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Impact of land use change on soil organic carbon: A case study of North Western Himalayas

Owais Bashir, Shabir Ahmad Bangroo, Nasir Bashir Naikoo, Sandeep Kumar, Rehana Rasool, Lareb Mir, Aamir Hassan Mir, Hafsa Abdullah and Omer Reshi

Owais Bashir
Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, India

Shabir Ahmad Bangroo
Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, India

Nasir Bashir Naikoo.
Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, India

Rehana Rasool
Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, India

Sandeep Kumar
Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, India

Lareb Mir
Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, India

Aamir Hassan Mir
Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, India

Hafsa Abdullah
Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, India

Omer Reshi
Centre for Environment and Marine Studies. King Fahd University if Petroleum and Minerals, Dhahran, Saudi Arabia

Corresponding Author:
Owais Bashir
Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, India

Abstract

The geological, ecological, and biological ecosystems of the planet have changed as a result of global climate change, and this poses a serious threat to human civilization and the maintenance of agricultural productivity with regard to food security. Due to an increase in atmospheric CO_2 concentration, climate change has been linked in recent decades to irregular rainfall distribution and significant diurnal temperature changes. This study intends to evaluate the impact of land-use changes on NWH's soil characteristics and carbon storage capacity. In the NWH, samples were taken from two soil depths at intervals of 30 cm between 0 and 60 cm under four contiguous land uses, including fallow areas, horticulture, agricultural, and forest. Forest soils had significantly greater total SOM stocks in the 0-60 cm range when comparing SOM stock among various land uses in all locations. The SOM stock generally decreased with increasing soil depth according to the distribution pattern of SOM stock in soil profiles. Despite the fact that SOM stocks declined with depth, subsoil stocks contribute to longer-term carbon storage than topsoil stocks do because they are better stable by adsorption onto clay fraction in subsoil with finer textures than topsoil stocks are. As seen in some agricultural land uses in some locations of our study, agricultural operations, particularly applications of organic materials, such as cattle manure, could increase subsurface SOM stock. The usage of agricultural land in the uplands accelerated soil deterioration. Appropriate agronomic techniques, such as the application of organic soil amendments, the return of crop wastes, and a reduction in soil disturbance to raise and preserve SOM stock, should be used to restore the soil fertility of these agricultural lands.

Keywords: Soil carbon, land use, agriculture, forest, top soil, subsoils

Introduction

Soil is a dynamic system consisting of water, nutritive minerals, organic materials, air, and living creatures regulated by various environmental elements, including weather elements, parent source, topography, organisms, and the passage of time (Ahmed *et al*. 2022; Vizuete-Jaramillo *et al*. 2022; Elliott *et al*. 2022; Prasad *et al*. 2021; Kleber *et al*. 2021) [1, 2, 3, 4, 5]. In the earth's ecosystem, soil acts as home to all species and contains nutrient sources for their sustainable growth and development. Carbon is stored in the soil through the root, root exudates and above ground litter (Dror & Klein 2022; Zhang *et al*. 2022) [6, 7]. Soil organic matter (SOM) is a key plant food source that impacts every process in the soil, including water retention, soil structure, soil colour, CEC, nutrient dynamics, soil colour, soil aeration, bulk density, soil microbial population, and gaseous exchange (Kane *et al*. 2021; Guenet *et al*. 2021; Witzgall *et al*. 2021) [8, 9, 10]. Soil organic carbon (SOC) stock is an essential component of the generic carbon cycling via soil, ocean, plants, and the atmosphere (Xu *et al*. 2021; Guan *et al*. 2021; Pekkan *et al*. 2021; Liu *et al*. 2021) [11, 12, 13, 14]. The SOC stock in the top metre of soil is believed to hold 1,500 PgC, accounting for more carbon than the combined effect of the atmosphere (800 PgC) and terrestrial plants (500 PgC) (Poulter *et al*. 2021) [15]. In recent years, SOC stocks have attracted global attention, with many policies framed by the united nation organisation. Soil is a major sink of atmospheric carbon (Wang *et al*. 2022; Yang *et al*. 2022; Khan *et al*. 2021) [16, 17, 18] Land-use changes are the second greatest source of greenhouse gases and contribute 12-20 percent of the greenhouse gases (IPCC 2007). The conversion of forests to agricultural systems is the predominant land-use change, with yearly deforestation rates exceeding 13 million hectares (FAO 2005). Large eminent scientists have worked on the land use and soil organic carbon (Table 1)

Table 1: List of the scientists who worked on land use and carbon stock in past two years

S. No	Topic	Country	Authors
1.	Determining impact of land use on soil nitrogen and carbon in loess china	China	Zhu *et al*. 2021 [18]
2.	A meta-analysis of land use change on carbon pool and soil properties	India	Padbhushan *et al*. 2022 [19]
3.	Impact of LULC on SOC pool in North west china	China	Li *et al*. 2022 [20]
4.	Impact of land use on soil organic carbon using geospatial techniques	Uganda	Njagi *et al*. 2022 [22]
5.	Variations of clay to organic matter ratios in various land uses Europe across different times	England and Wales	Prout *et al*. 2022 [23]

Factors that may help increase SOC storage capacity include litter production, litter quality, increasing below-ground inputs or surface mixing by soil organisms, increasing physical protection via intra-aggregate or organic mineral complexes, and microclimate change (Amanuel *et al*. 2018; Shapkota and Kafle 2021; Kooch *et al*. 2021) [24, 25, 26]. On the other hand, regional and local elevation and temperature variations affect SOC stock (e.g., soil properties, pH, clay content, soil type, and soil moisture). Small-scale variability may impose substantial scattering and obscure the links between SOC, topography, and climate even at vast scales. Small variations in the SOC pool may substantially affect atmospheric CO2 concentrations. The rapidly expanding population in North-Western Himalayas has resulted in extensive changes to the land use pattern, mostly due to raising agricultural productivity. In this area, during the last four decades, cultivated fields have steadily expanded at the cost of forests and grasslands. Soil organic carbon concentration displays great geographical heterogeneity, horizontally and vertically, depending on land use. The SOC decreases with depth irrespective of clay size fraction, vegetation, and soil particle size distribution. The world's soils are potentially effective carbon sinks and may considerably contribute to mitigating global climate change. The purpose of the research was to characterise changes in concentration and stock of SOC in paradigm to various land-use patterns in the North-Western Himalayas. The current study's objective was to determine the impact of soil depth, land-use changes and other soil properties on SOC stock and concentration.

2. Material and Methods

2.1. Outline of the study area

The comprehensive study area (34º12′ to 34º20′ North latitude and 74º20′ to 74º34′ East longitude) is located in the Northern part of temperate Indian Himalayas. The average annual temperate of the study area is 24° C and annual rainfall ranges from 1270 mm to 1300 mm. the area is located at an elevation of 1584 meters and has an area of 3353 km2. Mountains, hills, and valleys may be found at high, medium, and low elevations across the area. A broad valley formed by the river Jhelum separates the two regions. The Jhelum River runs through the northern section, while Pakistan is located in the southern part. The area's geography ranges from steep to moderately sloppy, with some plain areas. Alfisol is the most dominant soil type.

Table 2: Site characterization of the study area

Site Name	Latitude and Longitude	Elevation (amsl)	Topography	Slope (%)	Depth of soil (cm)	Natural vegetation
(Agriculture)	34°10'19 " N 74°31' 02 " E	1983	Undulating	3-8	0-179	*Pinusspp., Ulmusspp.,Populusspp., Salix* spp., *Fir* spp., *Berberis* spp., *Aaicheria* spp.
(Horticulture)	34° 12' 57" N 74° 21' 49" E	2385	Rolling	8-16	0-83	*Pinus* spp. , *Ulmus* spp., *Populusspp., Wild grass* spp., *Walnut* spp., *Celtisspp., Aaicheria* spp.
(Agro-Forestry)	34°15' 50"N 74°18' 18" E	2162	Foot Hills	16-25	0-188	*Pinus* spp. , *Ciderus* spp., *Populusspp., Ailanthus* spp., *Walnut* spp., *Urticaspp., Aaicheria* spp., *Rumexspp.*
(Fallow Land)	34°2' 32" N 74°14' 06" E	2110	Rolling	8-16	0-114	*Populus* spp., *Salixspp, Walnut* spp, *Taraxicum* spp., *Malwa* spp., *Berberis* spp., Cotoneaster spp., Aliesthusspp

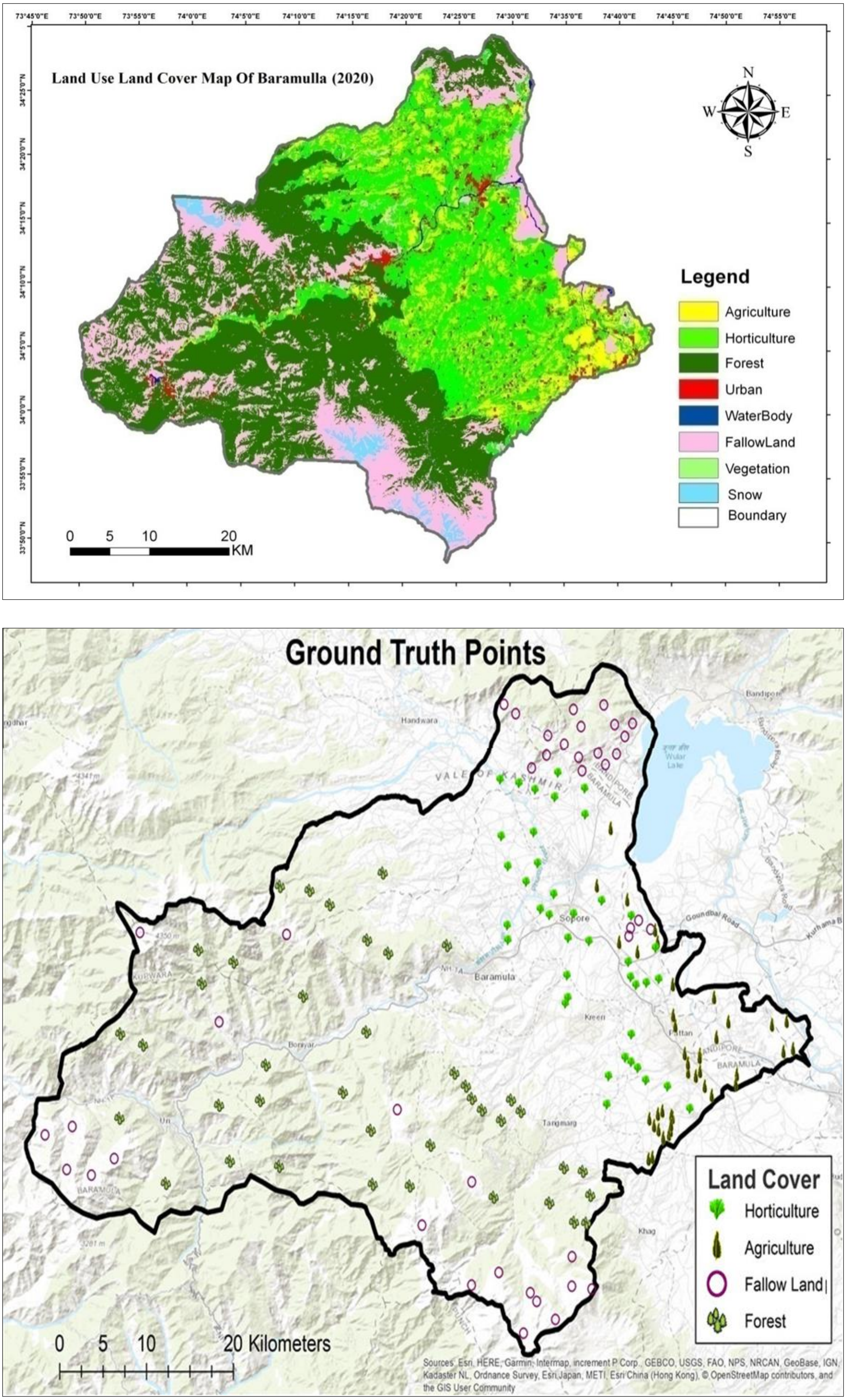

Fig 1: Land use map of the North Western Himalayas region along with ground truth points.

2.2 Criteria for site selection

The sampling sites were selected on certain criteria; they should be idle of that land use; should have a major impact on that land use on that area; sampling site should have no effect of any other source.

2.3 Sampling site selection

On the arrival of the spring season, soil sampling was carried out (depending on land use and sampling design). Sampling was done at three altitudes; low, mid and high altitude. Four land use classes were considered: agriculture, horticulture, forest, and fallow land. Equivalent proportion of soil samples were collected among the land uses irrespective of the area of any land use. Hence, 100 soil samples were obtained from overall study and were analysed at the faculty of agriculture Wadoora Sopore.

2.4 Laboratory analysis

All the soil samples were air-dried, polished and pulverized using mortar and pestle and then sieved through a 2mm mesh sieve. The hydrometer method (Bouyoucos, 1962) [27] was used to determine particle size distribution. Blake and Hartge's (1986) [28] method was used to estimate soil bulk density in which each core of soil sample was oven-dried at 105 °C for at least two to three days. The soil pH was determined potentiometrically 1:2.5 (w/v) soil-water supernatant suspension (Carter 1993) [29]. The (Walkley and Black) [30] were used to estimate SOC using potassium dichromate and sulphuric acid as the main chemicals. The soil organic carbon stock for each land-use was calculated according to the following equation

Soil organic carbon Stock (SOC Mg ha− 1)
= L X Bd X SOC (g/kg) X10 (Eq-1)

Where; SOC stock is (Mg ha^{-1}); L = thickness of soil layer (m), and BD = bulk density (Mg m− 3).

2.5 Descriptive statistics

The soil parameters were first examined for equality of variance and normality ('Kolmogorov-Smirnov & Levene statistic'). Using SAS software's general linear model (Proc GLM) was examined. To examine the influence of soil depth and land uses on soil physicochemical characteristics, ANOVA models were applied. The significance of regression equations and Pearson's correlation coefficients were evaluated using a significance threshold of p 0.05 and 0.01. In addition, the pairwise comparison approach was utilised to determine the average difference across depth levels, and land uses based on soil attributes. By summing the ratio of squares of the variances between both the measured and the average of the response variable and dividing by the degree of freedom we estimated mean square error (R). Multiple comparison of the mean for every variable (soil organic carbon, depth, land uses and bulk density) was conducted using the DUNCAN test, with a significance threshold of = 0.05, to see if there was a statistically significant difference between the means. We estimated the variation in soil physicochemical characteristics across soil depth and land uses using 0–30 cm soil depth and forest land use as a peer group. Therefore, the variance indicates the percentage increase relative to the reference group for a particular physiochemical soil parameter. For instance, the variance (percent) for 30–60 cm soil depth and agricultural land was calculated as follows:

$$\text{Cultivated land shift} = \frac{CLV - FLV}{FLV} \text{ X } 100 \qquad \text{Eq-2}$$

$$\text{Variation}_{30-60}\,(\%) = \frac{V_{30-60} - V_{0-30}}{V_{0-30}} X\ 100 \qquad \text{Eq-3}$$

CLV is Cultivated land value, FLV is Forest land value and V is value

3. Result and Discussion

3.1 Impact of land use change on the physical properties of soil

3.1.1 Textural fraction of soil

The textural components of clay (p_{value}= 0.0431) and sand (p_{value}= 0.0346) revealed substantial change with land use (Table 3). No statistical variation was seen in the silt percent in all land-use categories. The proportion of sand was greater in forest area (38.95 ± 6.17), trailed by fallow land (34.30 ± 5.29) as opposed to other land-use categories (Table 3). The total average proportion of sand was less in agricultural land (26.27± 5.89) than that of other land-use groups (Table 3). The agricultural land had a larger clay component (33.38 ± 7.27) than that of other land-use classifications. The major soil textural group within 0-30 cm of soil depth is sandy clay loam. The findings suggested that textural soil components behaved differently after natural forest conversion to other land-use patterns. A component of sand under forest and fallow land were greater than other land-use categories. This could be linked to the higher rainfall conditions, which eliminate the tiny particles. The results are in agreement with Wang *et al.* 2022 [31]; Parkhurst *et al.* 2021 [32]; Chen *et al.* 2022 [33]. The large amounts of sand in the research region were connected to the influence of the soil erosion processes owing to excessive rainfall, which has preferentially moved the very fine soil grains and left behind the very coarsegrains. The rise in clay component with depth in the examined soils can be connected to translocation of clay from the topsoil layer to subsurface horizon and clay production owing to continuous process such as weathering in the soil profile. Similarly, Negasa *et al.* 2017 [34]; De Wispelaere *et al.* 2015 [35]; Gil *et al.* 2022 [36]; Alawamy *et al.* 2021 [37]; Reichert *et al.* 2022 [38] revealed the impacts of leaching on clay component distribution with depths.

Table 3: Descriptive statistics of the physical parameters of various land uses.

Land uses	Depth (cm)	Agri	Horti	Forest	Fallow	Overall
Sand	0-30	24.17+5.76	34.29+3.41	39.65+7.99	37.53+4.44	33.91+3.43
	30-60	29.28+4.13	30.42+2.93	34.26+5.21	31.08+3.33	31.26+4.57
	Overall	26.72+5.89	32.35+5,.49	38.95+6.17	34.30+5.29	
Silt	0-30	41.29+9.33	44.45+5.27	40.29+6.98	31.64+6.98	39.67+6.32
	30-60	34.22+6.17	40.56+6.29	33.16+4.65	36.13+2.65	36.01+8.43
	Overall	37.75+4.46	42.50+4.77	38.57+5.18	34.04+4.11	
Clay	0-30	34.54+4.58	21.26+5.98	20.06+4.32	30.83+6.44	26.69+7.53
	30-60	36.5+4.98	29.02+4.44	32.58+7.89	32.79+8.21	32.72+3.32
	Overall	35.58+7.27	25.08+1.89	26.05+2.19	31.88+7.11	
Bulk density	0-30	1.39+0.16	1.33+0.25	0.96+0.25	1.33+0.18	1.30+0.67
	30-60	1.43+0.14	1.42+0.22	1.09+0.14	1.44+0.14	1.29+0.66
	Overall	1.41+0.33	1.30+0.27	1.03+0.12	1.38+0.87	

Table 4: Two-way ANOVA of the physical parameters of the various land uses.

Source of variation	DF	Sand		Silt		Clay		Bulk density	
		Mean of square	p value	Mean of square	p value	Mean of square	p value	Mean of square	p value
Land use	3	637.29	0.0346	542.39	0.3194	626.23	0.0431	0.234	0.0061
Depth	1	1.04	0.873	7.531	0.3172	9.527	0.437	0.039	0.0218
Land use *depth	3	37.89	0.914	18.571	0.4597	15.297	0.843	0.004	0.3689
Mean		32.89		37.67		29.42		1.27	
R^2		0.541		0.578		0.488		0.236	
Error	100	192.34		163.49		154.27		0.0084	

3.1.2 Soil bulk density

A Significant (p_{value} = 0.0001) impact of land-use pattern was recorded on soil bulk density (Table 4). Compared to other land uses, it was largest on agricultural land 1.41+0.33), trailed by fallow land (1.38+0.87). Forest land use was identified to have the least soil bulk density category (1.03+0.12). Table 3 demonstrates that the soil bulk density varied substantially with the depth of soil (p = 0.0218), with the exception of soil inside forest land use soil as it got reduced. Compared to other land uses, the bulk density in the surface layer 0–30cm was low (1.30+0.67) (Table 3). Contrary to other land use patterns, forest land may have a lower bulk density due to the greater content of organic matter, which enhances soil volume without diminishing its weight. (Padalia *et al*. 2022; Ortiz *et al*. 2022; Schlüter *et al*. 2022; Tesfaye *et al*. 2016) [39, 40, 41, 42] observed that variation in organic matter of soil and lesser perturbations under forest land use were responsible for the reduced bulk density of the soil in forest land use and the greater bulk density of the soil under agricultural land. On the other hand, recurrent ploughing of soil, which modifies the soil structure and generates a compressed surface soil layer, may result in greater bulk density in agricultural land use. According to (Li *et al*. 2022) [43], the transformation of natural forests into agricultural land significantly enhanced bulk density due to the loss of organic matter. Similar findings were obtained by (Tolimir *et al*. 2020) [44], who reported that repeated tillage enhanced the soil's bulk density. The bulk density of soil varied considerably with depth of soil. Among all land use patterns, the bulk density of the surface soil was the greatest, which may be attributable to the moisture levels and soil texture. The Pearson's correlation coefficient demonstrated a positive link (p = 0.05) between bulk density and silt percentage. This shows that the lower bulk density is the consequence of higher moisture content and a smaller amount of silt. Conversely, the amount of clay in the soil texture may influence bulk density. This result is analogous to that of (Davis *et al*. 2022) [45] who discovered that an elevation in clay content and soil organic matter led to a commensurate reduction in bulk density. According to (Zikeli *et al*. 2013) [46], the implementation of organic matter from the plants reduces the bulk density of the topsoil in comparison to the layer underneath. (Mondal and Chakraborty 2022; Hansen *et al*. 2021) [47, 48] posited further that the greater bulk density in the subsurface might be a result of the compaction induced by the weight of the top layer

3.2 Effect of land use change on soil chemical properties

3.2.1 Soil pH.

The land use had a significant impact on the soil pH (p_{value} = 0.0007; Table 6). Based on land use, the data indicated that overall soil pH ranged from 6.45 to 7.39. In the 0-30 cm soil layer, soil pH of fallow land was considerably higher (p_{value} = 0.0007, 7.26±0.56) than in other land uses, but forest soil pH was substantially lower (6.49±0.23). According to the findings, the soil pH did not vary substantially with the depth of soil (p = 0.4132; Table 6). At 0–30 and 30–60 cm soil levels, the mean pH value was found to be greater in fallow land use (p_{value} = 0.6419, 7.14±0.56 and 7.39±0.23) than in horticulture land use (6.78±0.09 and 6.83±0.32). It was noticed that forest areas had much higher acidic soil compared to other land uses. Possibly as a result of the acidifying effect of some forest tree species. According to (Leghari *et al*., 2022) [49], the polyphenolic compounds and resilient oils generated by the foliage, trunk, and roots of some forest species have an adverse effect on alternative plants. This conclusion is analogous to the findings of (Munir *et al*., 2022; Ergin *et al*., 2022) [50, 51], who proclaimed that forest trees had an acidic impact on soil properties. In contrast, the enhanced acidic effect of agricultural land in comparison to forest land is likely the result of the contiguous expulsion of basic cations by crops and the removal of exchangeable bases due to soil erosion. Wang *et al*. 2021 [52] found that management practices and land-use patterns had substantially altered soil pH. This conclusion is supported by their research. There were no substantial changes between soil depths and soil acidity. However, with increasing soil depth, the pH value of the forest soil declined by 8%. This might be owing to the delayed discharge of base cations from perennial plant roots, which pump bases preferentially from the subsurface. This is in accordance with Uhlig *et al.* 2019 [53], who indicated that the continual discharge of basic cations from the deposition of bases at the surface by the deep roots of forest trees from the subsurface and slow breakdown of organic wastes contribute to the acidity of the surface soil.

Table 5: Descriptive statistics of the chemical parameters of various land uses.

Land uses	Depth (cm)	Agri	Horti	Forest	Fallow	Overall
pH	0-30	6.54+0.21^{a}	6.45+0.15^{ab}	6.78+0.09^{a}	7.14+0.1^{b}	6.72+0.09
	30-60	6.89+0.17^{a}	6.53+0.31^{ab}	6.83+0.32^{ab}	7.39+0.26^{b}	6.91+0.45
	overall	6.71+0.17^{ab}	6.49+0.23^{ab}	6.80+0.15^{b}	7.26+0.56^{ab}	
SOC	0-30	1.47+0.54^{a}	1.65+0.07^{b}	2.56+0.67^{a}	1.29+0.06^{b}	1.74+0.33
	30-60	1.21+0.11^{ab}	1.32+0.31^{a}	2.33+0.55^{a}	1.26+0.24^{b}	1.53+0.18
	overall	1.34+0.23^{a}	1.48+0.44^{b}	2.43+0.71^{a}	1.27+0.31^{a}	
SOC (Mg/ha)	0-30	12.32+0.1^{a}	14.63+0.16^{b}	19.34+0.33^{a}	11.19+0.01^{b}	14.37+0.22
	30-60	11.07+0.26^{a}	13.56+0.26^{b}	17.56+0.28^{b}	10.84+0.13^{b}	13.25+0.40
	overall	12.06+0.55^{a}	14.39+0.14^{b}	18.97+0.13^{a}	11.06+0.44^{ab}	

Table 6: Two way ANOVA of the chemical parameters of the various land uses.

Source of variation	DF	pH		SOC		SOC stock	
		Mean of square	p value	Mean of square	p value	Mean of square	p value
Land use	3	1.553	0.0007	15.46	0.0004	654.08	0.0003
Depth	1	0.136	0.4132	41.18	0.0001	3146.15	0.0001
Land use *depth	3	0.07	0.6419	2.172	00.976	91.67	0.429
Mean		6.70		1.62		13.84	
R^2		0.131		0.29		0.416	
Error	100	0.217		0.176		92.64	

3.2.2 Soil organic carbon concentration

The proportion of SOC changed considerably depending on land usage (p_{value} 0.0004; Table 6). In comparison to other land uses, the overall average SOC content was higher in forest land (p_{value} 0.0004, 2.33±0.55) and lesser in fallow land (p_{value} 0.0004, (2.1.27±0.31). Also, the mean SOC concentration varied substantially with the depth of soil (p 0.0001; Table 6). In the 0–30 and 30–60 cm soil layers, the average SOC content was greater in forest land use (p_{value} = 0.0001, 2.56±0.67 and 2.33±0.55) and lower in fallow land (p_{value} = 0.0001, 1.29±0.06 and 1.26±0.24) and agricultural land use (p_{value} = 0.0001, 1.47 ±0.54 and 1.21 ± 0.550.11) than under other land uses, respectively. Usually, it diminishes with increased depth of soil (Table 6). The average SOC content of forested land was 44.85, 39.09, and 47.7 percent higher than that of agricultural, horticultural, and fallow land uses, respectively. This may be the consequence of agricultural waste being removed from agricultural land following crop harvesting and continued cultivation. Under agriculture land , the lower SOC concentration may be caused by repeated crop harvesting, removing soil nutrients. The removal of agricultural byproducts for human consumption and livestock feed (Forsberg *et al.* 2021) [54] enables almost little biomass to be recurred to the soil. The smaller size of the primary crops (rice, maize, and wheat) grown in area of study provides an additional barrier to nutrient return to the soil via plant residues, a crucial reservoir for labile carbon (sarkar *et al.* 2020) [55]. Cultivation also exposes the accessible organic substances to wetness, aeration, and other decaying agents, accelerating the quick breakdown and mineralization of the exposed organic matter, thereby decreasing soil carbon (Palaniveloo *et al.* 2020) [56]. Frequent intense exploitation of farmlands as a result of land scarcity is an additional factor contributing to the deterioration of farmland quality since crops take a high amount of nutrients each year with a poor rate of return (Chianu *et al.* 2012; Uddin *et al.* 2022; Viana *et al.* 2022) [57, 58, 59]. The SOC proportion was altered by depth of soil and exhibited a declining pattern with a gradual increase in soil depth. Assuming that forests are adequate ecological references, agricultural land use via forest clearance have released roughly 40.23% of the carbon content initially stored in surface layers of forest soil, followed by horticulture land (32.9%) and fallow land usage 23.6 percent. The concentration of SOC reduced the least in forest area, by about 23.00 percent, followed by horticultural land 03.00 percent. The reduced SOC content measured in the subsurface layer may be a result of fewer exogenous inputs into the soil. This is in accordance with the findings of (Ghosh *et al.* 2021; Dong *et al.* 2022; Wei *et al.* 2021; Fu *et al.* 2021; Zheng *et al.* 2021) [60, 61, 62, 63, 64], who determined that chemical fertilizer, plant and other bio-waste remain on the top of the soil rather than entering deeper. According to (El-Naggar *et al.* 2022) [65], fine-textured soils are more prone to retain dissolved organic matter because fine particles tend to bond firmly with organic matter.

3.3 Conversion of various land uses

3.3.1 Conversion effect of land use on carbon stocks

The results suggested that land use had a substantial effect on the average SOC stock (p_{value} 0.0003, Table 7). The total average SOC stock was bigger in forested soils (p_{value} = 0.0003, 18.97±0.13), but it was lower in fallow land (11.06 ± 0.04). Conversely, soil depth significantly influenced SOC stock (p 0.0001; Table 7). In the 0–30 and 30–60 soil layers, the average SOC stock was bigger in forest land use (19.34±0.33 and 17.56±0.28) and lesser under fallow land (11.19±0.01 and 10.84±0.13) than in other land uses (Table 6). The SOC stock under forest land use was discovered to be 41.69% bigger than horticultural land use, which has been trailed by agricultural land use (36.42%) and horticultural land use (24.14%). The SOC stock follows the following hierarchy: forest > horticulture > agriculture> fallow land use. Moreover, the SOC stock varied significantly with depth of soil and demonstrated a falling trend (Sheikh *et al.* 2021) [66]. Agriculture land use through clearance of forests has liberated about 35.8 percent of the carbon stock originally contained in the upper layers of the forest soil, followed by horticulture land use (42.0%) and fallow land use (51.8%). Taking soil depth into account across land uses, the SOC stock reduced by 2.30 percent in agricultural soils and 7.31 percent in horticulture soils. In comparison, the SOC stock variation was 29.14 percent less variable when fallow land was used.

Table 7: Variation (%) of the various land uses in reference to the forest land use

Soil properties	Agriculture land use	Horticulture land use	Fallow land use
pH	-1.324*	-4.559*	6.76**
SOC	-44.856**	-39.095**	-47.737**
SOC stock	-36.426**	-24.143**	-41.698**
Sand	-31.329**	-16.945*	-11.938**
Silt	-2.126 NS	10.189 NS	-11.745 NS
Clay	-36.58**	-3.724**	22.380NS
Bulk density	-21.59 NS	26.21 NS	33.981 NS

3.3.2 Conversion of forest land use to horticulture land use

The SOC stock fell by 24.14 percent due to the conversion of forest land use to horticulture land use. This may have been caused by the early removal of vegetation, which dramatically decreased soil inputs. This conclusion is consistent with Guo and Gifford's (2002) [67] estimate that the transformation of forests to horticulture plantations results in an average loss of 13 percent in SOC. Similarly, (Chernov *et al.* 2021) [68] observed that plantation forest soils had less organic matter than wild forest soils. In contrast, Novita *et al.* 2021 [69] observed that converting native hardwood forests to pine plantations may increase the system's carbon emissions.

Table 8: Variation (%) of the various land uses in reference to 0-30 cm depth

Soil properties	Agriculture land use	Horticulture land use	Forest land use	Fallow land use
pH	5.352**	1.240*	0.737**	3.501**
SOC	-17.68**	-20.00**	-8.984*	-1.550*
SOC stock	-10.146NS	-6.699 NS	-9.024 *	-3.128 NS
Sand	21.14*	-11.286*	-13.594	-17.186 NS
Silt	-17.12 NS	-8.75 NS	-4.264 NS	7.589 NS
Clay	5.675**	36.500**	62.41*	6.375**
Bulk density	1.613**	6.769*	13.524 NS	8.271

3.3.3 Conversion of forest to fallow land use

The transformation of forest land to fallow land decreased the SOC stock by 41.69 percent. The SOC stock in forest land was larger than under fallow land, presumably because of SOC variances between the two land-use patterns. This conclusion agrees with (Rolinski *et al.* 2021) [70], who reported that forest soils havelimited disturbance and are well protected, but the soils of fallow fields were heavily overgrazed, mismanaged, and are susceptible to surface erosion and waterlogging. Most of the biowastes including cow dungare used as a source of fuel rather than to increase the SOC of fallow land. In the same study, (Kataki *et al.* 2021) [70] discovered that after pasture conversion, SOC decreased.

3.3.4 Conversion of forest land use to cultivated land

Due to the transformation of natural and mixed forests into agricultural land, the stock of SOC decreased by 36.42%. Extensive cultivation, enhanced decomposition of organic matter in the soil, and full removal of feedstock from the fields, as well as extensive deforestation, sharp topography, and extreme erosion hazards, may all contribute to lower physical protection of soil organic matter. Numerous other studies have reached the same conclusion. Similar to the finding reached by (Das *et al.* 2020) [71], who analysed 37 studies and determined that 42 percent (34–50 percent) of soil carbon was lost due to the conversion of forested land to agricultural land. The variation in soil characteristics within the depth of soil across land use land cover types in the northwestern Himalayas are discussed in Table 5. The difference in soil physical and chemical properties with soil depth for the agricultural, horticultural, forest, and fallow land uses in the northwestern Himalayas is shown in Table 7 below.

Table 9: Pearsons correlation coefficient of the various physical and chemical properties in 0-30 cm depth.

Soil properties	pH	SOC	SOC content	Sand	Silt	Clay	BD
pH	1						
SOC	0.032*	1					
SOC stock	0.034	0.576**	1				
Sand	NS	-0.124*	NS	1			
Silt	NS	0.231	NS	-0.564**	1		
Clay	0.342*	0.348**	NS	-0.412**	-0.178**	1	
Bulk density	NS	-0.498**	0.154	0.322	0.118	0.415**	1

4. Conclusions

Alterations in land use have had an effect on some soil properties in the area under study. Differences in the textural components of the four land use may be attributable to human influences, such as overexploitation and overgrazing, which promotes rapid soil erosion. In the studied area, there are also substantial disparities in soil bulk density among land uses. Land use affects the organic carbon content of the soil. As a result, agricultural land has low organic carbon than other land use categories, highlighting the need for sustainable farming methods, such as the organic matter addition, rotational cropping, and implementation of crop residues. The low carbon supply from crops was inadequate to offset the significant mineralization of organic elements in farmed regions. On the subsoil layer, the variance in organic carbon across various land-use patterns was less evident than on the topmost layer, indicating that diversified management techniques had the greatest effect on the surface soil layer. This research reveals an immediate need to enhance soil fertility by implementing sustainable land-use techniques to decrease soil erosion and maintain the agricultural system's long-term viability. Consequently, nationwide programmes must be framed to safeguard the remaining forests and develop extension programmes to guarantee the appropriate use of land and protection of foreșt land. When coupled with climate change, land-use change often poses a bigger threat to carbon storage.

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