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Variation in Soil Physical Properties under Different Land Uses in Himachal Pradesh

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Abstract

The study assessed soil physical properties under three lands uses *viz.,* natural, agriculture-based and horticulture-based across four locations in the Himachal Pradesh, based on 168 soil samples collected from two depths (0-15 and 15-30 cm). The findings of study indicated that natural systems exhibited comparatively lower soil bulk and particle densities and higher porosity, relative to agriculture and horticulture-based land use. The sub-surface soils exhibited slightly higher mean bulk and particle densities, with a noticeable decline in mean porosity. Soils in natural systems exhibited less fluctuations in bulk density and porosity, implying more stable soil conditions. In contrast, agricultural and horticultural soils displayed alternating positive and negative skewness and kurtosis. These findings indicated comparatively better soil physical properties in natural systems than cultivated systems, highlighting the need for sustainable practices in cultivated lands to maintain soil physical health and the conservation of natural systems.

Keywords: Land Use, Natural Systems, Physical Properties, Soil Health

The rapid population growth and economic development during the twenty-first century have driven unsustainable exploitation of natural resources and associated environmental changes. Human interventions are increasingly transforming natural ecosystems into croplands, pastures, urban infrastructure and roads, while the remaining natural areas are often subjected to considerable anthropogenic pressures and disturbances. Globally, cropland area has expanded to approximately 1,244 million hectares and between 2003 and 2019, there was a 9% increase in cropland area, with nearly half (49%) of this expansion occurring at the expense of natural vegetation and tree cover (Potapov *et al.* 2022).

The conversion of natural vegetation, such as forests and grasslands, into croplands has historically been the most significant and dramatic change in land uses globally (Chen *et al.* 2006). Different land uses and land cover managements, such as agriculture, pastures, urbanization and forestry, can significantly influence soil health and exert tremendous impact on soil quality. Land use change, particularly the transformation from forests to croplands, induce shifts in the chemical, biological and physical characteristics of the soil (Houghton *et al.* 1999; Zhang *et al.* 2004 and Viollete *et al.* 2009).

Soil physical properties are equally or even more important than chemical and biological properties, given their direct influence on nutrient cycling, water dynamics and soil biota. Numerous studies and reports have documented how intensive and conventional agricultural practices can deteriorate soil physical properties and overall soil health. Land use has a direct and measurable impact on soil physical quality. For instance, natural ecosystems like forests and grasslands typically maintain favourable soil conditions. They contribute organic matter, protect the soil surface from erosion, and support biological

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activity that enhances aggregation and porosity. In contrast, intensive agricultural practices often involve repeated tillage, use of heavy machinery, and limited organic inputs. These activities can compact the soil, reduce porosity, and degrade structure, leading to diminished water-holding capacity and increased runoff. Over time, such degradation not only affects crop yields but also compromises the resilience of soils to climate variability.

Moreover, assessing soil physical properties under different land uses helps in understanding the extent of soil degradation, particularly in regions experiencing transitions from natural to cultivated landscapes. Soil compaction, increased bulk density and lower porosity are often among the first signs of soil physical degradation, often resulting from intensive land use and mechanical disturbances (Hamza & Anderson 2005). These changes reduce the ability of soils to retain water and nutrients, directly impacting agricultural productivity and threatening food security. Monitoring these indicators provides early warning and helps in adopting appropriate land management strategies. Understanding how different land use types influence soil health provides a critical foundation for developing effective management strategies that promote long-term soil productivity, ecosystem resilience and sustainable development.

MATERIALS AND METHODS

General Description of Study Area

The present study was done in four locations lying within agro-climatic zone I and II of Himachal Pradesh, situated between 30°23′40″ N to 33°12′40″ N latitudes and 75°45′55″ E to 79°04′20″ E longitudes. The study area is characterised by typically shallow soils, with relatively high mean annual rainfall. The 4 selected sites *viz.,* Palampur, Sunder Nagar, Kullu and Berthin are representative of acid soils regions of HP under these agro-climatic zones. Three predominant land uses characterized by agriculture-based, horticulture-based and natural system under these locations were studied. Agriculture-based land use comprised the cereals, legumes and fodder crops, whereas horticulture-based land use included vegetable cultivation and orchards. Natural systems encompassed forests and grasslands with minimal anthropogenic interference.

Soil Sampling and Analysis

A total of 168 soil samples were collected from 2 soil depths; surface (0-15 cm) and sub-surface (15-30 cm), across 3 selected land uses in the acid soils regions of Himachal Pradesh. Soil samples were obtained from fields that had been under continuous, uniform land use and managed using the recommended agronomic practices of the state Department of Agriculture for not less than seven years. Conversely, forest and grassland sites were unmanaged, without any fertilizer or manure inputs. To minimize sampling error, all samples were collected within a 1 km radius. The collected samples were air-dried in the shade, gently ground using a wooden pestle and mortar, and passed through a 2 mm stainless steel sieve. The processed samples were then stored in polyethylene bags for subsequent laboratory analysis. The processed soil samples were examined for key physical properties, using standard procedures. Bulk density was determined by core sampler method given by Singh (1980), particle density using Pycnometer method and porosity using Empirical method (Gupta and Dhakshinamoorthy 1980). The general soil properties of the locations are given in Table 1.

Statistical Analysis

To assess the variability in soil physical properties among land uses (agriculture-based, horticulture-based and natural system), descriptive statistics including range, mean, skewness and kurtosis were calculated using Microsoft excel 2021, which followed the standard procedure detailed by Gomez and Gomez (1984). Skewness measures the asymmetry of a distribution around its mean. Kurtosis measures peakedness or flatness of the data distribution, how heavy or light the tails are compared to a normal distribution.

Table 1. General soil properties of sampling locations

Location	Texture	pH	OC (%)
Palampur	Silty clay loam	4.39-5.41	0.66-1.96
Sunder Nagar	Silty clay loam	5.27-5.69	0.55-1.95
Kullu	Silty loam	5.95-6.82	0.66-1.76
Berthin	Silty loam	6.18-6.88	0.42-1.28

RESULTS AND DISCUSSION

Bulk Density

There was considerable variation in soil bulk density among different land uses *w.r.t* the minimum and maximum values (Table 2) and mean (Figure 1). Across all the locations, natural systems consistently exhibited the lowest bulk densities, with mean surface and sub-surface values of 1.24 and 1.36 g cm^{-3} in Palampur, 1.26 and 1.29 g cm^{-3} in Sunder Nagar, 1.22 and 1.30 g cm^{-3} in Kullu, and 1.26 and 1.39 g cm^{-3} in Berthin. Natural systems had minimum values, exhibiting the least compaction, which might be Moreover, the bulk density increased with depth, which might be attributed to weight of the overlying soil mass. Additionally, the decline in soil organic matter with increasing depth, coupled with the repeated use of heavy tillage implements lead to the development of a compacted layer within the 15-30 cm depth range (Santra *et al.* 2008) which increases soil bulk density under lower layers. Comparable observations were documented by Rajput *et al.,* (2016) and Gautam *et al.*, (2023).

Skewness analysis showed how land uses affected soil bulk density distribution. Natural systems showed positive skewness (means more low values) at upper soil depth, indicating looser soil, which might be due to undisturbed roots and regular litter input. While, alternate between positive and negative skewness (more high values) was common in the top soils of agriculture-based system and horticulture-based system, might be due to management-induced variability. Moreover, all land uses showed negative kurtosis, indicating flat distribution of bulk density values and more even distribution, except in the upper depth of natural system in Berthin and lower soil depth of agriculture and horticultural systems of Sunder Nagar and agricultural system of Kullu, indicating more consistent and peaky bulk density values which might be due to compaction.

Particle Density

In general, the particle density ranged from 2.60 to 2.75 g cm^{-3} in Palampur, 2.49 to 2.64 g cm^{-3} in Sunder Nagar, 2.47 to 2.66 g cm^{-3} in Kullu and 2.59 to 2.72 g cm^{-3} in Berthin, regardless of soil depth. Particle density exhibited minimal variation across land uses as depicted by mean values. However, the natural systems recorded comparatively lower values than agriculture and horticulture-based land uses in Sunder Nagar, Kullu and Berthin with the respective mean values of 2.56, 2.51 and 2.61 g cm^{-3} in 0-15 cm soil depth and 2.57, 2.56 and 2.63 g cm^{-3} in 15-30 cm soil depth. These slight variations observed could be linked to differences in soil organic matter content, as natural systems exhibited the lowest bulk density owing to higher organic content than cultivated lands. These observations are in agreement with the findings of Longchar *et al.,* (2023) and Priyadarshini *et al.,* (2024).

Table 2. Soil bulk density (g cm^{-3}) under land uses

Location	Land use	0-15 cm			15-30 cm		
		Range	Skewness	Kurtosis	Range	Skewness	Kurtosis
Palampur	Agriculture-based	1.25-1.34	-0.73	-0.38	1.35-1.49	-0.05	-0.87
	Horticulture-based	1.27-1.34	0.80	-1.87	1.33-1.47	0.01	-1.27
	Natural system	1.19-1.30	0.57	-0.95	1.30-1.41	-0.25	-1.40
Sunder Nagar	Agriculture-based	1.28-1.36	0.00	-1.20	1.38-1.46	0.80	0.05
	Horticulture-based	1.29-1.35	-1.21	-0.46	1.36-1.45	0.57	0.15
	Natural system	1.20-1.34	0.53	-0.56	1.21-1.37	0.00	-2.88
Kullu	Agriculture-based	1.22-1.32	-0.65	-1.11	1.31-1.42	-0.74	0.79
	Horticulture-based	1.24-1.34	0.66	-0.24	1.31-1.40	-0.71	-0.51
	Natural system	1.17-1.28	0.19	-2.58	1.24-1.40	0.20	-1.25
Berthin	Agriculture-based	1.34-1.38	0.39	-0.77	1.37-1.49	-0.60	-1.31
	Horticulture-based	1.31-1.43	0.25	-0.19	1.39-1.49	0.06	-1.51
	Natural system	1.21-1.31	0.75	0.05	1.29-1.49	-0.04	-0.56

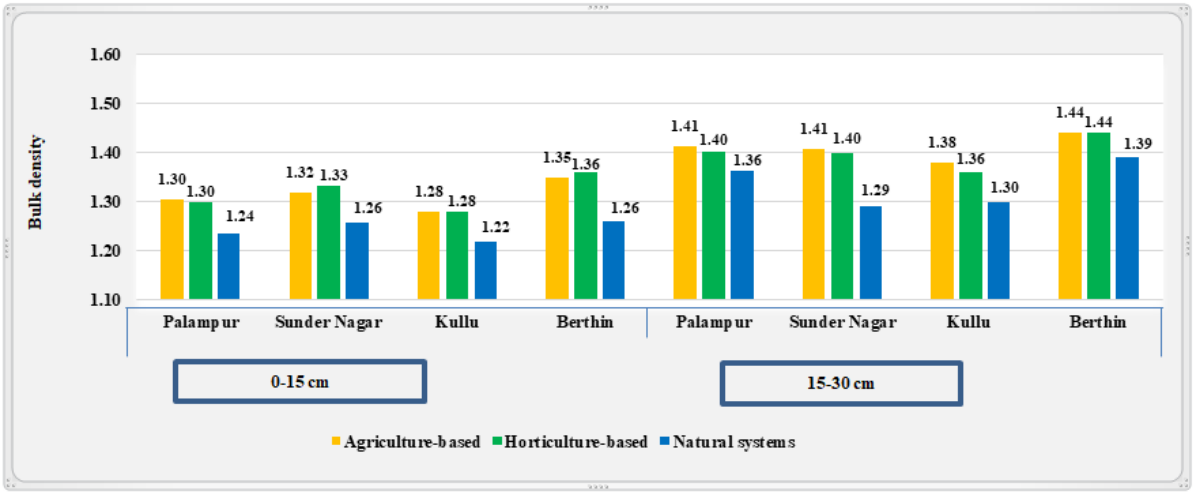


Figure 1. Mean soil bulk density under land uses

Table 3. Soil particle density (g cm^{-3}) under land uses

Location	Land Use	0-15 cm			15-30 cm		
		Range	Skewness	Kurtosis	Range	Skewness	Kurtosis
Palampur	Agriculture-based	2.62-2.71	0.32	-1.22	2.63-2.72	-0.70	0.21
	Horticulture-based	2.62-2.72	0.63	0.38	2.66-2.70	0.42	-0.86
	Natural system	2.62-2.71	1.16	1.10	2.60-2.75	-0.41	-0.29
Sunder Nagar	Agriculture-based	2.55-2.61	0.08	-1.62	2.56-2.63	0.45	0.21
	Horticulture-based	2.53-2.64	-0.23	-0.79	2.55-2.63	-0.05	-1.41
	Natural system	2.49-2.60	-0.89	1.02	2.52-2.60	-0.72	-1.32
Kullu	Agriculture-based	2.49-2.61	-0.10	-0.58	2.54-2.63	0.42	-1.16
	Horticulture-based	2.54-2.61	-0.08	-0.87	2.57-2.66	1.44	2.44
	Natural system	2.47-2.55	0.23	-1.63	2.52-2.62	1.01	0.60
Berthin	Agriculture-based	2.59-2.72	0.03	-1.42	2.61-2.72	-0.27	-0.54
	Horticulture-based	2.57-2.69	0.78	1.22	2.60-2.70	0.45	-1.48
	Natural system	2.57-2.65	0.25	-0.47	2.60-2.66	-0.46	-0.30

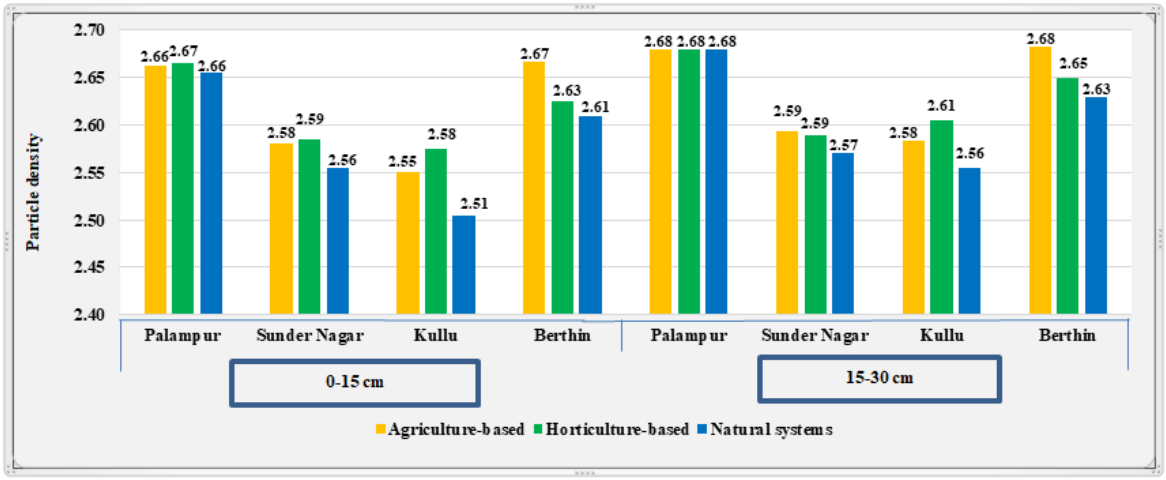


Figure 2. Mean soil particle density under land uses

Furthermore, varied patterns of positive, negative and zero skewness and kurtosis were observed across the agriculture-based, horticulture-based and natural systems with respect to particle density, which might be due to site-specific variations in soil mineral composition, organic matter content and management practices which influence the distribution of particle density.

Porosity

A broad range of porosity was recorded under different land uses. Overall, soil porosity values varied between 44.9 and 55.4 % in Palampur, 43.4 and 53.3 % in Sunder Nagar, 45.0 and 52.9 % in Kullu and 43.5 and 50.6 % in Berthin, irrespective of soil depth. The natural systems showed the highest soil porosity compared to the agriculture and horticulture-based systems in both the depths, with the mean values of 53.4, 50.9, 51.5 and 51.9 % in the surface soils and 49.2, 49.8, 49.5 and 47.2 % in the sub-surface soils of Palampur, Sunder Nagra, Kullu and Berthin, respectively. This enhanced porosity could be due to lower bulk density (since pore space is inversely related to bulk density) and higher organic matter content, which promotes soil aggregation and reduces compaction through microbial decomposition (Bhatia & Shukla 1982). These observations are

Table 4. Soil porosity (%) under land uses

Location	Land Use	0-15 cm			15-30 cm		
		Range	Skewness	Kurtosis	Range	Skewness	Kurtosis
Palampur	Agriculture-based	48.6-52.4	1.03	2.46	44.9-50.0	0.25	-0.81
	Horticulture-based	48.2-51.9	-0.51	-1.45	46.1-48.9	-0.42	0.35
	Natural system	51.3-55.4	-0.16	-2.20	45.8-51.5	-0.59	-0.57
Sunder Nagar	Agriculture-based	47.5-50.6	0.62	-0.81	43.4-47.7	-0.25	-0.83
	Horticulture-based	46.6-51.1	1.00	2.13	44.3-47.1	-0.91	-1.08
	Natural system	48.1-52.9	-0.55	0.40	46.1-53.3	-0.11	-1.33
Kullu	Agriculture-based	48.4-52.7	0.50	-0.91	45.0-48.4	0.08	-0.91
	Horticulture-based	48.3-51.2	-0.40	-1.44	45.7-48.8	-1.17	1.71
	Natural system	48.4-53.9	-0.43	-0.68	46.6-52.9	0.04	-1.62
Berthin	Agriculture-based	46.7-50.7	-0.66	1.10	44.3-48.2	0.70	0.14
	Horticulture-based	45.2-50.4	-0.36	-1.24	43.5-47.4	0.07	-0.02
	Natural system	50.2-53.6	-0.32	-1.36	44.5-50.6	0.64	-1.25

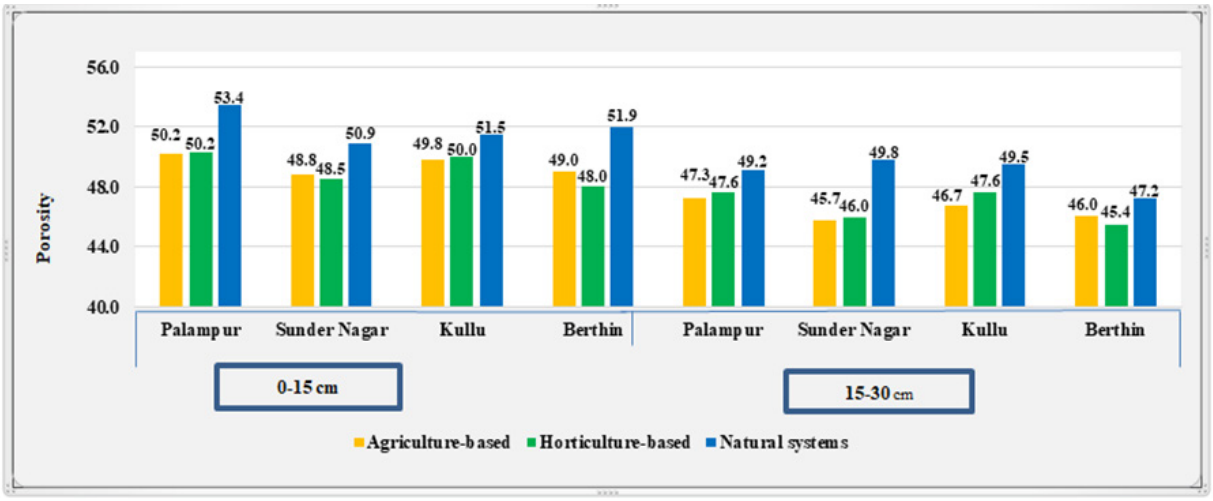


Figure 3. Mean soil porosity under land uses

consistent with findings of Kebebew *et al.,* (2022) and Asmare *et al.,* (2023). Moreover, surface soils exhibited comparatively higher porosity than the sub-surface soils primarily due to their lower bulk density and higher organic matter levels. These results align with the work of Roheela (2019) and Priyadarshini *et al.*, (2024), who noted lower particle density in surface horizons compared to sub-surface soils across various land use types.

Natural systems showed negative skewness (more high porosity values) in the upper soil depth, indicating better soil porosity compared to managed systems. However no such trend was observed in lower soil depth. Furthermore, natural systems predominantly showed negative kurtosis, indicating flatter, less peaked distributions. This suggested that natural systems had more uniform porosity distributions (less extreme values), while managed systems (agriculture and horticulture) showed more variability, with some highly peaked distributions, reflecting clustering around certain values. This might be due to variations in management practices, tillage intensity, and crop residue incorporation affecting soil structure and porosity.

CONCLUSION

Soils under natural systems possessed better physical attributes compared to those under agriculture and horticulture-based land uses. This was evident through consistently lower bulk and particle densities, along with higher porosity values under natural systems, which indicate reduced compaction and greater pore space. In contrast, soils under horticulture and agriculture often experience compaction, reduced porosity and degradation of structure due to frequent tillage, machinery use and organic matter depletion. The findings highlight the need for sustainable soil management in cultivated lands by adopting practices that mimic natural processes, such as organic matter incorporation, reduced tillage and cover cropping to restore and maintain soil physical quality. This also underscores the importance of conserving natural ecosystems, not only for biodiversity but for healthy soil functioning.

Conflict of interest: Authors declare no competing interest.

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