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Land use impacts hydro-physical attributes of soil

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Abstract

The study was undertaken with an aim to assess the variability in hydro-physical properties of soil as influenced by divergent land use systems. It was anticipated that studied properties under natural systems are optimum for plant growth while cultivated systems might be experiencing deterioration in soil quality. To test this hypothesis, a soil survey comprising of 168 surface and sub-surface soil samples was conducted in zone I and II of Himachal Pradesh. The results aligned with the hypothesis and indicated that bulk density and particle density were lower in natural systems with 50 per cent of the samples below 1.26 and 2.58 g cm^{-3} in surface soils, respectively. Improved porosity (median, 51.2%) and water holding capacity (median, 45.0%) were also observed under natural systems. Conversely, sub-surface soils exhibited marginally higher bulk and particle densities, alongside markedly reduced mean porosity and WHC across all the land uses examined.

Keywords: Hydro-physical, intensive cultivation, land use, Soil health

Soil physical properties make up the framework of soil body and provides a base for external factors to influence its suitability for plant growth. Physical properties tend to vary depending on land use (Abera and Wolde-Meskel 2013) because of different soil management practices like soil disturbance frequencies, input additions, intensity of cultivation etc. Extensive studies have documented that land use transitions, whether bringing landscapes of natural vegetation to human use or altering management practices after a certain time span on farm lands, lead to short-or long-term soil health implications. In natural or semi-natural ecosystems *i.e*., forests and grasslands, cultivation and management disturbances are often minimal, allowing such ecosystems to keep the soils properties nearly optimal for plant growth. Conversely, in agro-ecosystems, frequent soil disturbances accelerate the disintegration of macro aggregates that limit the physical stabilization, ultimately leading to deteriorated soil health (Six *et al*. 1999; Chadha and Saini 2012). Over geological time scales, land forms and soils also undergo formation, alteration, and destruction due to natural forces. However, these changes in land use and land cover resulting from anthropogenic activities typically occur more rapidly over natural ones, exerting a significant impact on physical health of soil (Houghton et al. 1999). This made us anticipate that naturally growing systems will exhibit optimal physical conditions, the hydro-physical attributes of intensively cultivated lands might be facing deterioration. Therefore, the present investigation was carried out with the aim to study the variability in hydro-physical properties of soil in response of varied land use systems.

Materials and Methods

Study area and soil sampling

The present study was carried out in agro-climatic zones I and II of Himachal Pradesh where the soils are shallow and mean annual rainfall is generally high. Four locations were selected in these zones (Latitude 28.39°N to 32.10°N; Longitude 76.53°E to77.62°E) *viz*., Palampur, Sundernagar, Kullu, and Berthin. Predominant land uses of these zones were identified as agriculture (cereal, legumes and fodder cultivation), horticulture (orchards and vegetable cultivation), and

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natural systems (grasslands and forests). A total of 168 samples were collected from the surface (0-15 cm) and sub-surface (15-30 cm) soils of the predominant land uses. From each location, eighteen surface and sub-surface samples were collected from agricultural soils, twelve each from horticultural and natural systems. The collected samples were air dried, crushed in wooden pestle and mortar then passed through the 2 mm sieve and stored in polythene bags for soil analysis.The soil properties of the sites are given in Table 1.

Laboratory analysis

The processed soil samples were subjected to laboratory analysis and important soil physical properties were estimated using standard procedures. For optimum plant growth, soil bulk density should be below 1.40 g cm^{-3} (USDA-NRCS 2019), porosity should be above 47% (USDA-NRCS 2019) and water holding capacity should be in the range 35-45% (Hollar 1999).

The bulk density (BD) was determined through the core sampler technique as given by Piper (1966) and it was calculated by using equation (1):

$$BD\,(g\,cm^{-3}) = \frac{Mass\ of\ oven\ dry\ soil\ (g)}{Volume\ occupied\ by\ the\ soil\ solids\ (cm^{-3})} \quad (1)$$

The particle density (PD) was determined by the pycnometer method given by Blake (1965) and estimated by the formula given in equation (2):

$$PD\,(g\,cm^{-3}) = \frac{Mass\ of\ oven\ dry\ soil\ (g)}{Volume\ occupied\ by\ the\ soil\ solids\ (cm^{-3})} \quad (2)$$

Porosity was calculated by the equation (3) formulated by Hao *et al*. (2008):

$$Porosity\ (\%) = \left(\frac{Bulk\ density}{Particle\ density} \right) \times 100$$

Water holding capacity (WHC) was estimated using Keen -Raczkowski box method (Piper 1966) and was expressed in percent {Equation (4)}.

$$WHC\ (\%) = \frac{W_1\text{-}W_2\text{-}W_3\text{-}+(F_w\text{-}F_d)}{W_3} \times 100$$

where, W_1 stands for weight of keen box + wet saturated soil; W_2 for weight of Keen box + filter paper; W_3 for weight of total oven dry soil; F_w for weight of one wet filter paper; F_d for weight of one dry filter paper

Statistical analysis

The obtained data were subjected to descriptive statistics using Microsoft excel 2021 which followed the standard procedure detailed by Gomez and Gomez (1984). The data distribution across different land uses is represented in violin plots formed using online portal of Statistics kingdom (https://www.statskingdom.com/violin-plot-maker.html)

Results and Discussion

Bulk density under varied land uses

Bulk density varied widely across land uses and recorded lowest mean value of 1.24 and 1.36 g cm^{-3} in Palampur, 1.26 and 1.28 g cm^{-3} in Sundernagar, 1.23 and 1.29 g cm^{-3} in Kullu, and 1.26 and 1.38 g cm^{-3} in Berthin under surface and sub-surface soils of natural system, respectively (Table 2). No discernible trend was found in the variation of bulk density in agriculture and horticulture soils. The bulk density increased with soil depth and the respective increase in the soils of agriculture, horticulture, and natural systems were 7.5, 7.6, and 9.6% in Palampur; 6.8, 3, and 1.5% in Sundernagar; 5.4, 3.8, and 4.8% in Kullu; and 6.5, 6.7, and 9.5% in Berthin. Across all locations, Berthin registered maximum values of bulk densities in each land use with a range of 1.34-1.40 g cm^{-3} in surface soils of agriculture, 1.28-1.42 g cm^{-3} in horticulture and 1.20-1.31 g cm^{-3} in the soils under natural systems. Irrespective of locations, half of the samples from soils of agricultural systems had bulk density less than 1.32 and 1.42 g cm^{-3} in surface and sub-surface soils,

Table 1. Basic soil properties of the sampling sites

Property Site	pH	OC	Texture
Palampur	4.31-5.47	Medium-High	Silty clay loam
Sundernagar	5.11-6.00	Medium-High	Silty clay loam
Kullu	5.93-6.97	Medium-High	Silt loam
Berthin	6.16-6.52	Low-Medium	Silt loam – clay loam

Table 2. Effect of land use on bulk density (g cm^{-3}) of soil

Depth (cm)		0-15		15-30	
	Land use	**Range**	**Mean**	**Range**	**Mean**
Palampur	Agriculture	1.30-1.35	1.32	1.36-1.48	1.42
	Horticulture	1.27-1.36	1.31	1.35-1.48	1.41
	Natural system	1.16-1.32	1.24	1.20-1.49	1.36
Sundernagar	Agriculture	1.27-1.33	1.31	1.36-1.44	1.40
	Horticulture	1.29-1.36	1.32	1.35-1.42	1.39
	Natural system	1.16-1.32	1.26	1.16-1.36	1.28
Kullu	Agriculture	1.27-1.31	1.29	1.32-1.40	1.36
	Horticulture	1.27-1.36	1.30	1.31-1.41	1.35
	Natural system	1.09-1.30	1.23	1.22-1.34	1.29
Berthin	Agriculture	1.34-1.40	1.37	1.42-1.48	1.46
	Horticulture	1.28-1.42	1.36	1.40-1.48	1.45
	Natural system	1.20-1.31	1.26	1.20-1.47	1.38

respectively, as depicted by median in Figure 1. In horticultural systems, 50% of the surface and sub-surface samples exhibited bulk density below 1.32 and 1.40 g cm^{-3} while half of the samples in natural systems were below 1.26 and 1.32 g cm^{-3}, respectively.

Minimum bulk density can be attributed to higher organic matter content in natural systems (range – 0.97-2.03%) compared to cultivated ones (range – 0.44-1.1%) where residue retention is negligible. These results were in line with the findings of Celik (2005) that also showed lower bulk densities in pasture and forest soils compared to cultivated ones. The values of bulk density increased down the depth as the organic matter content and frequencies of disturbance were higher in the upper soil depths that most likely lowered the compaction in the surface soils. Franzluebbers (2002) also detailed decrease in bulk density in response to increased organic matter. Across all locations, maximum bulk density was reported in the soils of Berthin as this site has lower moisture regime and receives lower precipitation compared to others and intensive cultivation under sub-optimal moisture levels leads to soil compaction. The results corroborate with the findings of Upadhaya and Kishor (2019) who reported formation of hard pans when tillage was done at sub-optimum moisture levels.

Particle density under varied land uses

Irrespective of soil depth, the particle density ranged from 2.56-2.77 g cm^{-3} in Palampur, 2.46-2.69 g

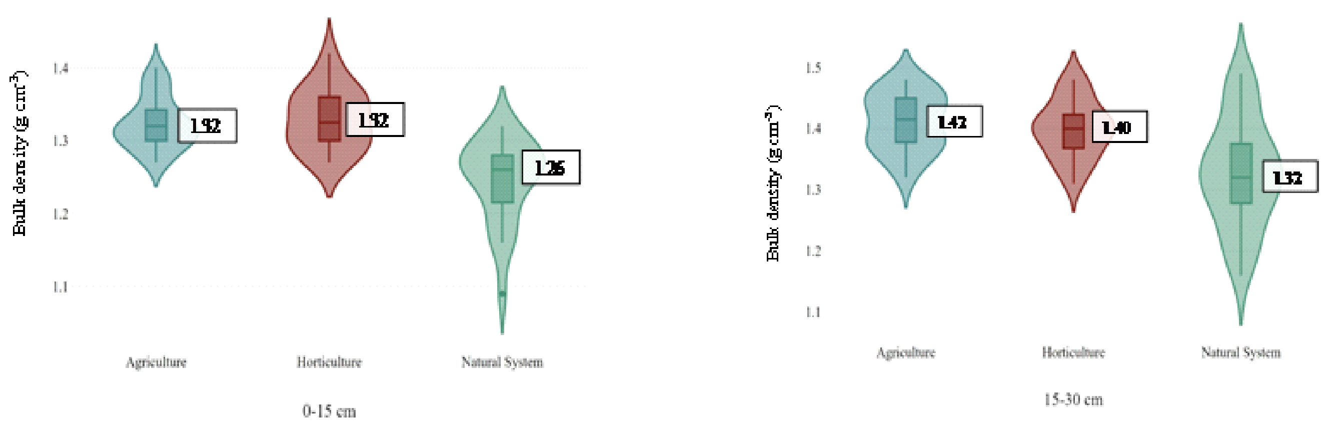

Fig. 1 Effect of land use on bulk density

cm^{-3} in Sundernagar, 2.41-2.68 g cm^{-3} in Kullu and 2.52-2.75 g cm^{-3} in Berthin. Particle density across land uses remained almost static (Table3) however, natural systems across all locations registered lower particle density compared to cultivated ones. The mean values in the surface soils of natural systems were 2.66, 2.54, 2.50, and 2.61 g cm^{-3} in Palampur, Sundernagar, Kullu, and Berthin, respectively. There was no discernible trend of particle density across soil depths. Half of the agricultural and horticultural soil samples had particle density below 2.61 g cm^{-3}, while in soils of natural systems; it was below 2.58 g cm^{-3} in 50% of the surface samples (Figure 2).

Particle density across land uses was low probably due to the reason that it depends on the mineralogy of the soil, which do not vary with management practices. Soils under natural systems recorded minimum bulk density likely due to higher organic matter content in the natural systems compared to cultivated ones. Present findings were in line with the results of Robinson *et al*. (2022) who also documented that organic matter decreases particle density.

Porosity under varied land uses

Porosity varied widely across land uses and maximum values were recorded in natural systems irrespective of locations. The range of porosity in surface soils of natural systems was 49.6-56.9% in Palampur, 48.2-52.8% in Sundernagar, 48.0-57.8% in Kullu and 49.3-52.8% in Berthin. No discernible trend was found in the variation of porosity in agriculture and horticulture soils. The porosity decreased with soil depth and the respective decline in the soils of agriculture, horticulture, and natural systems were 5.6, 5.2, and 7.8% in Palampur; 6.5, 4.1, and 0.3% in

Table 3. Effect of land use on particle density of soil

Depth (cm)		0-15		15-30	
	Land use	**Range**	**Mean**	**Range**	**Mean**
Palampur	Agriculture	2.61-2.72	2.67	2.63-2.75	2.67
	Horticulture	2.58-2.77	2.67	2.61-2.76	2.68
	Natural system	2.57-2.77	2.66	2.56-2.77	2.68
Sundernagar	Agriculture	2.50-2.68	2.58	2.50-2.69	2.60
	Horticulture	2.53-2.62	2.58	2.54-2.69	2.60
	Natural system	2.46-2.59	2.54	2.47-2.66	2.58
Kullu	Agriculture	2.50-2.60	2.56	2.51-2.68	2.58
	Horticulture	2.52-2.66	2.59	2.56-2.67	2.61
	Natural system	2.41-2.60	2.50	2.52-2.64	2.56
Berthin	Agriculture	2.61-2.75	2.67	2.62-2.75	2.69
	Horticulture	2.57-2.68	2.63	2.62-2.70	2.66
	Natural system	2.52-2.69	2.61	2.59-2.70	2.64

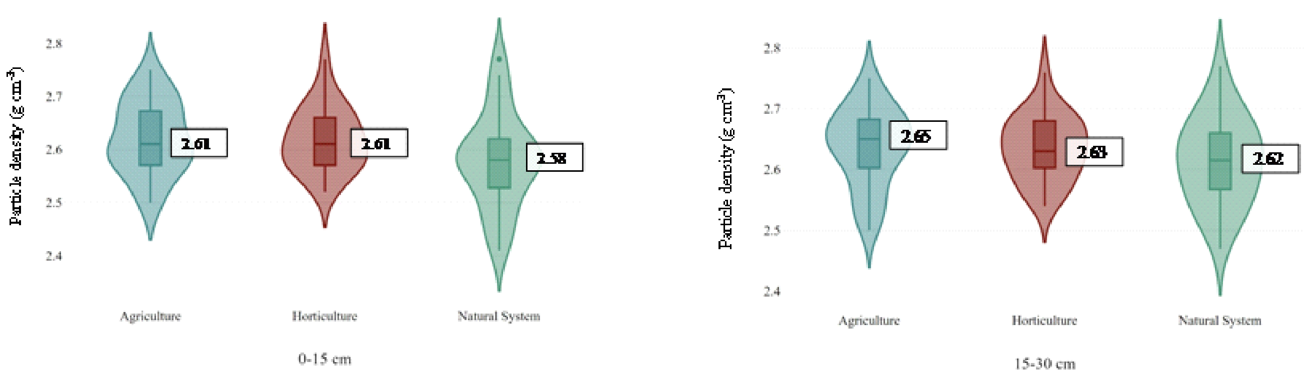

Fig. 2 Effect of land use on particle density

Sundernagar; 2.3, 2.6, and 2.3% in Kullu; and 5.9, 5.0, and 7.9% in Berthin. Half of the agricultural and horticultural soil samples had particle density below 49.3 and 49.2%, respectively, while in soils of natural systems, it was below 51.2% in 50% of the surface samples (Figure 2).The empirical formula for porosity is derived from the values of bulk density and particle density. Since, particle density is not a dynamic property in soil, variations in porosity are primarily due to changes in bulk density. Surface soils exhibited higher bulk density, leading to lower porosity due to their inverse relationship. Additionally, bulk density was lower in natural systems compared to cultivated ones, explaining the higher porosity observed in natural systems. Sekucia *et al*. (2020) reported higher porosity in meadows followed by forests, which strongly supports the present results. The decline in porosity with soil depth in the present study corroborated with the findings of Haghighi *et al*. (2010).

Water holding capacity under varied land uses

The water holding capacity showed huge variability across land uses (Table 4). The mean values in the soils under agriculture, horticulture and natural systems were 42.8, 42.5, and 46.3% in surface soils of Palampur, 39.5, 41.6, and 41.8% in Sundernagar, 41.7, 43.3, and 47.7% in Kullu and 37.7, 37.6, and 40.8% in Berthin. The highest porosity was recorded in natural system's soils across all locations while no discernible trend was found in the variation of water holding capacity in agriculture and horticulture soils. Irrespective of locations, half of the samples from soils of agricultural systems had WHC less than 40.2 and 37.9% in surface and sub-surface soils, respectively, as depicted by median in Figure 3. In horticultural systems, 50% of the surface and sub-surface samples exhibited WHC below 39.9 and 38.6% while in natural systems the median values were 45.0 and 39.7%.

The range of WHC in agricultural systems showed close conformity to the values reported by Choudhary

Table 4. Effect of land use on porosity of soil

Depth (cm)		0-15		15-30	
	Land use	Range	Mean	Range	Mean
Palampur	Agriculture	48.3-51.7	49.8	44.3-50.5	47.0
	Horticulture	47.5-51.7	50.0	43.8-49.7	47.4
	Natural system	49.6-56.9	53.4	41.9-54.8	49.2
Sundernagar	Agriculture	46.8-50.7	49.1	43.4-47.6	45.9
	Horticulture	46.2-50.6	48.5	44.1-49.8	46.5
	Natural system	48.2-52.8	50.5	47.6-56.5	50.3
Kullu	Agriculture	47.9-50.9	49.6	44.1-50.1	47.3
	Horticulture	48.8-51.3	49.6	46.5-50.0	48.3
	Natural system	48.0-57.8	50.9	47.9-53.8	49.7
Berthin	Agriculture	46.7-50.7	48.6	44.3-47.3	45.7
	Horticulture	46.4-50.3	48.0	44.8-46.9	45.6
	Natural system	49.3-52.8	51.7	43.2-54.5	47.6

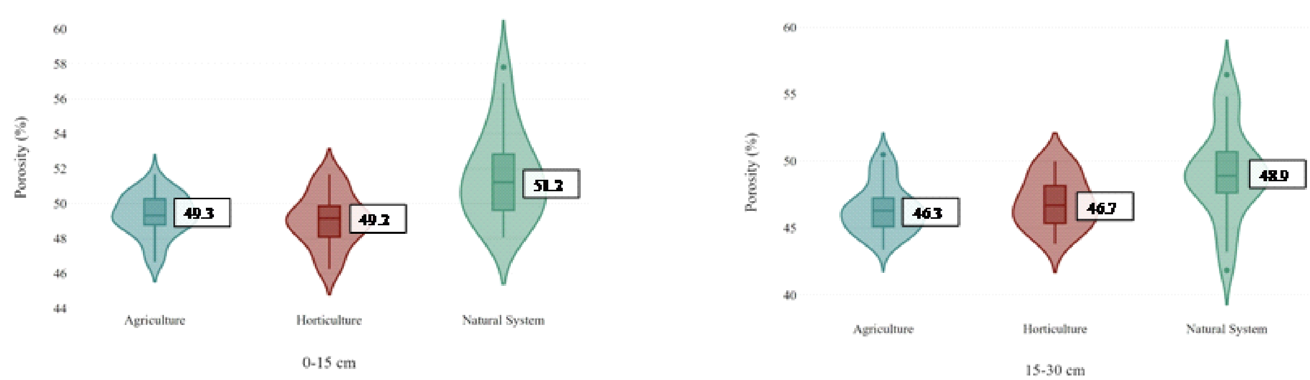

Fig. 3 Effect of land use on soil porosity

Table 5. Effect of land use on water holding capacity of soil

Depth (cm)		0-15		15-30	
	Land use	Range	Mean	Range	Mean
Palampur	Agriculture	37.8-48.5	42.8	37.5-43.3	40.8
	Horticulture	38.6-48.5	42.5	35.4-43.1	38.1
	Natural system	44.1-51.3	46.3	37.2-53.9	43.0
Sundernagar	Agriculture	32.4-44.5	39.5	31.9-40.0	35.5
	Horticulture	39.1-44.8	41.6	37.6-42.0	39.5
	Natural system	33.1-48.3	41.8	29.0-42.5	38.1
Kullu	Agriculture	34.7-46.4	41.7	34.3-44.8	39.3
	Horticulture	39.7-49.4	43.3	33.7-42.5	39.8
	Natural system	45.0-52.2	47.7	39.6-46.3	43.8
Berthin	Agriculture	31.4-45.4	37.7	33.6-40.5	36.7
	Horticulture	32.6-39.9	37.6	32.2-41.0	36.7
	Natural system	36.4-46.6	40.8	31.3-43.5	37.7

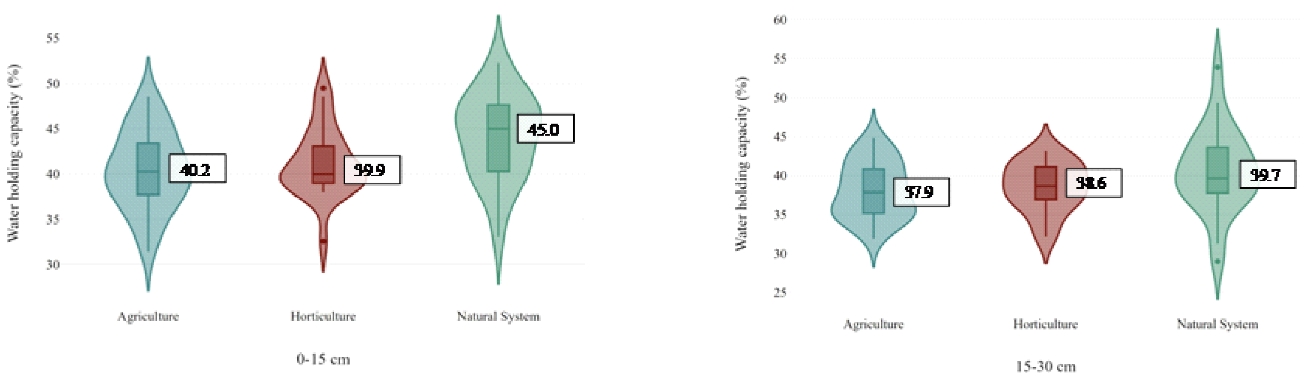

Fig. 4 Effect of land use on water holding capacity of soil

and Dixit (2021). Soil porosity is one of the key factors that affect water content and its retention in soil, thereby higher porosity in natural systems resulted in increased WHC in the same. Moreover, it is a well-documented fact that organic matter can retain water upto ten times of its weight, owing to charged surfaces that adheres water like static cling (Bhadha *et al*. 2017) which might have enhanced WHC in natural systems compared to cultivated ones. Jaswal *et al*. (2022) also registered higher moisture content in minimum tillage systems because of more residue retention. The present findings were underpinned by Acín Carrera *et al*. (2013) in which highest WHC was recorded in afforested soils compared to vineyards and abandoned lands owing to greater OC content in afforested soils.

Conclusion

Land uses significantly affected the hydro-physical properties of soil. Compared to cultivated systems (agriculture and horticulture), natural systems recorded lower bulk and particle densities; and higher porosity and water holding capacity indicating less compaction, higher water retention and more feasible conditions for plant growth. Our hypothesis was confirmed with the present investigation, as physical properties under natural systems were closer to optimum values compared to cultivated systems, which was in line with our anticipation.

Conflict of interest: Authors declare no competing interest.

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