Journal of Bioresources 12 (2): 57-62, October – December 2024

JOURNAL OF BIORESOURCES

journal webpage: https://jbr.rgu.ac.in

ISSN: 2394-4315 (Print)
ISSN: 2582-2276 (Online)

RESEARCH ARTICLE

Comparative analysis of soil health parameters across diverse land use systems in the hilly terrain of Northeast India: a case study from Changlang district, Arunachal Pradesh

Nemjong Ronrang[1*], O. P. Tripathi[3], Ashish Paul[1], Krishna Kumar Mourya[2], Sandeep Kumar[2], Ravi Kumar[2], Arijit Barman[2], S. Ramchandran[2,8] Ram Swaroop Meena[2], Surabhi Hota[2,4], Uday Shankar Saikia[2,] Prasenjit Ray[4,5,6], Roomesh Kumar Jena[2,7], Gulshan Kumar Sharma[2,9] and Sanjay Kumar Ray[2]

[1]North Eastern Regional Institute of Science and Technology, NERIST, Department of Forestry, Nirjuli, Dist. Papum Pare, 791110, Arunachal Pradesh, India.

[2]ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, Jorhat, 785004 Assam, India.

[3]Department of Environmental Science, Mizoram University, Aizawl-796004, Mizoram, India.

[4]ICAR-Directorate of Weed Research, Jabalpur - 482004, Madhya Pradesh, India.

[5]ICAR-Indian Agricultural Research Institute, New Delhi-110012, India.

[6]Auburn University, Alabama-36849, USA.

[7]ICAR-Indian Institute of Water Management, Bhubaneswar-751023, Odisha, India.

[8]ICAR-Indian Institute of Horticultural Research, Bengaluru-560089, Karnataka, India.

[9]ICAR- Indian Institute of Soil and Water Conservation, Research Centre, Kota-324002, Rajasthan, India.

*Corresponding author-mail: wangleenemjong@gmail.com
Article No.: NRJBR117; Received: 02.10.2024; Peer-reviewed: 22.11.2024; Accepted: 22.11.2024; Published: 31.12.2024.
Doi: https://doi.org/10.5281/zenodo.14892060

Abstract

In the context of climate change, declining agricultural land, increasing land degradation, a growing population, and rising food demand, assessing soil health parameters under various land use systems (LUS) is crucial for optimal land management. This ensures the long-term productivity and sustainability of agroecosystems. This study examines the impacts of four LUS—agriculture, tea plantations, horticulture, and forests on soil health parameters in the northeastern region (NER) of India. Soil samples were collected from two depths (0–15 cm and 15–30 cm) in 2020. Significant differences in soil health parameters were observed among the LUS. All soils were acidic, with the lowest pH (4.40) under forests and the highest pH (5.4) under agriculture at the 0–15 cm depth. At the 15–30 cm depth, pH increased under forests and decreased under tea plantations, while no change was observed under agriculture and horticulture. Cation exchange capacity (CEC) was low (<15 cmol (+) kg^{-1}) across all LUS. Soil organic carbon (SOC) was medium to high across LUS, following the order: forests (1.05%) > tea plantations (0.78%) > horticulture (0.71%) > agriculture (0.70%) at the 0–15 cm depth. SOC decreased at the 15–30 cm depth for all LUS, with the highest decrease (42.9%) under agriculture and the lowest (9.5%) under forests. Compared to forests, agricultural land showed 9.35% to 116.7% lower values for organic carbon, nitrogen, potassium, sulfur, base saturation, iron, and copper. These findings will aid in implementing effective soil management practices to restore soil health, boost yields, and enhance the region's resilience and sustainability across different land uses.

Keywords: Agriculture; Land Use; Northeast India; Soil health; Tea plantations

1. Introduction

Understanding and assessing soil health under various land use systems (LUS) is indeed critical, especially in the context of climate change, agricultural land decline, productivity challenges, population growth, rising food demand, and land degradation (Fuglie, 2018). Detailed information on soils, with respect to their physical, chemical, and biological health, is essential for promoting sustainable land management practices (FAO, 2011; Lal, 2013). Soil health encompasses various chemical, physical, and biological properties that support plant and animal health (Karlen et al., 1997). Healthy soil is characterized by adequate nutrient levels, optimal soil physicochemical properties (such as texture, bulk density, soil structure, pH, and moisture content), and robust biological activity (Sokolov et al., 2020). However, poor agricultural practices such as excessive tillage (Nunes et al., 2020), shifting cultivation (Tripathi et al., 2003), imbalanced fertilization (Pahalvi et al., 2021), and rice monoculture disrupt this balance, leading to various types of soil degradation, ultimately reducing fertility and productivity (Reza et al., 2018; Kumar et al., 2022, 2024). Shifting cultivation, a common practice in the northeastern Hill (NEH) region of India, involves clearing patches of forestland for cultivation and abandoning them after a few years. Traditional methods are sustainable (Giri et al., 2020), but modern variations often involve shorter fallow periods, excessive deforestation, and inadequate soil conservation practices (Mishra et al., 2017), leading to excessive soil erosion and nutrient loss. Deforestation for agriculture, logging, or infrastructure exacerbates soil degradation by removing protective forest cover, increasing vulnerability to erosion and nutrient depletion (Kumar et al., 2022). Land use change and management practices have diverse and significant effects on the physical, chemical, and biological properties of soil (Fu et al., 2021).

The NEH region of India is highly affected by soil erosion due to its irregular topography, steep slopes, and extreme climatic variability (Reza et al., 2024). Comprehensive research on the impact of land use systems on soil health focused on NER is sparse and is mostly based on surface soil data (Barbhuiya et al., 2008; Choudhury and

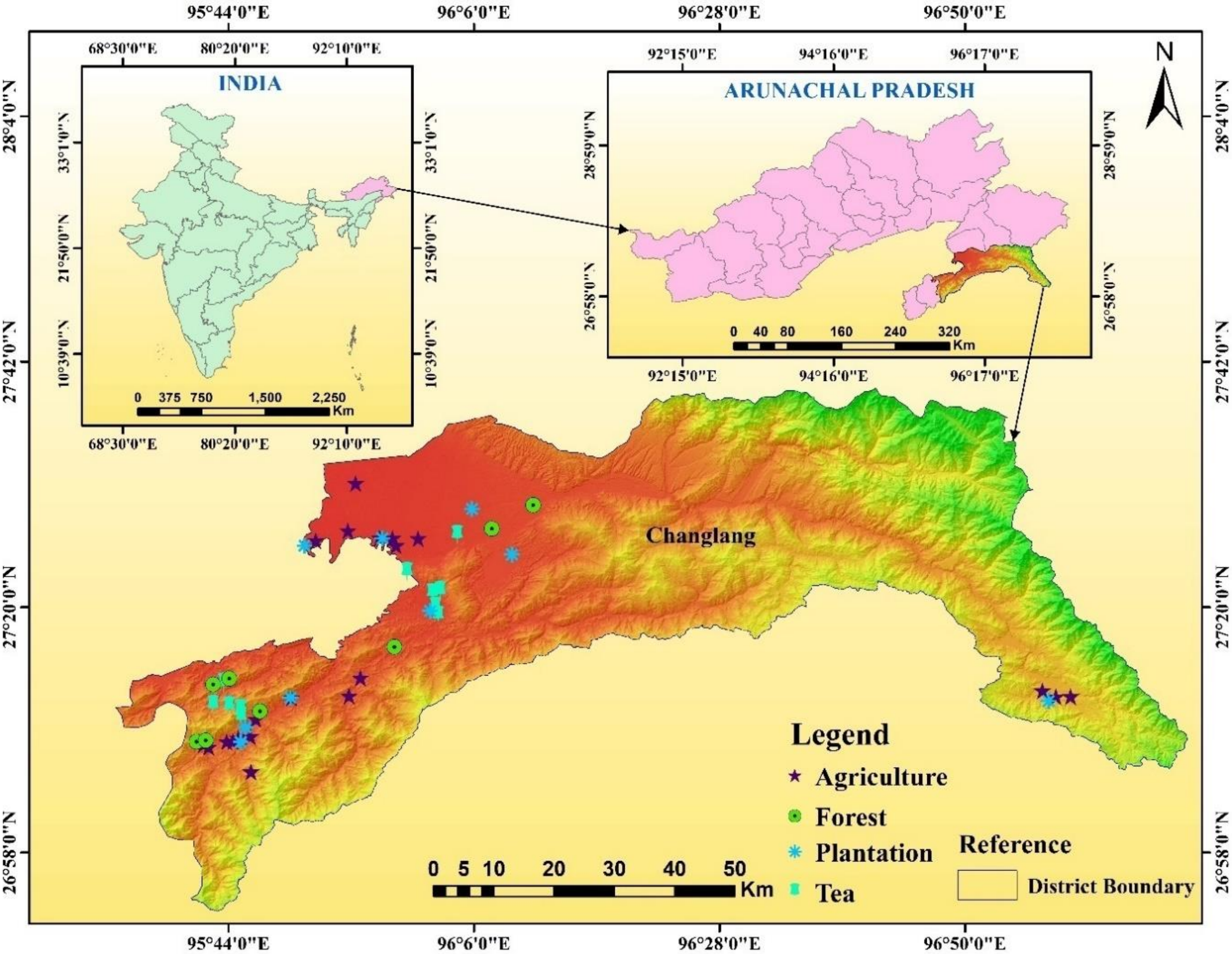

Figure 1. Study area map and sampling point locations

Mandal, 2021; Singh et al., 2014). Hence, a comprehensive study was conducted in 2020 by collecting soil samples from four major land use systems (LUS) in the Changlang district of Arunachal Pradesh at two depths (0–15 cm and 15–30 cm). This study aimed to understand how different LUS affect soil health parameters both at the furrow slice layer and at the immediate subsurface soil layer.

2. Materials and methods

2.1. Study area

This study was conducted in the Chaglang district of Arunachal Pradesh, which lies in the easternmost part of India between Latitudes 26°40'N and 27°40'N and Longitudes 95°11'E and 97°11'E and is positioned along the Indo-Myanmar border. The study area map and sampling points are shown in Figure 1. This district is swiftly evolving into a hub for agriculture and horticulture activities. The climate of the region is characterized by warm summers and cold winters. The mean annual rainfall ranges from 3800 mm to 4866 mm. The majority of the rainfall is received from June to October. The soils in the study area are primarily Inceptisols and Entisols, with significant areas also covered by Alfisols and Ultisols (Nayak et al., 1996). The natural vegetation comprises wet evergreen and tropical moist deciduous forests. The region features various species, including oak, rhododendron, bamboo, ferns, orchids, pine, fir, maple, laurel and cypress. Major horticultural crops include ginger, turmeric, pineapple, orange, strawberry, passion fruit and areca nut. Small tea plantations are found on the slopes of low and medium hills. Paddy is the most widespread crop, grown in both agricultural fields and on forest-cut lands used for shifting cultivation.

2.2. Soil sampling

Soil sampling sites were chosen randomly from four major land-use systems, namely, agricultural, horticultural, tea plantation and forest systems, which are distributed across different slopes. Slope gradients vary from 0-3% in lower areas dominated by agriculture, 3-8% in middle areas with horticulture, and 8-15% in upper areas, predominantly featuring tea plantations and native forests. Soil sampling was performed at depths of 0–15 and 15–30 cm and 98 soil samples were collected from 49 (21 from agriculture, 9 from plantations, 11 from tea plantations, and 8 from forests) sampling points (Figure 1) in 2020. We made composite soil samples by collecting 4–5 subsamples 2–5 m apart from each location. Soil samples were air-dried, ground, sieved through a 2 mm sieve in general, labelled, and stored in polythene bags and were used for laboratory analysis.

2.3. Soil analysis for various physical and chemical parameters

Standard procedures were followed for analysis of various physical and chemical parameters of soil. Particle size analysis was performed via the intsernational pipette method (Jackson, 1973). Soil pH and electrical conductivity (EC) were determined using a combined glass–calomel electrode in aqueous suspensions (1:2 soil/water ratio) following the standard method outlined by Jackson (1973). Soil organic carbon (SOC), available nitrogen, available phosphorus (P), and available potassium (K) were determined using the wet digestion method of Walkley and Black (1934), alkaline permanganate method (Subbiah and Asija, 1956), Bray II method (Bray and Kurtz, 1945), and flame photometry (Jackson, 1973), respectively. The cation exchange capacity (CEC) and exchangeable base cations were determined following the procedures outlined in Jackson (1973). Available micronutrients copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn) were determined using DTPA extraction (Lindsay and Norvell, 1978). Available sulfur (S) and boron (B) were determined using the standard methods of Williams and Steinbergs (1959) and Berger and Truog (1939), respectively.

2.4. Statistical analyses

Table 1. Effects of different land use systems on soil separates

Land Use system	Sand (%)		Silt (%)		Clay (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Agriculture	18.57 ± 4.4[a]	16.72 ± 4.1[a]	43.34 ± 3.7[b]	43.34 ± 3.6[a]	38.01 ± 2.7[b, c]	39.41± 2.5[bc]
Tea	19.46 ± 3.4[a]	17.30 ± 3.2[a]	27.38 ± 6.1[d]	29.21± 5.9[c]	53.15 ±5.6[a]	53.48 ± 5.4[a]
Horticulture	21.52 ± 6.4[a]	19.52 ± 6.1[a]	47.47 ± 7.7[a]	42.22 ± 7.4[a]	34.97 ± 4.5[c]	37.97 ± 4.4[c]
Forest	19.12 ± 5.4[a]	19.62 ± 5.2[a]	37.70 ± 2.4[c]	36.20 ± 2.3[b]	43.16 ± 3.7[b]	44.16 ± 3.6[b]

The values followed by different lowercase letters are significantly different according to Duncan's multiple range test at P ≤0.05. Significant differences with respect to land use.

Table 2. Effects of different land use systems on EC, pH and SOC

Land Use system	pH		EC (dS/m)		SOC (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Agriculture	5.4 ± 0.1[a]	5.39 ± 0.09[a]	0.6 ± 0.12[a]	0.6 ± 0.10[a]	0.70 ± 0.07[b]	0.40 ± 0.03[c]
Tea	4.5 ± 0.3[b]	4.39± 0.22[c]	0.40 ± 0.09[c]	0.30 ± 0.09[c]	0.78 ± 0.11[b]	0.62 ± 0.05[b]
Horticulture	4.7 ± 0.2[b]	4.70 ± 0.15[b]	0.42 ± 0.08[bc]	0.31 ± 0.05[c]	0.71 ± 0.07[b]	0.56 ± 0.05[bc]
Forest	4.4 ± 0.2[b]	4.49 ± 0.18[bc]	0.43 ± 0.06[b]	0.41 ± 0.06[b]	1.05 ± 0.05[a]	0.95 ± 0.04[a]

The values followed by different lowercase letters are significantly different according to Duncan's multiple range test at P ≤0.05. Significant differences with respect to land use.

Table 3. Effects of different land use systems on micronutrients

Micronutrients	Depth	Agriculture	Tea	Horticulture	Forest
Fe (mg/kg)	0-15 cm	82.15 ± 12[a]	96.45 ± 19.12[a]	76.40 ± 11.20[a]	66.13 ± 16.12[a]
	15-30 cm	82.12 ± 10[a]	93.30 ± 19[a]	76.31 ± 10.05[a]	66.41 ± 15.06[a]
Zn (mg/kg)	0-15 cm	0.54 ± 0.21[b]	0.62 ± 0.15[b]	0.55 ± 0.12[b]	0.80 ± 0.10[a]
	15-30 cm	0.53 ± 0.10[b]	0.57 ± 0.11[b]	0.55 ± 0.10[b]	0.81 ± 0.13[a]
Cu (mg/kg)	0-15 cm	1.45 ± 0.17[b]	1.49 ± 0.18[b]	1.13 ± 0.17[c]	1.59 ± 0.18[a]
	15-30 cm	1.45 ± 0.13[b]	1.44 ± 0.15[b]	1.13± 0.15[c]	1.59 ± 0.14[a]
Mn (mg/kg)	0-15 cm	33 ± 8.13[a]	39 ± 12.15[a]	52 ± 19.4[a]	34 ± 8.14[a]
	15-30 cm	33 ± 8.13[a]	36 ± 9.15[a]	52 ± 19.1[a]	34 ± 8.14[a]

The values followed by different lowercase letters are significantly different according to Duncan's multiple range test at P ≤0.05. Significant differences with respect to land use.

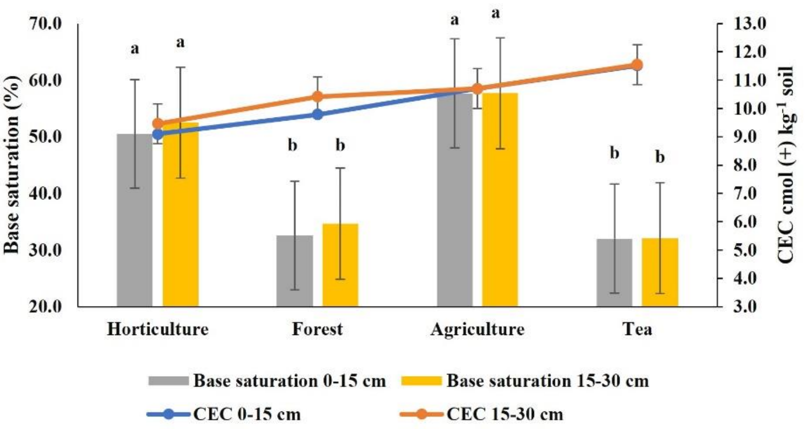

Figure 2. Effects of different land use systems on base saturation and cation exchange capacity

The data were analyzed for significant differences in soil properties across land uses using one-way ANOVA in a completely randomized design. The DMRT test was applied at a 0.05 significance level, following Gomez and Gomez (1984). Pearson correlation analysis was performed using R packages "metan" and "corrplot."

3. Results

The results revealed significant differences in the sand, silt, and clay contents among the various land use systems and soil depths (Table 1). Compared with Horticulture and Forest plantations, Agricultural and Tea plantations exhibit relatively lower sand contents. At the 0–15 cm depth, agriculture had the lowest sand content (18.57%), followed closely by tea (19.46%), while horticulture and forest had higher levels (21.52% and 19.12%, respectively). Similarly, at the 15–30 cm depth, agriculture and tea still maintain lower sand contents (16.73% and 17.30%, respectively), whereas horticulture and forest remain higher (19.52% and 19.62%, respectively). In the study, agricultural land use systems (LUS) had the highest silt content at both depths, with values of 43.35% at 0–15 cm and 43.35% at 15–30 cm, followed by horticulture, tea plantations, and forest LUS. Tea plantations exhibited significant variation in silt content between depths, with 27.38% at 0–15 cm and 29.21% at 15–30 cm. Horticultural land had higher silt content at the 0–15 cm depth (47.47%) than at 15–30 cm (42.23%). Conversely, forest areas showed a consistent decrease in silt content from 37.71% at 0–15 cm to 36.21% at 15–30 cm. Among the various land use types and soil depths, tea plantations had the highest clay content at both depths, with 53.16% at 0–15 cm and 53.49% at 15–30 cm, followed by forest areas, agriculture, and horticulture.

Soil pH levels varied across different land use systems and soil depths. Agriculture has slightly acidic *p*H values, with values of 5.4 at 0–15 cm depth and 5.39 at 15–30 cm depth (Table 2). Tea plantations have comparatively lower *p*H levels, measuring 4.5 at 0–15 cm depth and 4.39 at 15–30 cm depth. Horticulture and forest areas have similar *p*H values, ranging from 4.4 to 4.7 across depths. In terms of electrical conductivity (EC), agriculture soils have lower values than tea, horticulture, and forest areas (Table 2). In agriculture, the EC is 0.70 dS m^{-1} at the 0–15 cm depth and decreases to 0.40 dS m^{-1} at the 15–30 cm depth. Tea plantations have relatively high EC values, with 0.78 dS m^{-1} at the 0–15 cm depth and 0.62 dS m^{-1} at the 15–30 cm depth. Horticulture has intermediate EC values, whereas forest areas have the highest EC values, indicating greater ionic concentrations in the soil solution. The organic carbon content varies across different land uses and soil depths. Forest soils have the highest organic carbon content, likely due to the continuous input of organic matter and minimal soil disturbance, with values of 1.1% at 0–15 cm and 1.0% at 15–30 cm (Table 2). The organic carbon content of agricultural soils decreases with depth, from 0.7% at 0–15 cm to 0.4% at 15–30 cm. Tea plantations and horticulture presented intermediate values, with tea soils containing 0.8% and 0.6%, respectively, and

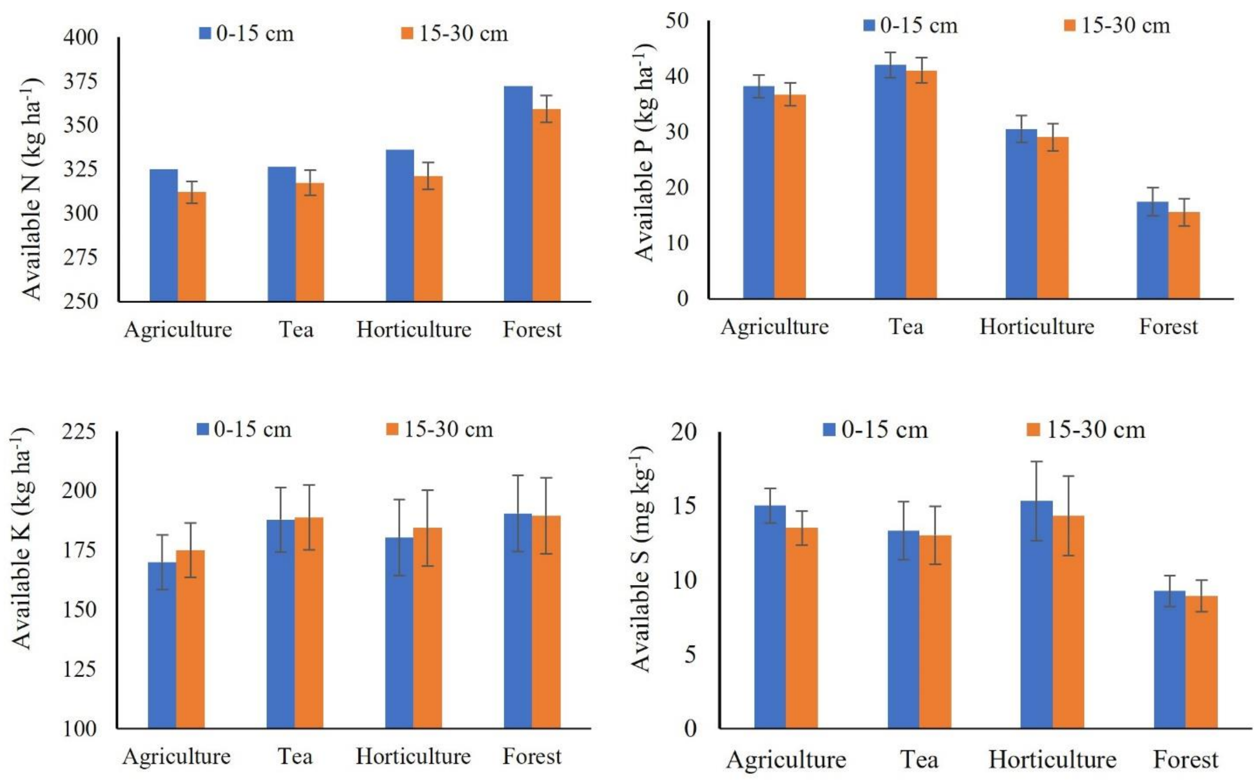

Figure 3. Effects of different land use systems on major available nutrients

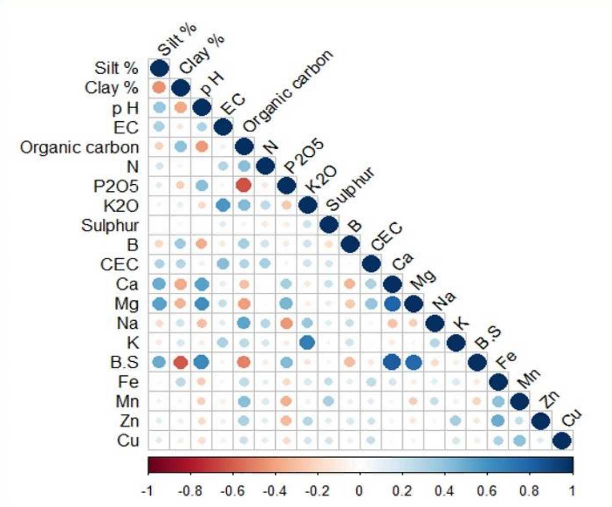

Figure 4. Pearson Correlation Matrix

horticulture soils containing 0.7% and 0.6%, respectively, at different depths.

The cation exchange capacity (CEC) varies marginally across different land use systems and soil depths. Agriculture has a CEC of approximately 10.67 cmol (+) kg^{-1} soil at both the 0–15 cm and 15–30 cm depths. The tea plantations presented slightly higher CEC values, with values of approximately 11.52 cmol (+) kg^{-1} soil at both depths. Horticulture has a CEC of approximately 9.10 cmol (+) kg^{-1} soil at both depths, whereas forest areas have a CEC of approximately 9.79. The base saturation (%) in agriculture was relatively stable, with values of approximately 57.67% at both depths. The base saturation of tea plantations decreased from approximately 32.02% at the 0–15 cm depth to 30.02% at the 15–30 cm depth. Horticulture exhibited an increase in base saturation (%) from approximately 50.51 at 0–15 cm depth to 52.51 at 15–30 cm depth. Forest areas also show an increase in base saturation (%) from approximately 32.55 at 0–15 cm depth to 34.65 at 15–30 cm depth. Clay and organic matter contents are the main determinants of the CEC.

The available nitrogen in agricultural land was 325 kg ha^{-1} at the 0–15 cm depth and decreased to 312 kg ha^{-1} at the 15–30 cm depth (Figure 3). The available nitrogen of tea plantations slightly decreased from 326 kg ha^{-1} at the 0–15 cm depth to 317 kg ha^{-1} at the 15–30 cm depth. The horticultural land had relatively high nitrogen availability, with 336 kg ha^{-1} at the 0–15 cm depth and 321 kg ha^{-1} at the 15–30 cm depth. Forested land had the overall highest nitrogen availability, with 372 kg ha^{-1} at the 0–15 cm depth and 359 kg ha^{-1} at the 15–30 cm depth. The phosphorus availability in agricultural soil was 38.2 kg ha^{-1} at 0–15 cm depth and 36.7 kg ha^{-1} at 15–30 cm depth. The tea plantations presented relatively high phosphorus levels, with 42.0 kg ha^{-1} at 0–15 cm and 41.0 kg ha^{-1} at 15–30 cm. Horticultural land presented phosphorus availability of 30.5 kg ha^{-1} at 0–15 cm depth and 29.0 kg ha^{-1} at 15–30 cm depth. The forest soil had the lowest phosphorus levels, with 17.4 kg ha^{-1} at 0–15 cm and 15.5 kg ha^{-1} at 15–30 cm. The potassium availability was 170 kg ha^{-1} at 0–15 cm and increased slightly to 175 kg ha^{-1} at 15–30 cm in agricultural land. Tea plantations presented high potassium levels, with values of 188 kg ha^{-1} at 0–15 cm and 189 kg ha^{-1} at 15–30 cm. Horticultural land has a potassium availability of 180 kg ha^{-1} at 0–15 cm depth and 184 kg ha^{-1} at 15–30 cm depth. The forest soil had the highest potassium availability, with 191 kg ha^{-1} at both the 0–15 cm and 15–30 cm depths. Sulfur availability in agricultural land was 15.0 kg ha^{-1} at 0–15 cm depth and decreased to 13.5 kg ha^{-1} at 15–30 cm depth. The tea plantations had lower sulfur levels, with 13.4 kg ha^{-1} at 0–15 cm and 13.1 kg ha^{-1} at 15–30 cm. Horticultural land presented a sulfur availability of 15.3 kg ha^{-1} at 0–15 cm depth and 14.3 kg ha^{-1} at 15–30 cm depth. The forest soil had the lowest sulphur level, at 9.3 kg ha^{-1} at 0–15 cm and 8.9 kg ha^{-1} at 15–30 cm.

The highest concentration of Fe was observed in tea plantations, with values of 95.9 mg kg^{-1} at the 0–15 cm depth and 92.9 mg kg^{-1} at the 15–30 cm depth (Table 3). The lowest concentration was recorded in forest soils, with 66.1 mg kg^{-1} at the 0–15 cm depth and 66.3 mg kg^{-1} at the 15–30 cm depth. Agriculture and horticulture land use types presented intermediate Fe concentrations. Horticulture land presented the highest Mn content, with 51.6 mg kg^{-1} at 0–15 cm depth and 51.6 mg kg^{-1} at 15–30 cm depth. Tea plantations had the second highest Mn concentrations, followed by forest soils and agricultural land, which presented the lowest Mn concentrations. The forest soils presented the highest Zn contents at both the 0–15 cm (0.80 mg kg^{-1}) and 15–30 cm (0.81 mg kg^{-1}) depths (Table 3). Agriculture presented the lowest Zn concentration. As shown in Table 3, forest soils also presented the highest Zn content at both depths (1.59 mg kg^{-1} at 0–15 cm and 1.594 mg kg^{-1} at 15–30 cm), whereas horticulture soils presented the lowest values. The forest soils presented the highest Zn contents at both the 0–15 cm (0.80 mg kg^{-1}) and 15–30 cm (0.805 mg kg^{-1}) depths, as shown in Table 3. Agriculture presented the lowest Zn concentration. As shown in Table 3, forest soils also presented the highest Zn content at both depths (1.59 mg kg^{-1} at 0–15 cm and 1.594 mg kg^{-1} at 15–30 cm), whereas horticulture soils presented the lowest values.

The results of all the soil samples from all the land use systems were compiled and analysed for the Pearson correlation matrix, and the physical and chemical parameters showed both positive and negative relationships. The correlation matrix for various soil properties reveals several significant relationships that are crucial for understanding soil fertility and management. Positive correlations are represented in shades of blue, whereas negative correlations are represented in red (Figure 4). By analysing these correlations, users can make informed decisions about fertilization, soil amendment, and other management practices to optimize soil.

4. Discussion

Soil properties are influenced by various factors, including climate, topography, parent material, vegetation, and human activities. Among these factors, land use changes significantly affect soil properties by disrupting the natural balance of soil formation and accelerating soil erosion. In the long term, frequent tillage in agricultural lands can lead to the breakdown of soil structure (Schlüter et al., 2018). This process causes finer particles to move below the root zone, resulting in soil compaction (Badalíková, 2010), which, in turn, hinders water percolation. Increased runoff due to compaction, along with the relatively high sand and silt content at the surface, intensifies soil erosion and nutrient loss (Wolka et al., 2021). In contrast, permanent vegetative cover in horticultural and forest areas protects the soil from erosion, thereby reducing particle loss. The permanent vegetative cover in tea plantations helps reduce soil erosion, preserving finer particles and contributing to the high clay content. Additionally, tea plantations often employ mulching and organic amendments to improve soil fertility, further enhancing the proportion of finer particles. Slope also plays a role in soil particle distribution by affecting erosion, deposition, transport, and hydrological processes. Steeper slopes tend to erode finer particles downslope, while gentler slopes promote particle deposition (Deka et al., 2009).

Forest soils experience minimal human intervention, allowing natural processes to dominate. This often leads to stable, acidic pH values due to the accumulation of organic acids from decaying plant material (Jiang et al., 2018). Tea plants thrive in acidic soils, so tea plantations are commonly established in naturally acidic environments or managed to maintain acidic conditions. The use of fertilizers like ammonium sulfate can further reduce soil pH over time, increasing soil acidity. In agricultural LUS, much of the land is used for rice cultivation (Wang et al. 2020). Rice, as a monocot, tends to absorb fewer divalent cations than monovalent cations (Tisdale et al., 1985), which may explain the higher pH observed in agricultural lands. Additionally, the rate of crop residue removal is high, while residue addition is low.

In the study area, electrical conductivity (EC) values were well below the limits (0–1.0 dS m^{-1}) considered optimal for the growth of most plant species and microbial activity (Smith et al., 1996). Across all land uses, the upper soil layer typically contains higher organic carbon (OC) than the subsoil layers, likely due to the input from litterfall (Panwar et al., 2011; Mourya et al., 2021). This finding is consistent with previous observations by Reza et al (2011), who reported higher OC levels in soils from horticultural and forest systems compared to agricultural lands. The relatively low cation exchange capacity (CEC) across land uses can be attributed to the dominance of low-activity clays like kaolinite, which result from advanced weathering under hot, humid conditions. This weathering leads to the leaching of bases, resulting in low base saturation (Hota et al., 2022; Reza et al., 2024). Nutrient availability varies across land uses due to several factors. Forested areas, tea plantations, and horticultural lands often benefit from natural nutrient cycling and organic matter accumulation, enhancing soil fertility. In contrast, agricultural lands may experience nutrient depletion due to intensive farming practices and limited organic inputs (Sileshi et al., 2020). Soil depth also influences nutrient distribution, with surface layers generally richer in nutrients due to organic inputs and biological activity.

5. Conclusion

The results of the present study revealed a substantial decline in essential nutrients and soil properties from forests to other LUS, with horticulture and agriculture resulting in marked reductions in organic carbon, nitrogen, potassium, sulfur and base saturation. This degradation suggests that converting forests to agricultural or horticultural land can negatively impact soil health. Compared with agricultural and horticultural plantations, tea plantations have relatively balanced impacts, with fewer reductions in key nutrients but still show declines in OC, N, and S. The implementation of best practices to replenish depleted nutrients and maintain soil fertility is crucial for sustainable land management. These findings serve as valuable guides for policymakers and farmers to increase soil resilience, achieve higher agricultural productivity, and ensure long-term sustainability in the NER of India.

Acknowledgement
The first author expresses sincere gratitude to the National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Regional Centre, Jorhat and Department of Agriculture, Government of Arunachal Pradesh (India) for their indispensable support and provision of resources.

Author (s) contribution
All the authors have significantly contributed for the completion of this manuscript.

Conflict of interest
Authors declare no conflict of interest

References

Badalíková B. 2010. Influence of soil tillage on soil compaction. Soil Engineering: 19-30.

Barbhuiya AR, Arunachalam A, Pandey HN, Khan ML and Arunachalam K. 2008. Effects of disturbance on fine roots and soil microbial biomass C, N and P in a tropical rainforest ecosystem of Northeast India. Current Science 94 (5): 572-574.

Berger KC and Truog E. 1939. Boron determination in soils and plants. Industrial & Engineering Chemistry Analytical Edition11(10): 540-545.

Bray RH and Kurtz LT. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Science 59: 39–46.

Choudhury BU and Mandal S. 2021. Indexing soil properties through constructing minimum datasets for soil quality assessment of surface and profile soils of intermontane valley (Barak, North East India). Ecological Indicators 123: 107369.

Deka B, Baruah TC, Dutta M, Karmakar RM. 2009. Landscape soil relationships and pedonegic evaluation of soils in Ghiladhari watershed of the Brahmaputra valley of Assam. Journal of the Indian Society of Soil Science 57:245–252.

Doran JW and Safley M. 1997. Defining and assessing soil health and sustainable productivity. In: Pankhurst CE, Doube BM, Gupta VVSR (eds) *Biological indicators of soil health*. CAB International, New York. Pp 1–28.

FAO 2017. *Sustainable land management (SLM) in practice in the Kagera Basin. Lessons learned for scaling up at the landscape level - Results of the Kagera Transboundary Agroecosystem Management Project (Kagera TAMP)*. Food and Agriculture Organization of the United Nations, Rome, Italy. P. 440.

Fuglie KO. 2018. Is agricultural productivity slowing? Global Food Security 17:73-83.

Hota S, Mishra V, Mourya KK, Giri K, Kumar D, Jha PK, Saikia US, Prasad PV and Ray SK. 2022. Land use, landform, and soil management as determinants of soil physicochemical properties and microbial abundance of Lower Brahmaputra Valley, India. Sustainability14(4): 2241.

Jackson ML. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd, New Delhi. Pp 498.

Jiang J, Wang YP, Yu M, Cao N and Yan J. 2018. Soil organic matter is important for acid buffering and reducing aluminum leaching from acidic forest soils. Chemical Geology 501: 86-94.

Karlen DL, Mausbach MJ, Doran JW, Cline RG, HarrisRF and Schuman GE. 1997. Soil quality: a concept, definition, and framework for evaluation (a guest editorial). Soil Science Society of America Journal 61(1): 4-10.

Kumar R, Kumar A and Saikia P. 2022. Deforestation and forests degradation impacts on the environment. In: *Environmental Degradation: Challenges and Strategies for Mitigation*, pp. 19-46. Cham: Springer International Publishing.

Kumar S, Singh VK, Shekhawat K, Upadhyay PK, Dwivedi BS, Rathore SS, Kumar A and Yadav A. 2024. Enhancing productivity, economics and energy efficiency through precision nitrogen and water management in conservation agriculture-based maize (Zea mays) in the Indo-Gangetic Plains. The Indian Journal of Agricultural Sciences 94(3): 333-336.

Kumar S, Singh VK, Shekhawat K, Upadhyay PK, Rathore SS and Didawat RK. 2022. Real time nitrogen and irrigation management for enhanced productivity and nutrient use efficiency of maize under conservation agriculture. Annals of Agricultural Research 43(2), 159-163.

Lal R. 2013. Food security in a changing climate. Ecohydrology & Hydrobiology 13(1): 8-21.

Lindsay WL and Norvell W 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil science society of America journal 42(3): 421-428.

Mishra G, Marzaioli R, Giri K, Borah R, Dutta A and Jayaraj RSC. 2017. Soil quality assessment under shifting cultivation and forests in Northeastern Himalaya of India. Archives of Agronomy and Soil Science 63(10):1355-1368.

Mourya KK, Jena RK, Ray P, Ramachandran S, Sharma GK, Hota S and Ray SK. 2021. Profile distribution of soil organic carbon fractions under different landforms in the Meghalaya plateau of India. Environment Conservation Journal 22 (3): 9-16.

Nayak DC, Chamuah, GS, Maji, AK, Sehgal J and Velayutham M. 1996. *Soils of Arunachal Pradesh for optimizing land use*. NBSS Publ. 55b (Soils of India Series). National Bureau of Soil Survey and Land Use Planning, Nagpur, India. Pp 54.

Nunes MR, Karlen DL and Moorman TB. 2020. Tillage intensity effects on soil structure indicators—A US meta-analysis. Sustainability 12 (5): 2071.

Pahalvi HN, Rafiya L, Rashid S, Nisar B. and Kamili AN. 2021. *Chemical fertilizers and their impact on soil health. Microbiota and Biofertilizers*, Vol 2: Ecofriendly tools for reclamation of degraded soil environs. Pp.1-20.

Panwar P, Pal S, Reza SK and Sharma B. 2011. Soil fertility index, soil evaluation factor, and microbial indices under different land uses in acidic soil of humid subtropical India. Communications in Soil Science and Plant Analysis 42: 2724–2737.

Reza SK, Baruah U, Sarkar D and Dutta DP. 2011. Influence of slope positions on soil fertility index, soil evaluation factor and microbial indice in acid soil of Humid Subtropical India. Indian Journal of Soil Conservation 39:44–49

Reza SK, Sharma GK, Alam NM, Mourya KK, Hota S, Mukhopadhyay S, Bandyopadhyay S and Ray SK. 2024. Assessing soil quality under different land-uses through constructing minimum datasets from soil profiles in a fragile ecosystem of northeastern region of India. Communications in Soil Science and Plant Analysis 55(11): 1629-1643.

Reza SK, Baruah U, Nayak DC, Dutta D and Singh SK. 2018. Effects of land-use on soil physical, chemical and microbial properties in humid subtropical Northeastern India. National Academy of Science Letters 41: 141-145.

Saha R, Chaudhary RS and Somasundaram J. 2012. Soil health management under hill agroecosystem of North East India. Applied and Environmental Soil Science 2012 (1): 696174.

Schlüter S, Großmann C, Diel J, Wu GM, Tischer S, Deubel A and Rücknagel J. 2018. Long-term effects of conventional and reduced tillage on soil structure, soil ecological and soil hydraulic properties. Geoderma 332: 10-19.

Sileshi GW, Mafongoya PL and Nath AJ. 2020. Agroforestry systems for improving nutrient recycling and soil fertility on degraded lands. Agroforestry for Degraded Landscapes: Recent Advances and Emerging Challenges 1: 225-253.

Singh AK, Bordoloi LJ, Kumar M, Hazarika S and Parmar B. 2014. Land use impact on soil quality in eastern Himalayan region of India. Environmental monitoring and assessment 186: 2013-2024.

Smith JL and Doran JW. 1997. Measurement and use of pH and electrical conductivity for soil quality analysis. Methods for assessing soil quality 49: 169-185.

Sokolov MS, Semenov AM, Spiridonov YY, Toropova EY and Glinushkin AP. 2020. Healthy soil—condition for sustainability and development of the argo-and sociospheres (Problem-Analytical review). Biology Bulletin 47: 18-26.

Subbiah BV and Asija GL. 1956. A Rapid Procedure for the Estimation of Available Nitrogen in Soils. Current Science 25: 259-260.

Tisdale SL, Nelson WL and Beaton JD. 1985. *Soil fertility and fertilizers*. Collier Macmillan Publishers.

Tripathi RS and Barik SK. 2003. *Shifting cultivation in north east India. Proc. Approaches for increasing agricultural productivity in hill and mountain eco system*. ICAR Research Complex for NEH region, Umiam, Meghalaya. Pp. 317-322.

Walkley A and Black IA. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil science 37(1): 29-38.

Wang J, Tu X, Zhang H, Cui J, Ni K, Chen J, Cheng Y, Zhang J and Chang SX. 2020. Effects of ammonium-based nitrogen addition on soil nitrification and nitrogen gas emissions depend on fertilizer-induced changes in pH in a tea plantation soil. Science of the Total Environment 747: 141340.

Williams CH and Steinbergs A. 1959. Soil sulfur fractions as chemical indices of available sulfur in some Australian soils. Australian Journal of Agricultural Research 10(3): 340-352.

Wolka K, Biazin B, Martinsen V and Mulder J. 2021. Soil and water conservation management on hill slopes in Southwest Ethiopia. I. Effects of soil bunds on surface runoff, erosion and loss of nutrients. Science of The Total Environment 757: 142877.