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EXPLORING VARIATIONS IN PHOSPHORUS FRACTIONS OF SOILS UNDER VARIOUS LAND USE SYSTEMS

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ABSTRACT

The present investigation was undertaken to study phosphorous fractions in different land use systems of North Kashmir where, sixty soil samples from three land uses (agriculture, horticulture and forest) at two depths *i.e.*, 0-20 and 20-40 cm were collected. The samples were processed and analyzed for physical, chemical and biological properties and different inorganic phosphorous fractions. There was a significant difference in saloid-P fraction in different land uses and it was observed forest soils had highest saloid-P horticulture soils with lowest value. The mean value of saloid-P reported was 17.59, 14.61 and 14.58 mg kg⁻¹ at 0-20 cm soil depth and 16.90, 14.23 and 13.91 mg kg⁻¹ at 20-40 cm soil depth for forest, agriculture and horticulture soils respectively. Significant negative correlation of soil pH with saloid-P and Reductant soluble-P was noticed whereas significant positive correlation was found between soil pH and Ca-P. Aluminium bound Phosphorus (Al-P) was highest in case of agricultural soils with a mean value of 1.88 and 1.71 mg kg⁻¹ at a depth of 0-20 and 20-40 cm respectively and lowest in horticulture soils with a mean value of 1.54 and 1.43 mg kg⁻¹ at 0-20 and 20-40 cm respectively. In case of agricultural soils, concentration of Iron bound Phosphorus (Fe-P) was highest 15.58 (0-20 cm) and 14.32 mg kg⁻¹ (20-40 cm). Horticultural soils were found to have lowest Fe-P content 13.72 (0-20 cm) and 12.87 mg kg⁻¹ (20-40 cm). Reductant soluble phosphorus (Red-S-P) and Calcium bound Phosphorus (Ca-P) showed insignificant difference between different land uses. Phosphorus fractions had significant positive correlation among themselves except with Ca-P which showed significant negative correlation with all other fractions in agriculture and horticulture land uses. In forest soils significant positive correlation was found between S-P and Red-S-P while Ca-P had negative correlation with all other fractions. Population of Phosphate solubilizing bacteria in different land uses ranged from 28.70-6.10 cfu × 10⁵/g soil at 0-20 cm depth. Forest soils were found to have highest population with mean value of 28.70 cfu × 10⁵/g soil, followed by horticulture soils (11.70 cfu × 10⁵/g soil) while the lowest population (6.10 cfu × 10⁵/g soil) was reported in agriculture soils.

Key words: Phosphorous fractions, Phosphorus solubilizing bacteria, agriculture, horticulture, forestry, correlation.

Introduction

Phosphorus (P) is widely distributed in the Earth's crust, constituting approximately 0.12% by volume, and ranks as the 11th most common element on the Earth's surface (Schlesinger *et al.*, 2022). Its indispensability

arises from its role in crucial physiological and biochemical processes within every living cell. Phosphorus is a vital component of RNA, DNA, ATP, phospholipids, and is essential for energy transfer across diverse metabolic pathways (Walsh, 2020). It plays a crucial role in functions

such as cell division, enzyme activation/inactivation, carbohydrate metabolism, tillering, root development, early flowering, and ripening (Razak *et al.*, 2017). Consequently, the production of crops for food, feed, fuel, and fiber necessitates an adequate supply of phosphorus in the soil. Among the essential plant nutrients required in substantial amounts, phosphorus is of particular concern due to the accelerated depletion of this non-renewable resource to meet current demands, exacerbated by the escalating global demand for agricultural production in the coming decades (Cordell *et al.*, 2009; Gilbert, 2009).

Phosphorus stands as one of the most limiting nutrients for food production, with its deficiency attributed to inherent soil characteristics or strong sorption to Al and Fe-hydroxides, rendering a large portion of total soil P unavailable (Fageria *et al.*, 2017). Nutrient mining from low-input agriculture practices further compounds the issue. The limited availability of phosphorus in soil, primarily existing in unavailable forms due to its high chemical reactivity, underscores the critical need for efficient phosphorus utilization, given its significance as a nutrient for global food security. The adsorption rate of phosphorous experiences acceleration with an increase in ionic strength, and phosphorous may additionally be occluded within nanopores present in Fe/Al oxides, leading to reduced availability for plants (Arai and Sparks, 2007). In neutral-to-calcareous soils, phosphorous retention is primarily governed by precipitation reactions, although phosphorous can also undergo adsorption on the surfaces of Ca carbonate and clay minerals (Devau *et al.*, 2010). Precipitation with calcium results in the formation of dicalcium phosphate, which is moderately available to plants (Bashan *et al.*, 2013).

Further transformations of dicalcium phosphate into more stable and less accessible forms, such as octocalcium phosphate and hydroxyapatite (HAP), occur at alkaline pH (Arai and Sparks, 2007). The solubility of HAP increases with a decrease in soil pH (Wang and Nancollas, 2008), suggesting that lowering the pH in the rhizosphere (rhizosphere acidification) could be a strategic approach to enhance the mobility of soil phosphorous in calcareous soils. Organic phosphorous typically constitutes 30 to 65% of the total phosphorous content in soils, existing in stable forms such as inositol phosphates and phosphonates, as well as active forms, including orthophosphate diesters, labile orthophosphate monoesters, and organic polyphosphates (Turner *et al.*, 2002; Condon *et al.*, 2005). The release of phosphorous from organic sources occurs through mineralization, facilitated by various soil microbes and plant roots, often accompanied by the release of the phosphatase enzyme (Tian *et al.*, 2021).

Table A: Correlation between different fractions of Phosphorous and soil properties.

	Saloid-P	Al-P	Fe-P	Red-P	Ca-P
pH	-0.640**	(NS)	(NS)	-.649**	0.436*
EC	(NS)	0.734**	0.483**	(NS)	(NS)
OC	-0.410*	0.521**	(NS)	(NS)	(NS)
Sand	(NS)	-0.704**	-0.484**	(NS)	(NS)
Silt	(NS)	(NS)	-0.567**	(NS)	(NS)
Clay	(NS)	-0.750**	0.590**	(NS)	(NS)
Av.P	0.469**	-0.526**	(NS)	0.397*	(NS)

Chemical fractionation serves as a valuable method for discerning the predominant individual forms of inorganic phosphorous (P) in soils, encompassing easily soluble P, active forms such as P adsorbed on Al and Fe oxides (Al-P and Fe-P), and P associated with calcium (Ca-P) through secondary precipitation or native minerals like apatite (Welty-Bernard, 2014). It also identifies inactive forms like P occluded within the interiors of Al and Fe oxides (occl-Al-Fe-P) and reductant-soluble Fe-P (red-Fe-P). These distinct fractions exhibit notable variations in mobility, bioavailability, and chemical behavior in soils, undergoing transformations from one form to another under specific conditions (Adoma *et al.*, 2018). Understanding the abundance of these P forms, their interactions, and their relationships with various factors influencing P availability is crucial for sustainable soil P management. Consequently, this study will be conducted across different land use systems (Forest, Horticulture, Agriculture) in the district of Kupwara to evaluate the P status, quantify the distribution of different inorganic P forms, and analyze their associations with other soil properties. The findings will provide insights into the implications for future P management, emphasizing the importance of measuring specific inorganic P fractions to study the transformation of both applied and native P, influenced by fertilizer application, soil properties, and land use patterns.

Materials and Method

The present investigation was carried out in North Kashmir (Kupwara). “Kupwara” is situated at a distance of 90 kms from the summer capital of UT, *i.e.* Srinagar. The district lies between 34 17' to 34 12' North latitudes and 73 16' East longitudes and at an altitude of 5300 meter above level. Sixty soil samples from three land uses (agriculture, horticulture and forest) at two depths *i.e.*, 0-20 and 20-40 cm were collected. Available potassium was extracted using 1N neutral normal ammonium acetate and determined on flame photometer as described by Jackson (1973). The samples were processed and analyzed for physical, chemical and biological properties and different inorganic phosphorous

Table 1: Descriptive statistics of population of PSB ($\text{cfu} \times 10^5/\text{g}$ soil) under different land uses.

Land uses	Agriculture		Horticulture		Forestry	
Depth (cm)	0-20	20-40	0-20	20-40	0-20	20-40
Mean	6.1	5.8	11.7	9.1	28.7	23.3
Standard dev.	1.66	1.03	2.63	2.88	3.74	4.19
C. V %	27.2	17.7	22.4	31.6	13.03	17.9
95% C. I	5.07-7.13	5.16-6.44	10.07-13.3	7.3-10.8	26.3-31.02	20.7-25.9
Range	5	4	8	9	12	14
C. D (<0.05)	0-20 cm : 2.6			20-40 cm: 2.7		

fractions along with Population of Phosphorous solubilizing bacteria (PSB).

1. **Soil Physico-chemical properties:** Soil texture, Bulk density, Particle density, Porosity, Soil pH, Electrical conductivity (EC) and Organic Carbon
2. **Available Primary macronutrients:** Available Nitrogen, Phosphorous and Potassium
3. **Different Phosphorous fractions in soil:** Saloid bound phosphorous (saloid-P), Aluminium bound phosphorous (Al-P), Iron bound phosphorous (Fe-P), Reductant soluble phosphorous (Red-Sol-P) and Calcium bound phosphorous (Ca-P)
4. **Population of Phosphorous solubilising bacteria (PSB)**

Soils samples were analyzed for various physico-chemical properties such as soil pH and EC by the method described by Jackson (1973), organic carbon by the method outlined by Walkley and Black (1934). Bulk density and particle density of soil samples was analysed via tapping method by Jalota *et al.*, (1998) and pycnometer method by Gupta and Dakshinamoorthy (1980) respectively. Determination of available phosphorous was done as per the procedure given by Olsen *et al.*, (1958). Mechanical analysis of soil samples was done by hydrometer method by Bouyoucos (1927). Various inorganic fractions of phosphorous in soil samples were analyzed through then method given by Peterson and Corey (1966).

PSB population in various soil samples was determined through serial dilution pour plate technique given by Aneja (2001). The results under laboratory

conditions on various parameters were subjected to statistical analysis as per the method outlined by Gomez and Gomez (1984). Different inorganic P fractions such a saloid-P, Al-P, Fe-P, Ca-P and reductant soluble P were analysed by following the method given by Peterson and Corey (1966) analysed through ascorbic acid method using spectrophotometer. The results under laboratory conditions on various parameters were subjected to statistical analysis using analysis of variance (ANOVA) and data was analysed through SPSS and OP-STAT.

Results and Discussion

The physico-chemical properties of soil play a vital role in understanding the dynamics of different land uses. Soil reaction, electrical conductivity, organic carbon content, bulk density, particle density, porosity, and particle size distribution vary significantly across forest, horticulture, and agriculture soils. The pH tends to be moderately acidic to neutral, with forest soils exhibiting the lowest values. Electrical conductivity is influenced by land use practices, with agriculture soils showing higher values due to fertilizer application. Organic carbon content is highest in forest soils, attributed to high biomass production and lower decomposition rates. Bulk density is highest in agriculture soils, indicating soil compaction from machinery use. Particle density increases with depth, while porosity decreases, influenced by changes in organic matter content and bulk density. Particle size distribution follows the trend of forest > horticulture > agriculture, with variations in sand, silt, and clay content. Understanding these soil properties is crucial for sustainable land management practices across different ecosystems.

Table 2: Descriptive statistics of Saloid-P (mg kg^{-1}) under different land uses.

Land uses	Agriculture		Horticulture		Forestry	
Depth (cm)	0-20	20-40	0-20	20-40	0-20	20-40
Mean	14.61	14.23	14.58	13.91	17.59	16.9
Standard dev.	2.95	3.8	2.94	2.03	1.46	1.74
C. V %	20.1	26.7	20.1	14.5	20.1	14.5
95% C. I	12.78-16.4	11.8-16.5	12.7-16.4	12.6-15.1	116.6-18.5	15.8-17.9
Range	8.8	12.7	7.9	5.7	4.9	6.3
C. D (<0.05)	0-20 cm : 2.3			20-40 cm: 2.4		

Table 3: Descriptive statistics of Al-P (mg kg⁻¹) under different land uses.

Land uses	Agriculture		Horticulture		Forestry	
Depth (cm)	0-20	20-40	0-20	20-40	0-20	20-40
Mean	1.88	1.71	1.54	1.43	1.58	1.46
Standard dev.	0.49	0.4	0.28	0.22	0.19	0.22
C. V %	26.06	23.3	18.1	15.3	12.02	15.06
95% C. I	1.58-2.18	1.46-1.96	1.37-1.71	1.30-1.56	1.46-1.70	1.32-1.60
Range	1.6	1.4	0.8	0.7	0.6	0.7
C. D (<0.05)	0-20 cm : NS			20-40 cm: NS		

Correlation between different fractions of Phosphorous and soil properties

Significant negative correlation was observed in case of soil pH with saloid-P and Reductant soluble-P (Table A). Rai *et al.*, (2020) found similar negative correlation in case of soil pH with saloid and reductant soluble-P and soil pH did not show any significant relationship with Al-P and Fe-P. Sharma *et al.*, (1979) also observed similar relationship of soil pH with Al-P and Fe-P. Significant positive correlation was found between soil pH and Ca-P. Kothandaraman and Krishnamoorthy (1979) also reported a significant positive correlation between soil pH and Ca-P.

EC did not show any significant relationship with Saloid-P, reductant soluble-P and Ca-P. Significant positive correlation was found in case of EC with Al-P and Fe-P. These results were coinciding with the findings of Rai *et al.*, (2020). OC was found to have significant negative correlation with saloid-P, Al-P. Non-significant correlation was found in case of OC with Fe-P and reductant soluble-P and Ca-P. Rai *et al.*, (2020) reported non-significant correlation in case of OC with various fractions of Phosphorous.

Population of Phosphorous Solubilizing Bacteria (PSB) in soil

Population of PSB in soils under studied land uses tabulated in (Table 1) ranged from 28.70-6.10 cfu × 10⁵/g soil (0-20 cm depth). Forest soils recorded highest population with mean value of 28.70 cfu × 10⁵/g soil, followed by horticulture soils (11.70 cfu × 10⁵/g soil) while the lowest population of 6.10 cfu × 10⁵/g soil was found in agriculture soils. The substantial presence of organic

matter in forest soils plays a crucial role in fostering an increased population of native phosphate mineral solubilizing microbes, ultimately enhancing phosphorous availability (Vikram *et al.*, 2007). This observation aligns with similar findings reported by Kesumadewi (2015) and Wani *et al.*, (2018). PSB population declined down the depth with highest mean values in forest soils (23.30 cfu × 10⁵/g) soil and lowest in agriculture soils (5.80 cfu × 10⁵/g). The results corroborate with the findings of Panhwar *et al.*, (2013).

Inorganic Phosphorous fractions in soil

Saloid Phosphorous (saloid-P)

As per the data in Table 2 different land uses significantly affected the saloid-P fraction and it was observed that saloid-P was found highest in forest soils and lowest in horticulture soils with a mean value of 17.59, 14.61 and 14.58 mg kg⁻¹ at 0-20 cm soil depth and 16.90, 14.23 and 13.91 mg kg⁻¹ at 20-40 cm soil depth in case of forest, agriculture and horticulture soils respectively.

Aluminium bound Phosphorous (Al-P)

Data presented in Table 3 show that Al-P was highest in case of agricultural soils with a mean value of 1.88 and 1.71 mg kg⁻¹ at a depth of 0-20 and 20-40 cm respectively and lowest in horticulture soils with a mean value of 1.54 and 1.43 mg kg⁻¹ at 0-20 and 20-40 cm respectively. In case of forest soils a mean value of 1.58 and 1.46 mg kg⁻¹ was observed at 0-20 and 20-40 cm depth respectively. The difference in the values obtained under various land use systems were non-significant.

Iron bound Phosphorous (Fe-P)

Agriculture land use showed highest Fe-P and

Table 4: Descriptive statistics of Fe-P (mg kg⁻¹) under different land uses.

Land uses	Agriculture		Horticulture		Forestry	
Depth (cm)	0-20	20-40	0-20	20-40	0-20	20-40
Mean	15.58	14.32	13.72	12.87	15.48	14.28
Standard dev.	2.33	2.22	2.19	1.55	1.22	1.06
C. V %	14.9	15.5	15.9	12.04	7.8	7.4
95% C. I	14.1-17.0	12.9-15.7	12.36-15.08	11.9-13.8	14.7-16.2	13.6-14.9
Range	7.2	7.5	6.8	4.6	4.2	3.6
C. D (<0.05)	0-20 cm : NS			20-40 cm: NS		

Table 5: Descriptive statistics of R-S-P (mg kg^{-1}) under different land uses.

Land uses	Agriculture		Horticulture		Forestry	
Depth (cm)	0-20	20-40	0-20	20-40	0-20	20-40
Mean	15.92	15.01	14.51	13.31	16.74	15.9
Standard dev.	2.91	2.8	2.81	2.59	1.45	1.53
C. V %	18.2	18.6	19.3	19.4	8.6	9.6
95% C. I	14.1-17.7	13.2-16.7	12.7-16.2	11.7-14.9	15.8-17.6	14.9-16.8
Range	8.9	8.1	7.2	7.1	4.9	4.8
C. D (<0.05)	0-20 cm : NS			20-40 cm: NS		

Horticulture land use lowest. The mean values as mentioned in Table 4 were 15.58, 15.48, 13.72 mg kg^{-1} at 0-20 cm depth and 14.32, 14.28, 12.87 mg kg^{-1} at 20-40 cm depth in agriculture, forest and horticultural land use systems respectively.

Reductant Soluble Phosphorous (Red-S-P)

As shown in Table 5 Red-S-P was found highest in forest soils and lowest in horticulture soils but the difference was not significant. Mean value of 16.74, 15.92 and 14.51 mg kg^{-1} at 0-20 cm depth and 15.90, 15.01 and 13.31 mg kg^{-1} at 20-40 cm depth in case of forest, agriculture and horticulture soils respectively was observed.

Calcium bound Phosphorous (Ca-P)

The mean values of Ca-P are presented in Table 6, showing non-significant difference as affected by different land uses on the fractions of inorganic P.

In case of agriculture land use (at 0-20 cm depth) saloid phosphorous, calcium bound phosphorous and aluminium bound phosphorous have mean values of 14.61, 8.66 and 1.88 mg kg^{-1} respectively. Reductant soluble phosphorous dominated the soil with the mean value of 15.92 mg kg^{-1} followed by iron bound phosphorous (15.48 mg kg^{-1}). This might be due to slightly acidic pH of rice soils. Abolfazli *et al.*, (2012) revealed from a study on paddy soils that dominant P fraction in acidic soils were iron bound phosphorous (Fe-P) and aluminium bound phosphorous (Al-P) and in case of calcareous soils calcium bound phosphorous (Ca-P) was dominant. Laxminarayana (2007) reported from a study on rice soils of Mizoram that the various fractions followed

the order: Red-Saloid-P > Fe-P > Al-P > Ca-P > S-P. Uzu *et al.*, (1975) concluded that in case of flooded soils iron bound phosphorous (Fe-P) and Saloid phosphorous (Saloid-P) constitute the majority of inorganic phosphorous fractions.

Among different fraction of phosphorous in horticultural soils (at 0-20 cm) reductant soluble phosphorous dominated the soil with a mean value of 14.51 mg kg^{-1} and aluminium bound phosphorous least (1.54 mg kg^{-1}). Other inorganic fractions including saloid phosphorous, aluminium bound phosphorous and calcium bound phosphorous having the mean values of 14.58, 1.54 and 8.79 mg kg^{-1} , respectively. Rao and Chakroborty (1994) reported that P fractions were in the order of: R-S-P > Fe-P > Ca-P > Al-P > Saloid-P in tea growing soils of Himachal Pradesh. Saloid phosphorous was found to be more in case of agricultural soils as compared to horticultural soils. These findings were consistent with Ojo *et al.*, (2015). Rai *et al.*, (2020) concluded that calcium bound phosphorous was dominant fraction followed by saloid phosphorous, reductant soluble phosphorous, aluminium bound phosphorous and iron bound phosphorous in jetropha growing soils of Varanasi region (U. P.). In forest soils P fractions were in the order of Saloid-P > Red-P > Fe-P > Ca-P > Al-P with mean values of 17.59, 16.74, 15.48, 9.11, 1.58 mg kg^{-1} respectively. Yuan *et al.*, (2017) conducted a study on *Camellia oleifera* forests of Hunan province in China and reported that iron bound phosphate content was highest followed by aluminium bound phosphates and accounted for 38 and 31% of total P respectively, followed by Calcium bound phosphorous and Residual phosphorous.

Table 6: Descriptive statistics of Ca-P (mg kg^{-1}) under different land uses.

Land uses	Agriculture		Horticulture		Forestry	
Depth (cm)	0-20	20-40	0-20	20-40	0-20	20-40
Mean	8.66	8.07	8.79	8.35	9.11	8.81
Standard dev.	1.44	1.17	1.8	1.19	0.76	0.6
C. V %	16.6	14.4	20.4	14.2	8.3	6.8
95% C. I	7.77-9.55	7.34-8.80	7.68-9.90	7.62-9.08	8.6-9.5	8.4-9.1
Range	4.9	4.4	4.9	3.2	2.1	1.6
C. D (<0.05)	0-20 cm : NS			20-40 cm: NS		

Table 7: Correlation between different Phosphorous fractions in soil (general overview).

Fraction	Saloid-P	Al-P	Fe-P	Red-P	Ca-P
Saloid-P	1.00				
Al-P	(NS)	1.00			
Fe-P	0.40*	0.68**	1.00		
Red-P	0.90**	(NS)	0.52**	1.00	
Ca-P	-0.60**	-0.40*	-0.51**	-0.62**	1.00

Correlation between different fractions of Phosphorous and soil properties

Correlation between different inorganic Phosphorous fractions shown in Table 7 under different land uses systems have been shown in Table 8, Table 9, Table 10.

In case of agriculture soils (Table 6), Saloid-P showed significant positive correlation with Al-P ($r = 0.917^{**}$), Fe-P ($r = 0.826^{**}$), R-S-P ($r = 0.953^{**}$) and significant negative correlation with Ca-P ($r = -0.804^{**}$). Significant positive correlation was expressed by Al-P with Fe-P ($r = 0.726^{*}$), R-S-P ($r = 0.864^{**}$) and significant negative correlation with Ca-P ($r = -0.833^{**}$). Fe-P has significant positive correlation with R-S-P ($r = 0.919^{**}$) and significant negative correlation with Ca-P ($r = -0.880^{**}$). Significant negative correlation was observed between R-S-P and Ca-P (-0.860^{**}).

In case of horticulture soils (Table 7), significant positive correlation was observed in saloid-P with Al-P ($r = 0.922^{**}$), Fe-P ($r = 0.877^{**}$), R-S-P ($r = 0.924^{**}$) and significant negative correlation with Ca-P ($r = -0.902^{**}$). Significant positive correlation was expressed by Al-P with Fe-P ($r = 0.891^{**}$), R-S-P ($r = 0.870^{**}$) and significant negative correlation with Ca-P ($r = -0.896^{**}$). Fe-P has significant positive correlation with R-S-P ($r = 0.836^{**}$) and significant negative correlation with Ca-P ($r = -0.783^{**}$). R-S-P showed Significant negative correlation with Ca-P (-0.923^{**}).

In case of forest soils, Saloid-P showed significant positive correlation with R-S-P ($r = 0.855^{**}$) and significant negative correlation with Ca-P ($r = -0.832^{**}$). Significant negative correlation was expressed by Fe-P

Table 8: Correlation between different P-forms in agricultural soils.

Land use-01 Agriculture	Saloid-P	Al-P	Fe-P	Red-P	Ca-P
Saloid-P	1.00				
Al-P	0.917**	1.00			
Fe-P	0.826**	0.726*	1.00		
Red-P	0.953**	0.864**	0.918**	1.00	
Ca-P	-0.804**	-0.833**	-0.880**	-0.860**	1.00

Table 9: Correlation between different P-forms in horticulture soils.

Land use-02 Horticulture	Saloid-P	Al-P	Fe-P	Red-P	Ca-P
Saloid-P	1.00				
Al-P	0.92**	1.00			
Fe-P	0.87**	0.89**	1.00		
R-S-P	0.92**	0.87**	0.83**	1.00	
Ca-P	-0.90**	-0.89**	-0.78**	-0.92**	1.00

Table 10: Correlation between different P-forms in forest soils.

Land use-02 Forest	Saloid-P	Al-P	Fe-P	Red-P	Ca-P
Saloid-P	1.00				
Al-P	0.92**	1.00			
Fe-P	0.87**	0.89**	1.00		
R-S-P	0.92**	0.87**	0.83**	1.00	
Ca-P	-0.90**	-0.89**	-0.78**	-0.92**	1.00

with Ca-P ($r = -0.724^{**}$). Significant negative correlation was observed between R-S-P and Ca-P (-0.766^{**}).

All the P fractions showed significant positive correlation with other fractions of P except calcium phosphates which showed significant negative correlation with all other fractions in agriculture and horticulture land uses (Raiesi *et al.*, 2017). In forest soils significant positive correlation was found between saloid phosphorous and reductant soluble phosphorous and calcium phosphate was found to have significant negative correlation with all other fractions of phosphorous. Gupta *et al.*, (2023), Gupta *et al.*, (2020), Devra *et al.*, (2014), reported existence of similar correlation among various fractions of phosphorous. Ahmed *et al.*, (2019), Prajapati & Pattanayak (2019) showed that all the fractions of phosphorous are correlated with one another.

Available P was found to have significant positive correlation with saloid-P and reductant soluble-P. Singh and Pathak (1973) reported significant and positive relationship between reductant soluble-P and available P in surface soils of UP. Gupta *et al.*, (2023), Patil (2020) reported non-significant positive correlation in case of available P with saloid and reductant soluble-P. No significant correlation was found in case of available P with Fe-P and Ca-P. Ma *et al.*, (2019) confirmed these results.

Conclusion

The study found no significant differences in various phosphorous fractions (Al-P, Fe-P, Ca-P) across different land uses. However, saloid phosphorous showed

significant variations, with the highest values in forests and the lowest in horticulture. Significant correlations were observed between phosphorous fractions in agriculture and horticulture, while forest soils exhibited specific correlations, notably between Red-P, Saloid-P, and Ca-P. Additionally, the phosphate-solubilizing bacteria (PSB) population ranked highest in forests, followed by horticulture and agriculture. These findings highlight the nuanced nature of phosphorous dynamics in different land use contexts, providing valuable insights for sustainable soil management practices.

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