International Journal of Environment, Agriculture and Biotechnology
Vol-11, Issue-4; Jul-Aug, 2026
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Phosphorus and Potassium Fixation-Resurgence rates for diverse Land Uses of Temperate Himalayas

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Received: 05 Jul 2026; Received in revised form: 02 Aug 2026; Accepted: 10 Aug 2026; Available online: 17 Aug 2026

***Abstract*— *The research was commenced to sought and evaluate the fixation and recovery rate dynamics of phosphorus and potassium across distinct land uses, shedding light on the relationship between these patterns. Soil samples were gathered at a depth of 0-15 cm from three land-use categories viz., Forest, Agriculture, and Horticulture, within the Ganderbal district of the temperate Himalayas. A total of 75 soil samples were collected from various locations for analysis. The results from different analysis revealed that the soils were slightly acidic to neutral in reaction and soil texture varied from silty clay loam to silt loam. The highest mean value of bulk density (1.44 g cm^{-3}) was recorded in grapes and rice soils, highest mean value of particle density (2.54 g cm^{-3}) was recorded in grapes soils and lowest (2.33 g cm^{-3}) in forest soils. Porosity was observed highest (44.14%) in forest soil. No salinity hazards were observed as electrical conductivity values among studied land uses were less than 1 dSm^{-1}. The soil organic carbon was found highest (1.66 %) in forest soils and lowest (1.06 %) in apple soils. The cation exchange capacity was observed highest mean value (15.47 Cmol (+) kg^{-1}) in rice soils and lowest (14.27 Cmol (+) kg^{-1}) in forest soils. The findings revealed noteworthy differences in phosphorus and potassium fixation and recovery rates among the land-use types. Phosphorus fixation rate was found to be highest in forest areas, reaching 66%, while the lowest fixation rate was observed in Apple orchards at 38%. Intriguingly, the recovery rate of phosphorus exhibited an inverse pattern, with the highest recovery observed in Apple orchards at 62%, and the lowest in Forest areas at 34%. Similarly, for potassium, Forest and orchards exhibited the highest fixation rate at 58%, contrasting with Maize, which had the lowest fixation rate at 46%. The recovery rate of potassium demonstrated a similar trend, with the highest recovery rate occurring in Maize at 62%, and the lowest in Forest orchards at 42%. These findings underscore the intricate interplay between land use and nutrient dynamics, providing valuable insights for sustainable land management practices in the Ganderbal district.*

***Keywords*— phosphorus, potassium, Fixation, Availability, Recovery.**

I. INTRODUCTION

Potassium is an important plant nutrient in soils, as it plays a role in a variety of physiology and biochemical functions that affect plant development and output. Soil test finding for potassium fertility status in Indian states among agriculture soil are divided into three categories: 21% low, 51% medium and 28% high. As a result, 72% of India's agricultural land requires rapid potassium fertilization (Rehanul Hasan, 2002). Phosphorus (P) is an essential soil component for plant growth and development. However, because of the fixation, its supply is limited. The soil pH range is considered to be most critical for the phosphorus fixation after which the preponderance of Aluminium (Al) and iron (Fe) oxides in both crystalline and amorphous forms is considered to be important. Under some situations, phosphorous and potassium fixation is clearly deleterious to crop consumption of phosphorus and potassium fertilizers. Phosphorus and potassium fixation in soils is influenced by soil pH, clay concentration, organic matter content and colloid mineralogical composition (Chatterjee *et al.,* 2014). Most of the added nutrients to soils, particularly phosphorus (P) and potassium (K), are fixed in soil in temporarily plant-unavailable forms (Kanwar, Goswami and Kamath 1982). The type and extent of these fixation reactions in soil are influenced by a number of factors such as soil pH, type and amount of clay and chemical composition of soil (Shaviv *et al.,* 1985). The potassium fixation research gives accurate information on the rates of added potassium response between distinct phases of soil potassium and the density of an applied fertilizer K. This process is crucial because it not only regulates the dynamics of various forms of potassium in soil, but it also signals the soil's ability to provide long-term potassium to plant. Phosphorus fixation is a process whereby the readily available forms of phosphorus are changed to sparingly soluble ones by reacting with inorganic and organic components of soil. It involves a series of reactions that remove phosphorus from the soil solution and render it unavailable for plants.

II. MATERIAL AND METHODS

Soils

Surface soil samples (0-20cm) were collected from different land uses viz., Forest, Grapes, Apple, Rice and Maize, of district Ganderbal and from each land use a total of fifteen soil samples were collected. The processed soil samples were used for laboratory studies. The samples were analyzed for various physical properties like Texture, Bulk density, particle density, porosity and Hydraulic conductivity. The chemicals properties investigated included pH, EC, OC, CEC, $CaCO_3$. The important available nutrients were also investigated like Nitrogen, Sulphur, calcium and magnesium.

Phosphorous fixation and Recovery studies

Surface soil samples (2 gm) were equilibrated with 2 ml of 0.01 M calcium chloride (CaCl2) solution containing graded levels of mono calcium phosphate [Ca(H2PO4) 2.H2O]. The phosphorus levels used were 0, 50, 100, 200, 400, 800 and 1600 mg phosphorus kg^{-1} soil. Two drops of toluene were added to each flask and incubated for 96 h at room temperature (25°C). After incubation, phosphorus was extracted by Olsen's method. The phosphorus concentration in the soil extracts was determined in the aliquot calorimetrically by the ascorbic acid method. Fixed phosphorus was determined by the difference between the initial and the equilibrium phosphorus concentrations.

Potassium fixation and Recovery studies:

Samples (2 g) of each of surface soil (0-20 cm depth) were incubated with 2 mL of potassium solution with varying levels for 72 hours at room temperature. The potassium levels used were 0, 50, 100, 200, 400 and 800 mg potassium kg^{-1} soil. After incubation, 8 mL of 1 N ammonium acetate solution was added and shaken for 5 minutes and potassium was estimated by flame photometer in the filtrates. The fixed potassium was computed using the following formula:

-fixed = potassium applied - (Extractable potassium in treated soil - extractable potassium in control soil)

Statistical Analysis

Statistical analysis was done by standard procedures. The least square regression equation was used for modelling. Value of coefficient of determination (R^2) was chosen as the criteria of goodness of fit. The data collected on various parameters during investigation was statistically processed (using R software and Microsoft Excel) and analyzed according to the procedures outlined by Panse and Sukhatme (1978).

III. RESULTS AND DISCUSSION

Soil properties

The texture of the soils of study area varied from silty loam to silty clay loam. Higher concentration of silt in the surface soils of this land use system was obviously due to the impact of precipitation, snow melt and temperature on these soils that might have resulted in soil erosion and loss of humus. The results are corroborated by the findings of Yang *et al.* (2019) who also reported higher silt in surface soils of forests. Bulk density reflects the soil's compaction level and affects its porosity, aeration and water infiltration rates. Lower bulk density generally indicates looser soil, which is beneficial for root growth and microbial activity. In this study, the bulk densities ranged from 1.29, 1.44, 1.42, 1.44 and 1.38 g cm^{-3} forest, grapes, apple, Rice and maize, respectively. Suggesting a moderately loose soil structure conducive to healthy plant and microbial life.(Table 1)

Similar results were found by Woldeamlak and Stroosnijder (2003), Semahugne (2008), Singh and Khera (2008), Gupta *et al.* (2010), Sofi *et al.* (2012), Sharma *et al*. (2013), Yitbarek *et al.* (2013), Osakwe and Igwe

(2013), Abad (2014) and Ali *et al.* (2014). The overall particle density ranged from 2.33-2.54 g cm^{-3} in all locations. The highest mean value of particle density (2.54 g cm^{-3}) was found in Grapes and lowest value (2.33 g cm^{-3}) was found in forest. Higher particle densities in grape and apple orchards suggest soils richer in minerals, which could affect water and nutrient holding capacities. similar results were found by Gupta *et al*. (2010). The final data suggested that the mean value of porosity ranged from 41.32 to 44.14 per cent in the studied locations. The highest mean value of porosity (44.14 per cent) was recorded in soil of forest.

Soil porosity, directly related to bulk and particle density, affects the movement of air and water within the soil. Higher porosity generally allows better root penetration and microbial activity. The results are in conformity with the findings of Regmi *et al.* (2004). The data indicated that the mean value of Hydraulic conductivity was 1.73, 1.39, 1.18, 1.37 and 1.1.22 cm hr^{-1} in forest, grapes, apple, rice and maize, respectively.

Hydraulic conductivity measures the ease with which water can move through soil pores. Values ranged from 1.00 to 2.65 cm/hr^{-1} across the studied land uses, affecting irrigation strategies and water management practices. Higher conductivity in forest and grape orchards allows for more efficient water usage, which is critical in regions requiring precise moisture management. The variability could be due to clay mineralogy, pore size distribution and pore continuity, moisture availability and particle size distribution and organic carbon content and biotic activity (Sarki *et al*., 2014). Soil pH varied widely, affecting nutrient solubility and microbial activities. The pH ranged from slightly acidic in rice fields (average pH 6.47) to mildly alkaline in apple orchards (average pH 7.14). Such variations require tailored management strategies to optimize nutrient availability, particularly for phosphorus, which becomes less soluble in alkaline conditions.

The soils were slightly acidic to neutral in reaction which may be due to high rainfall which results in leaching of salts from upper layers and higher organic matter content, which reduces pH by releasing organic acids. Excess leaching of bases from the soil profile due to heavy rainfall might have caused acidity in these soils (Sharma and Singh, 2002). The variation may also be attributed to the amount of clay and organic matter in the soil. These results are in agreement with the findings of Bhat (2009), Sharma (2013) and Bashir *et al.* (2016). EC readings indicated varying levels of soil salinity, with higher mean values in apple soil (0.30 dSm^{-1}) suggesting potential issues with salinity management. Salinity affects nutrient ion competition at root absorption sites, impacting particularly the efficiency of potassium uptake.(Table 2)

However, the electrical conductivity was within the normal range across different land use systems as value were less than 1 dSm^{-1} and do not impact most crops and soil microbial processes. The low electrical conductivity may be due to leaching of soluble salts to lower soil depths resulting from heavy precipitation in soils. The differences in electrical conductivity under different land uses may be attributed to soil management practices and altitudinal variation. These results are in conformity with the results of Dhale and Prasad (2009) and Parihar *et al.* (2013). Organic carbon content was highest in forest soils (average 1.66%) and influenced soil structure and fertility. While beneficial for water retention and nutrient supply, high organic carbon also increases phosphorus fixation, presenting challenges for phosphorus management.

The higher amount of organic carbon in high altitudes may be due to plant biomass, litter quality and climatic factors like temperature, precipitation etc. Because of low temperatures at high altitudes are likely to limit decomposition and other soil processes, researchers have proposed that soil organic carbon (C) concentration may increase while as low values in lower altitudes owe to rapid mineralization and loss of carbon from soils (Sundqvist *et al*., 2013). These results are in conformity with the findings of Bhat (2009), Pal *et al*. (2013). Among the soil chemical properties, CEC was a key indicator of nutrient retention capacity, with higher mean values in rice fields (15.47 cmolc/kg^{-1}) suggesting better nutrient retention capabilities. This is crucial for sustained nutrient availability and reduced leaching. The higher content of cation exchange capacity can be ascribed to higher organic matter content and clay. Wani *et al*. (2010) also reported a higher range of cation exchange capacity in soils attributed to their corresponding high content of organic matter and clay. The calcium carbonate content in surface soil layers under different land uses varied from 0.13 to 0.90 per cent with a mean value 0.32 per cent in forest, 0.28 to 0.63 per cent with a mean value of 0.48 per cent in grapes, 0.52 to 0.68 per cent with a mean value of 0.59 in apple, 0.44 to 0.67 per cent with a mean value of 0.56 in rice and 0.40 to 0.69 per cent with a mean value of 0.0.58 in horticulture.(Table2)

Calcium carbonate content in forest land use was almost negligible which might be due to low precipitation of calcium carbonate by physiological processes which are not typically favored in acidic environments (Niu *et al.,* 2015). The data revealed that the mean value of available nitrogen content in surface soils under different land uses varied from 333.87 Kg/ha, 318.88 Kg/ha, 336.10 Kg/ha, 309.53 Kg/ha and 307.34 Kg/ha in forest, grapes, apple, rice and maize, respectively. The highest mean values were found in forest 333.87 Kg/ha and lowest available mean value present in maize, 307.34 Kg/ha. This could be related to the influence of higher organic matter as well as enhanced enzymatic activities, mineralization and mobilization of nitrogen and greater amount of humus in natural forests in comparison to cultivated soils. The results are in agreement with the findings of Regmi and Zoebisch (2004), Yimer *et al*. (2007), Yitbarek *et al*. (2013), Yihenew *et al*. (2015). The data revealed that the available phosphorus content in surface soils under different land uses varied from 17.94 to 23.23 Kg hac^{-1} with a mean value 20.99 Kg hac^{-1} in forest, 14.46 to 21.68 Kg hac^{-1} with a value of 17.70 Kg hac^{-1} in grapes, 13.63 to 22.11 Kg hac^{-1} with a mean value of 17.75 in apple, 12.66 to 20.86 Kg hac^{-1} with a mean value of 16.56 Kg hac^{-1} in rice soils and 12.45 to 21.02 per cent with a mean value of 16.23 Kg hac^{-1} in maize soils.

Available phosphorus levels are crucial for energy transfer in plants. Variability in available phosphorus across land uses highlights the need for custom-made phosphorus management strategies to address specific soil conditions and crop needs.

This could be due to the application of Diammonium phosphate (DAP) fertilizer on the cultivated land may have resulted in the increase of phosphorus in the soil in line with the explanation made by Woldeamlak (2003) and Gebeyaw (2007). And high content of OM in case of forests which releases organic anions on decomposition and form chelates with Fe and Al and make the phosphorus available. The results were in conformity with the studies of Najar (2002), Regmi and Zoebisch (2004), Dwivedi *et al.* (2005), Kumar *et al.* (2006), Yihenew *et al.* (2015). The data showed that the mean values of Available potassium of the studied locations was 198.29, 187.76, 185.21,164.27 and 157.92 kg/ha in forest, grapes, apple, rice and maize soils, respectively. Among different locations the highest mean value (198.29 kg/ha) was found in forest and lowest value (157.92 kg/ha) in maize. Potassium is found in medium range in almost all the sites in all land use systems as found by Gupta *et al.* (1977), he also found that soils of Kashmir have illite as its dominant mineral which is rich in potassium, however due to intensive cultivation in case of irrigated agriculture which leads to removal of potassium and formation of organic complex's with clay in forests and makes potassium available. The results were similar with the studies of Alemayehu (1990), Singh *et al.* (2012), Regmi and Zoebisch (2004), Kiflu and Beyene (2013), Gandhe Aparna (2015). The data showed that the mean values of available Ca of the studied locations was 1353.06, 1366.53, 1339.18, 798.17 and 828.07 mg kg^{-1} in forest, grapes, apple, rice and maize soils, respectively. Among different locations the highest mean value (1366.53 mg kg^{-1}) was found in grapes and lowest value (798.17 mg kg^{-1}) in rice soils. The mean values of magnesium among studied land uses exhibited a range from 344.10, 306.19, 303.76, 106,12 and 107.75 mg kg^{-1} in forest, grapes, apple, rice and maize soils, respectively. Among different locations the highest mean value (344.10 mg kg^{-1}) was found in forest and lowest value (106.12 mg kg^{-1}) in rice soils. Calcium and magnesium are important for plant structure and photosynthesis, respectively. The availability of these nutrients varied across land uses, affecting crop health and productivity. Managing their levels is crucial for optimizing plant growth and ensuring balanced nutrient uptake. The results were similar with the studies of Dudal and Decaers (1993), Gebrelibanos and Assen (2013). The data presented in the Table** revealed that the Available sulphur ranged 10.92 to 16.63 Kg hac^{-1} in forest, 8.21 to 10.83 in grapes, 8.41 to 11.02 Kg hac^{-1} in apple, 8.71 to 13.42 Kg hac^{-1} in rice and 8.71 to 13.49 Kg hac^{-1} in maize soils. Lowest available sulphur was present in grapes and highest was seen in forest. Sulphur is essential for protein synthesis and enzyme function in plants. The levels of available sulphur were adequate across the land uses, supporting healthy plant growth and development. It may be due to high amount of OM in forests as compared to agri-horticulture and intense cultivation of pulses and vegetables which leads to removal of more sulphur for protein synthesis. The results were similar with the studies of Farida *et al.* (2008), Sharma *et al.* (2013).

Table 1 Physical Characteristics of Land Uses of District Ganderbal

Location Mean	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	Predominant Textural class	BD (gcm^{-3})	PD (gcm^{-3})	Porosity (%)	Hydraulic Conductivity (m/s)
Forest	3.26	28.12	50.89	17.33	Silt Loam	1.29	2.33	44.14	1.73
Grapes	1.50	33.25	40.64	24.71	Loam	1.44	2.54	42.94	1.39
Apple	1.56	20.77	51.47	26.33	Silt Loam	1.42	2.52	44.09	1.18
Rice	1.19	29.56	33.89	35.35	Clay Loam	1.44	2.45	41.32	1.37
Maize	1.09	34.20	31.03	33.77	Clay Loam	1.38	2.46	43.93	1.22

Table 2 Chemical Characteristics of Land Uses of District Ganderbal

Location Mean	pH (1:2.5)	EC (dSm^{-1})	OC (%)	CEC ($cmol^{+}$ kg^{-1})	CaCO3 (%)	Av. N (Kg/ha)	Av. P (Kg/ha)	Av. K (Kg/ha)	Av. Ca (mg/kg)	Av. Mg (mg/kg)	Av. S (mg/kg)
Forest	6.71	0.18	1.66	14.27	0.32	333.87	20.99	198.29	1353.06	344.10	12.77
Grapes	6.92	0.15	1.46	15.36	0.48	318.88	17.70	187.76	1366.53	306.19	9.81
Apple	7.14	0.30	1.06	15.28	0.59	336.10	17.75	185.21	1339.18	303.76	09.81
Rice	6.47	0.24	1.34	15.47	0.56	309.53	16.56	164.27	798.17	106.12	10.46
Maize	7.20	0.24	1.32	15.00	0.58	307.34	16.23	157.92	828.07	107.75	10.83

Fixation and Recovery Rate Patterns of Phosphorous and Potassium under Different Land Uses

Phosphorous

Phosphorus fixation rates were notably high in forest soils, reaching up to 66.13% at higher concentrations, indicating a significant amount of applied phosphorus becomes chemically inactive and unavailable to plants. In contrast, agricultural lands, particularly apple orchards, showed higher recovery rates of up to 62%, likely due to lower fixation rates and more effective management practices enhancing phosphorus availability. These observations are consistent with the findings of C. Srinivasarao *et al*. (2007) Rashmi *et al*. (2019).

Potassium

Potassium exhibited generally lower fixation rates across all land uses compared to phosphorus, with the highest fixation rate in forest soils being about 58%. The recovery rates of potassium were highest in grapes fields, reaching up to 54%, demonstrating that agricultural management practices are effectively enhancing the bioavailability of potassium. These observations are consistent with the findings of C. Srinivasarao *et al*. (2007) Rashmi *et al*. (2019).

Relationship Between Fixation and Recovery Rate Patterns of Phosphorous and Potassium with Soil Properties

The study highlighted a strong negative correlation between phosphorus fixation and CEC, with a correlation coefficient of -0.8245**. This indicates that soils with higher CEC tend to have lower phosphorus fixation rates, enhancing the availability of phosphorus for plant uptake. This relationship underscores the importance of CEC in influencing nutrient dynamics, where higher CEC can improve nutrient retention and availability, reducing the need for frequent fertilization.

For potassium, the relationship between EC and recovery rates (correlation coefficient of 0.9420*) suggests that soils with higher EC, indicative of higher soil salinity, have better potassium mobility and availability, highlighting the need for precise salinity management to optimize nutrient dynamics. These observations are consistent with the findings of C. Srinivasarao *et al*. (2007) Rashmi *et al*. (2019).

Table 3 Recovery of phosphorus Fixation and unit fertilizer rate required for unit increase in available nutrient in different Land Uses of Ganderbal

Phosphorus	R^2	Equation connecting increase in available phosphorus added phosphorus	P recovery rate/unit	P fixation rate/unit	Unit fertilizer phosphorus rate required per unit increase in available phosphorus
Forest	0.7173	Y=0.3448x +0.0379	0.34	0.66	2.90
Apple	0.9454	Y=0.6195x - 0.0029	0.62	0.38	1.61
Grapes	0.9532	Y=0.5021x +0.0146	0.50	0.50	2.00

Rice	0.8706	Y=0.5638x +0.0081	0.56	0.44	1.77
Maize	0.8809	Y=0.6084x +0.0062	0.61	0.39	1.64

Table 4. Recovery of potassium Fixation and unit fertilizer rate required for unit increase in available nutrient in different Land Uses of Ganderbal

Potassium	**R^2**	**Equation connecting increase in available potassium added K**	**K recovery rate/unit**	**K fixation rate/unit**	**Unit fertilizer potassium rate required per unit increase in available K**
Forest	0.809	Y=0.4232x++4.2007	0.42	0.58	2.36
Apple	0.5005	Y=0.2716x+8.4604	0.27	0.73	3.68
Grapes	0.9273	Y=0.5397x+1.3848	0.54	0.46	1.85
Rice	0.969	Y=0.4656x+1.3144	0.47	0.53	0.15
Maize	0.9536	Y=0.494x+0.7662	0.49	0.51	2.02

Correlation coefficient between soil parameters and various phosphorus and potassium parameters in different land use systems

In the analysis of soil parameters and their correlation with nutrient dynamics, the table presents a moderately positive correlation between soil pH and the phosphorus recovery rate per unit (0.3113), suggesting that higher soil pH modestly improves phosphorus uptake. However, organic carbon content shows a moderate negative effect on phosphorus recovery (-0.4304), indicating that as the soil's organic carbon increases, the efficiency of phosphorus recovery decreases. The cation exchange capacity (CEC) of the soil exhibits a strong positive correlation (0.8245**) with phosphorus recovery, signifying that soils with higher CEC are more effective in recovering phosphorus.

Conversely, phosphorus fixation rates present a direct negative relationship with these parameters, mirroring the recovery rates. Notably, CEC has a strong negative correlation (-0.8245**) with phosphorus fixation, suggesting that soils with greater CEC have reduced phosphorus fixation, thus retaining less unusable phosphorus.

For the potassium dynamics, there is a slight positive correlation with pH (0.2108) and a very strong positive correlation with electrical conductivity (EC, 0.9420*), highlighting the significant role of EC in potassium recovery. Organic carbon inversely affects potassium recovery with a moderate negative correlation (-0.6023), suggesting that higher organic matter may lower the efficiency of potassium recovery.

Furthermore, the table indicates that soils with lower EC are more likely to increase potassium fixation, as evidenced by the strong negative correlation with EC (-0.9420*). Finally, the unit fertilizer rate needed for increasing the availability of potassium is negatively influenced by EC (-0.8740**) and positively by OC (0.4558), pointing to a higher demand for potassium fertilizer in soils with lower conductivity and higher organic carbon.

The correlation values are statistically significant where marked with asterisks, confirming the reliability of these relationships. These insights are essential for tailoring fertilizer applications to optimize nutrient use and enhance crop yield, considering the specific soil conditions of different land use systems.

Table 5 Correlation coefficient between soil parameters and various phosphorus and potassium parameters in different land use systems

Particulars	pH	EC (dSm^{-1})	(OC %)	CEC (cmol kg^{-1})
Phosphorus recovery rate/ unit	0.3113	-0.0144	-0.4304	0.8245 **
Phosphorus fixation rate/ unit	-0.3113	0.0144	0.4304	-0.8245 **
Unit fertilizer Phosphorus rate required per unit increase in available Phosphorus	-0.3037	-0.1079	0.5406	-0.8865 *
Potassium recovery rate/ unit	0.2108	0.9420 *	-0.6023	-0.0083
Potassium fixation rate/ unit	-0.2108	-0.9420 *	0.6023	0.0083
Unit fertilizer Potassium rate required per unit increase in available Potassium	-0.1164	-0.8740 **	0.4558	0.1404

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The correlation values are statistically significant where marked with asterisks, confirming the reliability of these relationships. These insights are essential for tailoring fertilizer applications to optimize nutrient use and enhance crop yield, considering the specific soil conditions of different land use systems.

IV. CONCLUSION

The study revealed that land use significantly influences soil properties and phosphorus and potassium dynamics in the temperate Himalayan soils of Ganderbal. Forest soils showed higher organic carbon, porosity, and phosphorus fixation, while agricultural and horticultural soils exhibited higher nutrient recovery. The contrasting fixation and recovery patterns highlight the importance of land-use-specific nutrient management for improving nutrient-use efficiency, maintaining soil fertility, and promoting sustainable crop production.

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