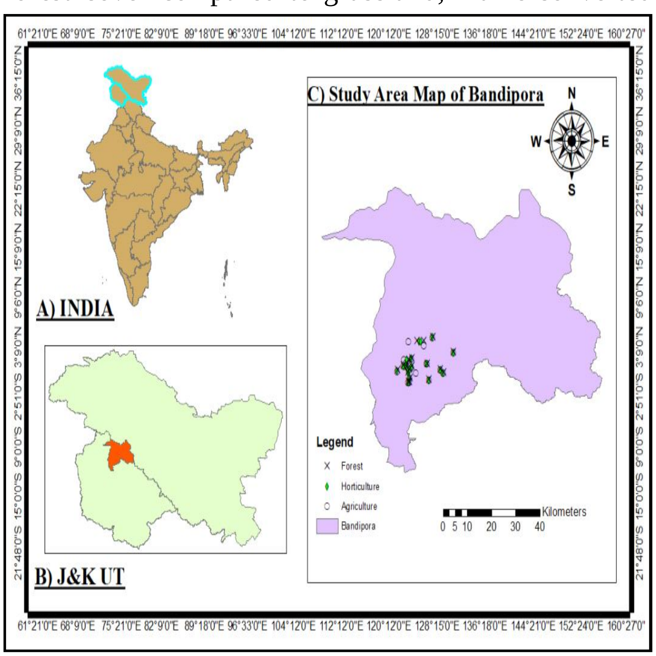

Fig. 1: Study area map of District Bandipora.

Materials and Methods

Location

The survey was conducted in a mountainous area of Bandipora District in North Kashmir. The district lies between longitude 74°392 003 E and latitude 34°252 123 N, with a geographical area of 398 km^2. The elevation ranges between 1578 and 1581 m above the mean sea level (msl). The valley has flat to slightly undulating topography and covers a total area of 39,800 ha. The study area has a temperate, Mediterranean climate with minimum and maximum temperatures ranging from -10°C to 32°C. The annual rainfall is approximately 1200 mm, in the form of rain and snow. ArcGIS software was employed to create a high-resolution study area map, accurately depicting the geographical setting of Bandipora District along with the spatial distribution of the sampling sites. The (Fig. 1) depicts the study area location from national (India) to regional (J&K UT) scale, highlighting Bandipora district with mapped sampling sites across forest, horticulture, and agriculture land uses.

Design of Survey and Sampling

The three land use types chosen for this study were Agriculture, Horticulture and forests. Geo-referenced soil samples were collected from two depths; 0-20 and 20-40 cm. Soil samples were collected from 20 locations and from each location six samples were collected, two from each land use type. In total 120 samples were collected for this study. A stratified random sampling method was used. The collected samples were then stored in cloth bags. The stored soil samples were carried to the research laboratory of the Division of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Wadura. Soil samples collected from each site and depth were air dried at room temperature, ground in a wooden mortar, sieved with a 2 mm sieve and 0.5 mm sieve (for SOC) and stored for analysis. Very labile carbon (VLC) was estimated through a modified Walkley and Black method (1934) as described by Chan *et al.*, (2001) employing normality (12N) of sulfuric acid (H_2SO_4). The VLC was measured using the organic carbon which can be oxidized by 12N H_2SO_4. For the analysis of Very Labile Carbon (VLC) distribution across different land uses and soil depths, R Studio served as the primary platform for data processing and visualization. The software was utilized to carry out detailed statistical analyses, enabling the identification of significant differences and trends in VLC content between agricultural, horticultural, and forest soils. Box plots were generated to graphically represent the variation, spread, and central tendency of VLC values, providing a clear visual comparison across the studied factors. These visualizations facilitated an intuitive interpretation of the data, highlighting depth-wise and land use-based patterns

Result

Very labile carbon consistently decreased with depth (D2 < D1) across all land uses, with the most pronounced decline in agricultural soils (mean drop: 2.86 mg/g). Forest soils retained the highest carbon content at both depths (mean D1: 7.73 mg/g, D2: 7.10 mg/g), indicating better carbon stabilization. Forest > Horticulture > Agriculture for carbon retention at both depths. Agricultural soils showed the highest variability (CV%: 14.41–24.91), suggesting that management practices significantly influence VLC. A low CV% in forests (< 9%) implies a uniform carbon distribution, whereas a higher CV% in agriculture highlights heterogeneity. The standard Error (SE) was the lowest for forest soils, reinforcing data reliability. Depth and land use interact significantly (e.g., tillage in agriculture may accelerate carbon loss in deeper layers). Forests' minimal D1-D2 difference (0.63 mg/g) suggests efficient vertical carbon cycling (Table 1).

The Boxplot (Fig. 2) shows the distribution of VLC across land uses reveals clear distinctions influenced by both land management and soil depth. Forest soils consistently exhibited the highest concentrations, particularly in the surface layer (D1), with relatively low variation among samples reflecting stable organic matter inputs and minimal disturbance. In contrast, agricultural soils displayed notably lower values, especially in the subsoil layer (D2), along with greater variability, likely due to frequent tillage and inconsistent organic matter returns. Horticultural soils present intermediate levels of VLC, with higher values at the surface and a marked reduction at depth, suggesting moderate carbon input as well as underlying soil disruption. These patterns illustrate how different land use practices and depth profiles influence the distribution and stability of active carbon fractions, as supported by the data shown in (Table 1).

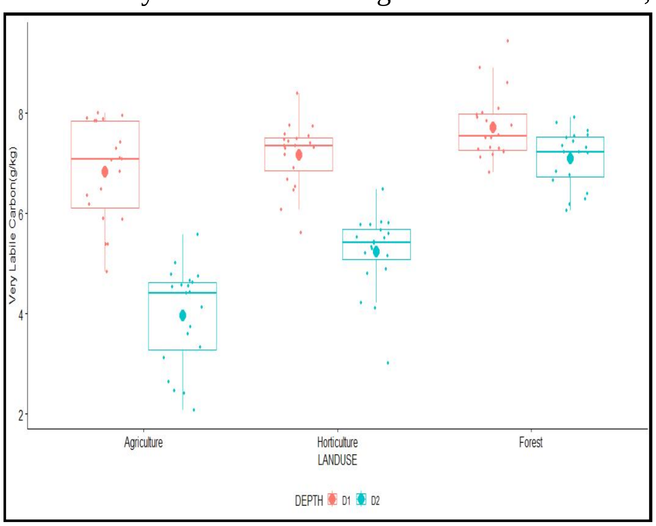

Fig. 2: Boxplot showing variability among various land uses of Very Labile carbon pool (g/kg).

Table 1: Very Labile Carbon (g/kg) under Various Land uses.

Locations	Agri.		Hort.		Fore.	
	D1	**D2**	**D1**	**D2**	**D1**	**D2**
Onagam	7.84	5.58	7.57	6.49	8.00	7.54
Khayar	7.29	4.66	7.35	5.77	7.30	7.22
Pazalpora	6.48	3.60	6.54	5.30	6.81	6.18
Bonakoot	6.84	4.13	6.46	4.80	7.24	7.21
Tanghat	7.09	4.56	7.30	5.59	7.92	6.76
Pannar	6.35	3.74	7.18	5.41	7.32	6.28
Ahamishareef	5.38	2.42	7.43	3.01	7.76	7.31
Check-reshipora	7.10	4.41	8.39	5.81	9.43	7.92
Ayat-mullah	4.83	2.47	7.75	5.15	8.60	7.51
Madar	5.89	2.65	7.74	5.43	8.90	7.80
Kunan	5.88	3.34	6.07	4.89	7.27	6.39
Arin	7.87	4.75	7.49	5.82	7.56	7.35
Sumlar	7.06	4.43	7.40	5.51	7.85	6.65
Rampura	5.38	2.07	7.47	5.52	8.09	7.65
Nadihal	6.18	3.12	5.62	4.12	7.51	7.22
Kehnoosa	7.42	4.57	6.67	5.21	7.11	6.84
Aloosa	7.84	4.62	7.35	5.33	7.22	7.13
Malangam	7.90	4.78	7.54	5.66	7.97	7.56
Quilmuqaam	8.00	5.01	7.31	5.77	7.51	7.43
Magnipora	7.95	4.54	6.91	4.21	7.18	6.06
Mean	6.83	3.97	7.18	5.24	7.73	7.10
SE(Mean)	0.22	0.22	0.14	0.17	0.15	0.12
CV%	14.41	24.91	8.86	14.47	8.42	7.78

Agri.: Agriculture; **Hort.:** Horticulture; **Fore.:** Forest

Discussion

The assessment of soil carbon fractions highlighted the significant influence of both land use and soil depth on the distribution and dynamics of organic carbon pools (Table 1). The very labile carbon (VLC) fraction representing the most biologically active and easily decomposable component was the most abundant in forest soils, suggesting that the quality and continuity of organic inputs strongly regulate this pool. This fraction primarily originates from fresh organic residues such as root exudates, microbial biomass, and undecomposed litter, which are quickly cycled through microbial processes. In contrast, agricultural soils exhibited the lowest VLC levels, particularly at D2, likely because of frequent soil disturbance and reduced organic matter inputs. Horticultural soils maintained intermediate VLC concentrations, reflecting moderate organic inputs and less intensive disturbance than agricultural systems. These observations underscore the role of land management in shaping the size and turnover of active carbon fractions in temperate soils. Similar results were also reported by (Kumar *et al*., 2022) during a study of soil carbon dynamics in the temperate Himalayas. (Ansari *et al*., 2022) recorded the highest VLC in forest soils. This difference probably reflects the quality of soil organic matter whereas differences in the quality of organic input due to different vegetation types substantially influence soil VLC pools in forest soils.

Conclusion

Across all land use types, a consistent decline in very labile carbon (VLC) was observed with increasing soil depth, with the sharpest reduction occurring in agricultural soils. Forest soils maintained the highest VLC concentrations at both depths, suggesting more effective vertical carbon movement and stabilization mechanisms within these ecosystems. This was further supported by the forest system's low variability indicators, including a narrow gap between surface and subsurface values, low coefficient of variation, and minimal standard error reflecting stable carbon dynamics. Horticultural soils showed moderate VLC levels, with a noticeable but less pronounced decline from the surface to the subsurface, likely because of intermediate levels of organic input and soil disturbance. These results clearly demonstrate that both land use practices and soil depth strongly influence VLC distribution, with forests being the most resilient in conserving surface carbon and supporting deeper carbon continuity, followed by horticulture and agriculture.

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