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Soil density-porosity relationship across land use systems in the mountainous ecosystem of the Pir Panjal region, Jammu and Kashmir

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ABSTRACT

This study investigated the effects of four land use systems namely, Natural Forest; Pasture Land; Terraced Maize and Upland Rice on selected soil physical properties in the mountainous valley of Pir Panjal, Jammu & Kashmir. Geo-referenced soil samples were collected from three depth intervals (0–15 cm, 15–30 cm, and 30–60 cm) using a stratified random design and undisturbed cores were obtained to determine bulk density. Conducting sampling across steep terrain, variable elevations, and limited field access posed major logistical challenges. Ensuring uniform sampling precision in highly heterogeneous soil conditions of a fragile mountain ecosystem further required meticulous field and laboratory procedures. Results revealed a clear gradient in soil structural stability corresponding to land use intensity. Natural Forest soils had the lowest bulk density and highest porosity, reflecting superior structural conditions, while intensively cultivated Upland Rice soils showed the highest bulk density and lowest porosity. Pasture and Terraced Maize systems exhibited intermediate values. Land use exerted a significant influence ($p \leq 0.05$) on soil physical properties, whereas soil depth and its interaction with land use were not statistically significant. Bulk density and porosity emerged as sensitive indicators of soil physical degradation linked to land use. This study contributes valuable empirical evidence on the vulnerability of Himalayan soils to intensive land use transitions. It highlights the critical role of permanent vegetation cover and organic matter in preserving soil physical health and reinforces the need for conservation-focused land management to ensure long-term soil sustainability in this vulnerable mountain ecosystem.

Keywords: *Land use systems; soil physical properties; soil depth; stratified random sampling; bulk density; total porosity; soil degradation; natural forest; Pir Panjal; soil sustainability.*

1. Introduction

Soil is a vital natural resource that underpins agricultural productivity, ecosystem sustainability, and environmental health. The interaction between soil properties and land use systems is a crucial factor in determining soil quality and its capacity to support various land uses. Land-use change is a critical driver of soil degradation in the fragile Himalayan ecosystem. Soil physical properties, such as bulk density, particle density, and total porosity are critical indicators of soil physical health and its ability to support sustainable crop production. These properties directly influence water retention, aeration, root penetration and soil productivity [1] and [2]. Variations in land use systems significantly affect these parameters by altering soil organic matter content, biological activity and compaction levels. Across the globe, intensive agricultural practices, deforestation, and improper land management have led to pronounced changes in soil physical conditions [3] and [4].

Bulk density (BD) is widely recognized as an indicator of soil compaction and porosity. Elevated BD in croplands and grazing areas typically indicate reduced porosity and degraded structure owing to frequent tillage, mechanical operations, or livestock trampling [5] and [6]. Conversely, natural forest soils generally possess lower BD, reflecting their higher organic carbon content, undisturbed structure, and well-developed root networks [7]. Particle density (PD), though less variable with management, reflects the intrinsic mineral composition and organic matter proportion of soils. Lower PD in forest systems is commonly linked to high organic matter fractions, as organic materials have lower density than mineral particles [8].

Porosity serves as an essential indicator, capturing the interconnected effects of BD and PD on the soil's capacity to store air and water. The differences in porosity among land-use types underscore the influence of vegetation cover, tillage frequency and organic residue return [9][10]. Forest soils generally exhibit higher porosity due to persistent litter input and minimal disturbance, whereas intensive cultivation practices or continuous grazing tend to compact the soil, lowering total pore space [11] [12].

Recent research has emphasized the significance of sustainable land management practices, such as conservation tillage, crop residue retention and integrated nutrient management, to mitigate the deterioration of soil physical quality under

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intensive cropping systems [13][14]. Hence, a comparative assessment aimed to systematically analyze the effects of different land use systems on the physical properties in the mountainous Pir Panjal region of North-western Himayala. By comparing upland rice, terraced maize, pasture and natural forest land use systems, this study seeks to elucidate the relationship between land use practices and soil properties, providing valuable information for enhancing soil management practices and promoting sustainable agriculture in the eco-sensitive Himalayan region.

2. Materials and Methods

2.1 Study area

The investigation was carried out on the southern slopes of the PirPanjal mountain range, which falls within the intermediate to temperate agro-ecological zone. The Pir Panjal, oriented in a NW-SE direction, is part of the Lesser Himalayas and acts as a natural divide between the Kashmir Valley and the Jammu region. This range traverses the districts of Poonch, Rajouri, Kishtwar, and parts of Reasi and Ramban. A systematic soil survey was undertaken in the northern blocks of Rajouri and Reasi districts, situated in the Union Territory of Jammu and Kashmir, northern India. The landscape is characterized by rugged terrain, steep slopes and terrace farming. The study area lies between 33°28.1187′ N, 74°15.2631′ E and 33°25.8231′ N, 74°56.0012′ E, with elevations ranging from 1188 to 2070 m above mean sea level (amsl). Agricultural land use in studied region is dominated by traditional rice-wheat and maize-wheat cropping sequences, well adapted to the local climate and terrain. Major cereal crops include upland rice, maize and wheat. The natural vegetation of the area comprises Chir-pine forests, temperate conifers, alpine pastures, and degraded scrublands prone to erosion.

2.2 Soil sampling

A stratified random sampling approach was employed to collect geo-referenced soil samples from four major land use systems (LUS), namely upland rice, terraced maize, pasture, and natural forest. Soil profiles were excavated to a depth of 60 cm using an auger and spade, and samples were collected from three depth intervals: 0-15 cm, 15-30 cm and 30-60 cm at each site.

In total, 84 soil samples were obtained from seven locations representing the four land use systems. Sampling sites were carefully selected to ensure that the land uses occurred in juxtaposition on comparable soil types, thereby minimizing variability arising from pedogenic differences. Soil samples were collected after the harvest of the monsoon season crop. In forest areas, samples were obtained between tree rows to obtain representative soil conditions. For bulk density determination, undisturbed soil samples were collected from the same depths using a core sampler.

2.3 Soil physical properties

Soil samples collected from different land use systems and locations were air-dried, ground with a wooden pestle and mortar, and passed through a 2 mm sieve. The processed samples were then labeled, stored, and subjected to analysis. Bulk density (BD) was assessed from undisturbed soil cores following the procedure described by [15]. For this purpose, soil cores were collected from each land use system and location, and the combined weight of soil and core sampler was recorded. The volume of the core sampler (V) was determined, and bulk density was calculated using the standard formula:

$$\mathrm{BD} = \frac{\text{Weight of core with oven dry soil (g)} - \text{Weight of core(g)}}{\text{Volume (cubic cm)}}$$

Particle density (PD) was determined by the pycnometer method following Blake and Hartge (1986) and was calculated using the following formula:

$$\mathrm{PD} = \frac{\text{Weight of soil (g)}}{\text{Volume (cubic cm)}}$$

Total porosity (TP) was calculated using particle density and bulk density as:

$$\text{Porosity (\%)} = 1 - \frac{\text{Bulk density}}{\text{Particle density}} \text{x}100$$

2.4 Statistical analysis

Descriptive statistics including mean, coefficient of variation, minimum, maximum, standard deviation, and standard error of the mean were computed using MS Excel. A two-way analysis of variance (ANOVA) with a randomized complete block design (RCBD) was performed using the opstat.pythonanywhere.com statistical system to assess the effects of soil depth, land use system, and their interaction on soil parameters. Pearson's correlation coefficient was used to evaluate relationships between selected soil physical properties. Data visualization was conducted using R (version 4.2.0) [16] with the ggplot2 package (version 3.3.5) [17].

3. Result and discussion

3.1 Soil bulk density

The results presented in Table 1 indicate that soil bulk density (BD) differed significantly ($p \leq 0.05$) among the four land use systems and across soil depths, whereas the interaction between land use system and depth was not significant. In all land use types, bulk density consistently increased with soil depth: for upland rice, BD ranged from 1.43 to 1.50 g/cm^3; for terraced maize, from 1.34 to 1.41 g/cm^3; for pasture land, from 1.54 to 1.57 g/cm^3; and for natural forest soils, from 1.15 to 1.24 g/cm^3.Mean bulk density was highest under pasture land (1.55 g/cm^3) and upland rice (1.47 g/cm^3), which may reflect a lack of structural renewal through organic matter inputs and the effects of mechanical compaction. This pattern agrees with previous findings where conventionally managed croplands and grazed lands showed greater bulk density compared to forest or conservation-managed soils, attributed to higher disturbance and reduced organic matter content [5]. In contrast, forest soils exhibited the lowest average BD (1.20 g/cm^3), likely resulting from greater organic matter accumulation, active root growth, and minimal disturbance, which collectively enhanced soil porosity and structure [7]. Lower BD values in vegetated systems are also associated with improved root penetration, better soil aeration, and increased water infiltration, all of which contribute to higher crop productivity and resilience. Higher bulk density observed in grazing lands compared to cultivated fields can be attributed to compaction from intensive animal grazing and reduced soil organic carbon levels, as also noted by [6] and [18]. These trends are corroborated by [19], [20], and [21]; who also reported the highest bulk densities in grazing lands and the lowest in forest soils, with the difference largely driven by organic matter content [22].

Additionally, increasing bulk density in subsurface soil layers is associated with lower organic matter content and greater compaction. This finding aligns with [23], who documented higher subsoil BD due to continuous cultivation, reduced aggregate stability, and increased sand content.

Continued tillage in annual cropping systems accelerates breakdown of soil structure, resulting in higher bulk densities, consistent with the results reported by [24].

3.2 Soil particle density

The data presented in Table 2 indicate that soil particle density (PD) remained relatively stable across different soil depths and land use systems. The highest PD values significantly ($p \leq 0.05$) were observed in uncultivated pasture land, ranging from 2.52 to 2.57 g/cm^3, followed by upland rice soils (2.42 to 2.43 g/cm^3). Terraced maize soils had PD values ranging from 2.39 to 2.42 g/cm^3, while natural forest soils consistently exhibited the lowest PD values, ranging from 2.37 to 2.41 g/cm^3, up to a 60 cm soil profile.

On average, particle density across land use systems followed the trend: pasture land (2.53 g/cm^3) > upland rice (2.41 g/cm^3) > terraced maize (2.39 g/cm^3) > natural forest (2.26 g/cm^3). Unlike bulk density, which is strongly influenced by soil compaction and management practices, particle density is predominantly determined by the soil's mineralogical composition and organic matter content, making it relatively invariant with depth and land use.

The higher particle density observed in uncultivated pasture soils is likely due to their higher mineral content and lower organic matter, whereas natural forest soils show lower particle density consistent with their greater organic matter fraction, as organic materials generally have lower density than mineral particles [8]. These results correspond with previous research demonstrating that particle density remains relatively constant in agricultural soils across varying depths and is typically lower in forest soils due to higher soil organic carbon content [24] and [25]. Overall, the stability of particle density across depth and land use emphasizes its dependence on inherent soil properties rather than external management or disturbance, distinguishing it from more dynamic soil indicators like bulk density and porosity.

3.3 Soil total porosity

The total porosity of the soil varied with depth and land usage. Forest soils had the maximum porosity (average 49.54%), followed by soils made of maize and wheat (42.56%), rice and wheat (39.23%), and uncultivated soils (38.63%). All systems showed a minor decrease in porosity with depth: it went from 40.78% (0–15 cm) to 38.41% (30–60 cm) for rice–wheat, from 44.22% to 41.82% for maize–wheat, from 38.93% to 39.01% (with little change) for uncultivated soils and from 51.56% to 48.72% for forest soils as seen in Figure 1.

The combined effects of organic matter content, natural biological processes, and land management techniques can be used to explain the variations in soil porosity among land uses. Undisturbed natural ecosystems have superior soil physical qualities, according to the data, which clearly illustrate a hierarchy of soil health indices. Because of the strong root systems and long-term build-up of organic matter from litterfall, forest soils have the maximum porosity. While preserving a balanced texture, these elements produce stable soil aggregates that increase macro- and micropore space, which is essential for aeration and water infiltration. The low coefficient of variation is explained by the limited disturbance and ongoing biological activity, indicating a very resilient and stable soil structure [26] and [9].

Compared to rice-wheat soils, maize-wheat soils had more porosity, most likely as a result of traditional tillage techniques that break up the soil. This technique may improve aeration at first, but it may have complicated long-term effects. In contrast to the more disruptive puddling techniques of the rice-wheat system, tillage seems to have preserved the soil structure in this instance [27] and [10]. In comparison to forest soils, uncultivated soils showed the lowest porosity, presumably as a result of a lack of active management and organic matter intake. Without the advantages of tillage or organic matter accumulation, these soils may eventually compress, resulting in less pore space and worse water retention [11] and [12].

3.1 Soil correlation study

The Pearson correlation matrix (Figure 2) demonstrates a strong and significant positive correlation between bulk density (BD) and particle density (PD) ($r = 0.969$, $p < 0.05$), indicating that these two soil properties increase together. Bulk density is strongly and significantly negatively correlated with porosity ($r = -0.979$, $p < 0.05$), reflecting that higher soil compaction reduces pore space. Although particle density also shows a negative correlation with porosity ($r = -0.916$), this relationship is not statistically significant, suggesting that particle density is less directly related to soil pore space. These findings highlight that bulk density and porosity are closely linked, with bulk density serving as a key indicator of soil compaction and structural quality, whereas particle density is more reflective of the soil's mineral composition and exhibits less variability with changes in porosity.

The forest land-use system exhibited the highest total porosity, which strongly correlated with its lower bulk density, reduced sand content, and elevated organic carbon levels. This was followed by the maize-cultivated system. Surface layers across all systems showed greater porosity, a consequence of higher organic matter and lower compaction. The inverse relationship between pore space and bulk density underscores how sustained organic inputs in forests preserve soil structure, minimize crust formation, and enhance both micro and microporosity, a finding consistent with [29].

Table 1. Depth-wise variation in soil bulk density under different land use systems

Depth (cm)	Land Use System			
	Upland Rice	Terraced Maize	Pasture Land	Natural Forest
	Bulk density (g/cm³)			
0-15	1.43	1.34	1.54	1.15
15-30	1.47	1.38	1.55	1.21
30-60	1.50	1.41	1.57	1.24
Mean	1.47	1.37	1.55	1.20
SE±(m)	0.04	0.03	0.03	0.03
CV (%)	7.81	6.83	5.95	6.94
CD (p ≤ 0.05)	Land use system (LUS) = 0.05; Depth (D) = 0.05; LUS x D = NS			

Table 2. Effect of different landuse systems on soil particle density across various soil depths

Depth (cm)	Land Use System			
	Upland Rice	Terraced Maize	Pasture Land	Natural Forest
	Particle density (g/cm³)			
0-15	2.42	2.39	2.52	2.37
15-30	2.38	2.36	2.50	2.34
30-60	2.43	2.42	2.57	2.41
Average	2.41	2.39	2.53	2.26
SE±(m)	0.02	0.01	0.03	0.11
CV (%)	2.97	1.93	3.55	13.70
CD (p≤0.05)	Land use system (LUS) = 0.04; Depth (D) = 0.03; LUS x D = NS			

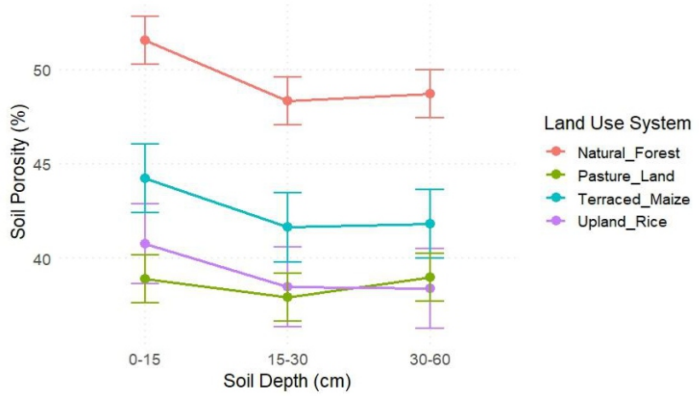
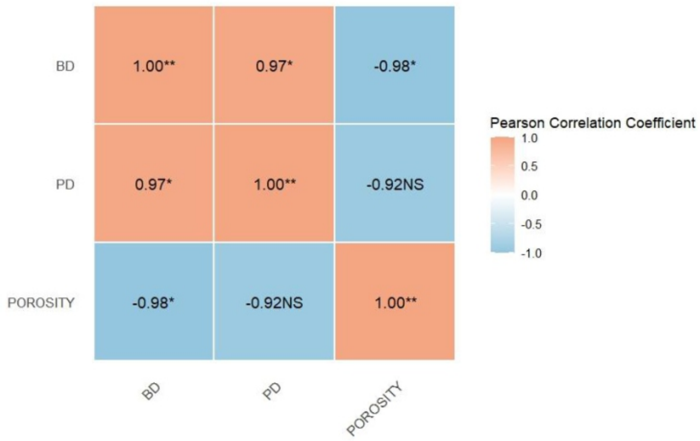


Figure 1. Depth-wise variation in total porosity under different land use system



**=significant at 5 %, ** = significant at 1 % and NS = non-significant*

Figure 2. Correlation between physical characteristics

Conclusion

In conclusion, this study underscores the profound vulnerability of the North-Western Himalayan soils to land-use change. The stark contrast between the resilient, porous structure of natural forests and the compacted state of intensively managed lands like pastures is a major concern for this fragile ecosystem. Given the region's steep slopes and high erosion risk, the degradation of soil structure directly threatens agricultural productivity, water security, and slope stability downstream. Therefore, moving away from intensive practices and actively promoting forest conservation, agroforestry and organic amendment is not merely a recommendation but an urgent imperative for the ecological security and sustainable development of the North-Western Himalayas.

Future scope

Future investigations may expand this research by incorporating soil quality indicies such as soil to gain a holistic understanding of soil functionality across mountain land uses. Long-term monitoring studies should be undertaken to capture temporal variability and climate-driven changes in soil physical properties under different management regimes. Integrating AI driven remote sensing technogolies, GIS-based landscape modelling, and machine learning approaches may further improve spatial prediction of soil degradation risks in complex terrains. Additional comparative studies across varying altitudinal gradients and diverse Himalayan agro-ecological settings would strengthen region-specific soil conservation strategies and support evidence-based policymaking for mountain agriculture and watershed management.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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References

1. Benbi, D. K., Brar, K., Toor, A. S., Singh, P. and Singh, H. 2012. Soil carbon pools under poplar-based agroforestry, rice-wheat and maize-wheat cropping systems in semi-arid India. *Nutrient Cycling in Agroecosystems,* 92(1):107-118. https://doi.org/10.1007/s10705-011-9475-8

2. Dash, A.K., Meena, M.C., Das, S., Dey, A., Sangwan, S., Bana, R.S., Aditya, K., Raza, M.B., Padhan, D., Tripathy, S. and Bardhan, T. 2025. Long-term conservation agriculture to enhance soil properties and quality in rice–wheat cropping system. *Scientific Reports*, 15(1):28393. https://doi.org/10.1038/s41598-025-11104-9

3. Molla, E., Getnet, K. and Mekonnen, M. 2022. Land use change and its effect on selected soil properties in the northwest highlands of Ethiopia. *Heliyon*, 8(8).

4. Li, J., Ma, X. and Luo, G. 2024. Trade-offs and synergistic relationships on soil-related ecosystem services in Central Asia under land use and land cover change. *Land Degradation & Development*, 35(16):5011-28.https://doi.org/10.1002/ldr.5274

5. Bogunovic, I., Viduka, A., Magdic, I., Telak, L.J., Francos, M. and Pereira, P. 2020. Agricultural and forest land-use impact on soil properties in Zagreb periurban area (Croatia). *Agronomy*, 10(9):1331. https://doi.org/10.3390/agronomy10091331

6. Assefa, E., Debella, F. and Gelaw, A. 2020. Effect of land use and land cover on selected soil physicochemical properties in Shenkolla watershed, southwestern Ethiopia. *Applied and Environmental Soil Science,* 2020, Article ID 8825171. https://doi.org/10.1155/2020/8825171

7. Amanuel, W., Yimer, F. and Karltun, E. 2018. Soil organic carbon variation in relation to land use changes: the case of Birr watershed, upper Blue Nile River Basin, Ethiopia. *Journal of Ecology and Environment*, 42(1):16. https://doi.org/10.1186/s41610-018-0076-1

8. Ruehlmann, J. 2020. Soil particle density as affected by soil texture and soil organic matter: 1. Partitioning of SOM in conceptional fractions and derivation of a variable SOC to SOM conversion factor. *Geoderma*, 375:114542. https://doi.org/10.1016/j.geoderma.2020.114542

9. Dhaliwal, J. K., Singh, M. J., Sharma, S., Gupta, N. and Kukal, S. S. 2020. Medium-term impact of tillage and residue retention on soil physical and biological properties in dry-seeded rice–wheat system in north-west India. *Soil Research,* 58(5):468-477. https://doi.org/10.1071/SR19351

10. Singh, V., Gupta, R. K., Kahlon, M. S., Toor, A. S., Singh, K. B., Al-Ansari, N. and Mattar, M. A. 2023. Effect of different tillage and residue management options on soil water transmission and mechanical behavior. *Land,* 12(10):1895. https://doi.org/10.3390/land12101895

11. Erdoğan Yüksel, E. and Yavuz, G. 2024. Evaluating the soil properties of different land use types in the Deviskel Watershed in the Hilly Region of Northeast Türkiye. *Sustainability*, 16(22):9732. https://doi.org/10.3390/su16229732

12. Murindangabo, Y.T., Kopecký, M., Hoang, T.N., Bernas, J., Parajuli, T., Dhakal, S., Konvalina, P., Ufitikirezi, J.D.D.M., Kaneza, G., Khanal, B.R. and Dhakal, S.C. 2023. Comparative analysis of soil organic matter fractions, lability, stability ratios and carbon management index in various land use types within bharatpur catchment, Chitwan District, Nepal. *Carbon Balance and Management*, 18(1):21. https://doi.org/10.1186/s13021-023-00241-1

13. Leharwan, M., Kumar, Y., Kumar, R., Kumar Saraswat, P., Kumar, R., Kumar ThaliyilVeetil, A., Bhattacharjee, S., Kumar, A. and Kumar, S. 2023. Assessing the effects of conservation tillage and in-situ crop residue management on crop yield and soil properties in rice–wheat cropping system. *Sustainability*, 15(17):12736. https://doi.org/10.3390/su151712736

14. Liang, X., Yu, S., Ju, Y., Wang, Y. and Yin, D. 2025. Integrated management practices foster soil health, productivity and agroecosystem resilience. *Agronomy*, 15(8):1816. https://doi.org/10.3390/agronomy15081816

15. Blake, G.R. and Hartge, K.H. 1986. Bulk density. *Methods of soil analysis: Part 1 Physical and mineralogical methods*, 5:363-375. https://doi.org/10.2136/sssabookser5.1.2ed.c13

16. R Core Team, 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. *http://www. R-project. org/*.

17. Wickham, H. 2016. Data analysis. In *ggplot2: elegant graphics for data analysis* (pp. 189-201). Cham: Springer international publishing. https://doi.org/10.1007/978-3-319-24277-4_9

18. Abera, Y. and Belachew, T. 2011. Effects of landuse on soil organic carbon and nitrogen in soils of Bale, Southeastern Ethiopia. *Tropical and subtropical agroecosystems*, 14(1):229-235.

19. Jemal, K. and Tesfaye, H. 2020. Soil physico-chemical property characterisation along with different land use system in Gurage zone, southern Ethiopia. *Mod. Chem*, 8(3):40. doi: 10.11648/j.mc.20200803.12

20. Desta, H.A. 2018. Effects of land use systems on soil fertility at antra Watershed, Chilga district, northwestern highlands of Russia. *Universal Journal of Agricultural Research*, 6(6):194-208. DOI: 10.13189/ujar.2018.060602

21. Cade-Menun, B.J., Bainard, L.D., LaForge, K., Schellenberg, M., Houston, B. and Hamel, C. 2017. Long-term agricultural land use affects chemical and physical properties of soils from southwest Saskatchewan. *Canadian journal of soil science*, 97(4):650-666. https://doi.org/10.1139/cjss-2016-0153

22. Weil, R. R. and Brady, N. C. 2016. The nature and properties of soils (15th ed.). Pearson.

23. Abad, J.R.S., Khosravi, H. and Alamdarlou, E.H. 2014. Assessment the effects of land use changes on soil physicochemical properties in Jafarabad of Golestan province, Iran. *Bulletin of Environment, Pharmacology and Life Sciences*, 3(3):296-300.

24. Dhanda, S., Yadav, A., Yadav, D.B. and Chauhan, B.S. 2022. Emerging issues and potential opportunities in the rice–wheat cropping system of North-Western India. *Frontiers in Plant Science*, 13:832683. https://doi.org/10.3389/fpls.2022.832683

25. Tellen, V.A. and Yerima, B.P. 2018. Effects of land use change on soil physicochemical properties in selected areas in the North West region of Cameroon. *Environmental systems research*, 7(1):1-29. https://doi.org/10.1186/s40068-018-0106-0

26. Kousar, R., Lone, A.H., Shah, Z.A., Dar, E.A., Mir, M.S., Alkeridis, L.A., Al-Shuraym, L.A., Ganie, M.A., Bhat, J.A., Alshehri, M.A. and Sayed, S. 2025. Farm-scale soil spatial variability at a mountain research centre in Northwestern Himalayas. *Scientific Reports*, 15(1):19705. https://doi.org/10.1038/s41598-025-03695-0

27. Kahlon, M.S. 2014. Soil physical characteristics and crop productivity as affected by tillage in rice-wheat system. *Journal of Agricultural Science*, 6(12):107. http://dx.doi.org/10.5539/jas.v6n12p107

28. Nie LiangPeng, N.L., Guo LiWei, G.L., Niu HaiYan, N.H., Wei Jie, W.J., Li ZengJia, L.Z. and Ning TangYuan, N.T. 2015. Effects of rotational tillage on tilth soil structure and crop yield and quality in maize-wheat cropping system. https://doi.org/10.3724/SP.J.1006.2015.00468

29. Geleta Likasa, W., FufaFeyessa, F. and Bekele Sima, A. 2024. Exploring the Influence of Land Use Types on Soil Properties at Arjo-Dhidhessa Sugar Estate, Western Ethiopia. *Applied and Environmental Soil Science*, 2024(1):6949296. https://doi.org/10.1155/aess/6949296

