



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(5): 466-472
Received: 12-02-2026
Accepted: 16-03-2026

Rajesh Kumar
Ph.D. Research Scholar,
Department of Soil Science and
Agricultural Chemistry, M.J.P.
Rohilkhand University Bareilly,
Uttar Pradesh, India

Ravi
Assistant Professor, Department of
Soil Science and Agricultural
Chemistry, R.S.M.(P.G.) College
Dhampur Bijnor, Uttar Pradesh,
India

Corresponding Author:
Ravi
Assistant Professor, Department of
Soil Science and Agricultural
Chemistry, R.S.M.(P.G.) College
Dhampur Bijnor, Uttar Pradesh,
India

Correlation and variability analysis of soil physico-chemical properties under different land use systems in Pilibhit District

Rajesh Kumar and Ravi

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i5Sf.5618>

Abstract

This study evaluated the spatial variability and interrelationships among soil physico-chemical properties in Pilibhit District, Uttar Pradesh, India, under different land use systems. A total of 200 geo-referenced surface soil samples (0–15 cm) were collected from seven blocks using GPS-based stratified random sampling and analyzed for physical, chemical, and nutrient parameters following standard procedures. Descriptive statistics and Pearson's correlation matrix were employed to assess variability and interrelationships. Soil texture was predominantly loam (41%) and sandy loam (31%), with sand (CV=24.53%), silt (21.42%), and clay (37.64%) showing moderate to high variability. Bulk density (mean 1.20 ± 0.073 g/cm³) and porosity (mean $54.65 \pm 2.77\%$) exhibited low variability (CV<7%). Soil pH ranged from 6.2 to 7.4 (mean 6.87 ± 0.26), and EC (mean 0.17 ± 0.058 dS/m) confirmed non-saline conditions. Organic carbon ($0.65 \pm 0.22\%$, CV=33.9%) and CEC (15.77 ± 4.97 cmol(p⁺)/kg, CV=31.54%) showed moderate variability. Available P exhibited the highest spatial heterogeneity (CV=63.08%), followed by K (45.75%) and N (33.51%). Correlation analysis revealed a perfect negative relationship between BD and porosity ($r = -1.000^*$). Organic carbon showed a very strong positive correlation with available N ($r = 0.903^*$) and strong positive correlations with Ca ($r = 0.700^*$) and Mg ($r = 0.368^*$). Clay content was strongly positively correlated with CEC ($r = 0.696^*$), while sand exhibited strong negative correlations with silt ($r = -0.731^*$) and clay ($r = -0.736^*$). Soil pH demonstrated a significant negative correlation with OC ($r = -0.440^*$). Nutrient index values classified N (1.01) and Zn (1.47) under low fertility as the most critical limiting nutrients, while P (1.96) and K (1.89) fell under medium fertility. It is concluded that organic carbon serves as the central regulator of soil fertility, and site-specific integrated nutrient management is essential to address nitrogen and zinc deficiencies for sustainable agricultural productivity in the Terai alluvial region.

Keywords: Soil properties, spatial variability, correlation analysis, nutrient index, GIS, land use, Pilibhit

1. Introduction

Understanding the interrelationships among soil physico-chemical properties is fundamental for assessing soil fertility, nutrient dynamics, and overall agricultural sustainability. Soil is a complex, dynamic natural resource in which physical, chemical, and biological properties are intricately interconnected (Doran & Safley, 1997) ^[9]. Any alteration in one property often induces corresponding changes in others, thereby influencing nutrient availability, crop productivity, and ecosystem functioning (Havlin *et al.*, 2010) ^[15]. In this context, correlation analysis serves as a powerful statistical tool to quantify the degree and direction of associations between different soil parameters, enabling researchers to identify key factors governing soil fertility (Wilding & Lin, 2006) ^[34].

The Pearson correlation coefficient, developed by Karl Pearson (1896), is widely employed in soil science to evaluate linear relationships between variables such as soil texture, organic carbon, pH, cation exchange capacity, and available nutrients (Srinidhi *et al.*, 2020; Bharne, 2021) ^[29, 1]. Numerous studies have demonstrated significant correlations between soil organic carbon and available nitrogen, confirming the role of organic matter as a primary nitrogen reservoir (Kumar *et al.*, 2022; Prajapat *et al.*, 2023) ^[8, 23]. Similarly, strong positive correlations between clay content and cation exchange capacity highlight the importance of fine-textured soil

fractions in nutrient retention (Gopan *et al.*, 2022; Subhash *et al.*, 2025) ^[11, 31]. Negative correlations between bulk density and porosity indicate the inverse relationship between soil compaction and pore space, directly affecting root penetration, water movement, and soil aeration (Haruna *et al.*, 2023; Yeboah *et al.*, 2022) ^[14, 35].

Soil reaction (pH) has been reported to exhibit significant negative correlations with organic carbon and micronutrient availability, as alkaline conditions reduce the solubility of Fe, Zn, and Mn (Dodia *et al.*, 2025; Renuka *et al.*, 2026) ^[8, 25]. Conversely, positive correlations between electrical conductivity and soluble cations such as Ca²⁺, Mg²⁺, and K⁺ reflect the influence of soluble salts on nutrient dynamics (Choudhary *et al.*, 2024; Harshitha & Prakash, 2026) ^[6, 13]. Correlation matrices have also been effectively used to identify limiting nutrients, where weak or negative associations between available nutrients and soil properties indicate fixation, leaching, or antagonistic interactions (Rahaman & Saha, 2025; Sarkar, 2024) ^[24, 27].

In the context of intensively cultivated alluvial landscapes such as the Terai region of Uttar Pradesh, systematic correlation analysis becomes particularly relevant. Continuous cropping, imbalanced fertilization, and land use changes can alter natural soil relationships, accelerating nutrient depletion and soil degradation (Padbhushan *et al.*, 2022; Surjeet *et al.*, 2025) ^[22, 32]. Therefore, evaluating correlation matrices alongside variability analysis provides a scientific basis for identifying nutrient deficiencies, understanding soil behavior, and formulating site-specific nutrient management strategies (Jena *et al.*, 2022; Saraswat *et al.*, 2023) ^[17, 26]. The present study, therefore, aims to evaluate the correlation matrix of various soil physico-chemical properties under different land use systems in Pilibhit District to identify key fertility determinants and support sustainable agricultural planning.

2. Materials and Methods

2.1 Description of the Study Area

The present investigation was conducted in Pilibhit district, located in the sub-Himalayan Terai belt of Uttar Pradesh, India, between 28°06' to 28°53' N latitude and 79°57' to 80°27' E longitude (Map 1). The district falls under a sub-humid, warm climatic regime, with mean annual temperature ranging from 4.3°C (minimum) to 38.4°C (maximum) and average annual rainfall varying from 1300 to 1400 mm, predominantly received during the southwest monsoon (June–September). The total geographical area of the district is approximately 376,180 ha, of

which 71.75% is under agriculture, 18.58% under forest, and the remainder under habitation, water bodies, and other uses (Table 12). Seven development blocks, namely Amaria, Maraori, Lalaurikhera, Barkhera, Bilsanda, Puranpur, and Bisalpur, were selected for the study to represent diverse land use systems and edaphic conditions.

2.2 Soil Sampling Design and Collection

A stratified random sampling design was employed to capture spatial variability across the study area. A total of 200 geo-referenced surface soil samples (0–15 cm depth) were collected during the pre-monsoon season (May–June 2024) prior to crop sowing. The sampling intensity was approximately one sample per 1,880 ha, ensuring representative coverage of all seven blocks (Table 2). At each sampling location, five subsamples were collected from a 10 m × 10 m area using a screw-type auger and thoroughly mixed to form a composite sample (approximately 500 g). The precise geographic coordinates (latitude and longitude in decimal degrees) of each sampling point were recorded using a handheld GPS receiver (Garmin eTrex 10, ±3 m accuracy) and simultaneously cross-verified using the GPS Map Camera mobile application (Version 1.9.12). Detailed metadata, including farmer name, village, current crop, and fertilizer application history, were documented for each location.

2.3 Sample Preparation and Storage

Collected soil samples were spread on clean polyethylene sheets, air-dried at ambient temperature (25–30 °C) for 7–10 days, and gently crushed using a wooden roller to avoid mechanical breakdown of soil particles. The air-dried samples were subsequently sieved through a 2 mm nylon sieve to remove coarse fragments, roots, and organic debris. The processed samples were stored in labeled, airtight polythene bags at room temperature (25±2 °C) until laboratory analysis.

2.4 Analytical Methods

All soil analyses were conducted in triplicate at the Soil Science Laboratory, Department of Soil Science and Agricultural Chemistry, R.S.M. (P.G.) College, Dhampur, and the Regional Soil Testing Laboratory, Bareilly. Standard analytical protocols were followed as summarized in Table 1. Analytical-grade reagents and double-distilled water were used throughout the study. Quality assurance was maintained through the analysis of certified reference materials and reagent blanks.

Table 1: Standard analytical methods for soil parameter determination

Parameter	Method	Reference
Physical Properties		
Particle size distribution (sand, silt, clay)	Bouyoucos hydrometer method (after dispersion with sodium hexametaphosphate)	Bouyoucos (1962) ^[4]
Soil colour	Munsell colour chart (moist condition)	Munsell Color Company (2009) ^[20]
Bulk density (BD)	Core method (core volume: 100 cm ³ , oven-dry at 105±2°C for 24 h)	Black (1965) ^[3]
Porosity	Calculated as: Porosity (%) = [1 – (BD/PD)] × 100, assuming particle density (PD) = 2.65 Mg m ⁻³	Danielson & Sutherland (1986) ^[7]
Chemical Properties		
Soil pH (1:2.5 soil:water suspension)	Potentiometric using glass electrode (calibrated with pH 4.0, 7.0, and 9.2 buffers)	Jackson (1973)
Electrical conductivity (EC) (1:2.5 soil:water suspension)	Conductometric using conductivity meter (standardized with 0.01 M KCl)	Jackson (1973) ^[16]
Organic carbon (OC)	Walkley and Black wet digestion method (potassium dichromate oxidation followed by ferrous ammonium sulphate titration)	Walkley & Black (1934) ^[3] ; Jackson (1973) ^[16]
Cation exchange capacity (CEC)	Sodium saturation method (1N sodium acetate, pH 8.2; displaced by 1N ammonium	Jackson (1973) ^[16]

	acetate; Na ⁺ estimated by flame photometer)	
Calcium carbonate (CaCO ₃)	Rapid titration method (neutralization with 0.5 N HCl followed by back-titration with 0.25 N NaOH)	Singh <i>et al.</i> (2007)
Primary Macronutrients		
Available nitrogen (N)	Alkaline potassium permanganate method (KMnO ₄ + NaOH) followed by Kjeldahl distillation and titration	Subbiah & Asija (1956) ^[30]
Available phosphorus (P)	Olsen's method (0.5 M NaHCO ₃ , pH 8.5; colorimetric determination at 882 nm using spectrophotometer)	Olsen <i>et al.</i> (1954) ^[21]
Available potassium (K)	Neutral 1N ammonium acetate extraction (pH 7.0); determination by flame photometer	Hanway & Heidel (1952) ^[12]
Secondary Nutrients		
Available sulphur (S)	0.15% CaCl ₂ extraction; turbidimetric determination at 420 nm using BaCl ₂	Chesnin & Yien (1950) ^[5]
Exchangeable calcium (Ca ²⁺) and magnesium (Mg ²⁺)	Neutral 1N ammonium acetate extraction (pH 7.0); EDTA complexometric titration (Ca ²⁺ with murexide indicator; Ca ²⁺ +Mg ²⁺ with Eriochrome Black T indicator)	Sparks (1996) ^[28]
Micronutrients		
Available zinc (Zn), iron (Fe), copper (Cu), manganese (Mn)	DTPA extraction (0.005 M DTPA + 0.01 M CaCl ₂ + 0.1 M triethanolamine, pH 7.3); determination by atomic absorption spectrophotometer (AAS, GBC Avanta, Australia)	Lindsay & Norvell (1978) ^[19]
Available boron (B)	Hot water extraction (boiling for 5 min); colorimetric determination using Azomethine-H reagent at 420 nm	Bingham (1982) ^[2]

2.5 Quality Control and Assurance

Analytical accuracy was ensured through the analysis of reagent blanks, duplicate samples (10% of total samples), and certified reference materials (CRM, Soil-5 from IAEA). The acceptable relative percent difference (RPD) between duplicate analyses was maintained below 5% for all parameters. Instrument calibration was performed before each analytical batch using standard solutions of appropriate concentrations.

2.6 Statistical Analysis: Variability Assessment

Descriptive statistics, including minimum, maximum, mean ($\bar{x}$), standard deviation (SD), and coefficient of variation (CV), were computed for each soil parameter using IBM SPSS Statistics (Version 26.0, IBM Corp., Armonk, NY, USA). The CV was calculated as:

$$CV(\%) = \left(\frac{SD}{\bar{x}} \right) \times 100$$

Spatial variability was classified according to Wilding (1985)^[33] as follows: low variability (CV <15%), moderate variability (CV 15–35%), and high variability (CV >35%). Standard error (SE) was also computed to indicate the precision of sample means.

2.7 Correlation Analysis

The linear relationships among all measured soil physico-chemical properties were evaluated using Pearson's product-moment correlation coefficient (r). The correlation matrix was constructed for 18 soil parameters, including sand, silt, clay, BD, porosity, pH, EC, OC, CEC, available N, P, K, S, Ca²⁺, Mg²⁺, Zn, Fe, Cu, Mn, and B. The Pearson correlation coefficient was calculated using the following formula:

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

Where

- x and y = values of two variables
- n = number of paired observations ($n = 200$)

The significance of correlation coefficients was tested at three probability levels: $*p \leq 0.05$ (), $*p \leq 0.01$ (), and $*p \leq 0.001$ (). A correlation matrix heatmap was generated using the corplot package in R software (Version 4.2.1, R Core Team,

2022) for visual interpretation of interrelationships.

2.8 Nutrient Index Calculation

The fertility status of soils was assessed using the Nutrient Index Value (NIV) approach as proposed by Ghosh and Hasan (1980)^[10]

$$NIV = \frac{(N_L \times 1) + (N_M \times 2) + (N_H \times 3)}{N_T}$$

Where

- N_L , N_M , N_H = number of samples in low, medium, and high categories, respectively
- N_T = total number of samples (200)

For primary macronutrients (N, P, K), fertility classes were defined as: low (<1.67), medium (1.67–2.33), and high (>2.33). For secondary nutrients and micronutrients, classes were: very low (<1.33), low (1.33–1.66), marginal (1.66–2.00), adequate (2.00–2.33), high (2.33–2.66), and very high (>2.66).

2.9 Geospatial Analysis and Thematic Mapping

Spatial distribution maps for soil properties were prepared using ArcGIS Desktop 10.8 (ESRI, Redlands, CA, USA). The point shapefile of 200 sampling locations was created by importing GPS coordinates (WGS 1984 datum, UTM zone 44N projection). The study area boundary was digitized from Survey of India topographic maps (scale 1:50,000; sheet nos. H44T₉ to H44U₇). Inverse Distance Weighting (IDW) interpolation with a power parameter of 2 was employed to generate continuous surface maps for pH, EC, OC, CEC, available N, P, K, and micronutrients. The IDW method assumes that points closer to each other are more similar than those farther apart, making it suitable for spatially continuous soil properties.

3. Results and Discussion

3.1 Correlation Matrix Analysis of Soil Properties

The correlation matrix analysis was undertaken to evaluate the degree and direction of association among various physico-chemical properties and available macro- and micronutrients of soils under different land use systems in Pilibhit district, Uttar Pradesh. Understanding these interrelationships is essential for interpreting soil behavior, nutrient dynamics, and overall soil fertility status (Wilding & Lin, 2006; Havlin *et al.*, 2010)^[34, 15].

The analysis revealed a highly complex and interdependent relationship among soil physical and chemical parameters, indicating that soil fertility is regulated by the combined influence of texture, organic matter, and nutrient interactions (Doran & Safley, 1997) ^[9].

3.1.1 Interrelationships among Soil Textural Fractions

The relationship among soil textural fractions exhibited strong and highly significant negative correlations. Sand content showed a highly significant negative correlation with silt ($r = -0.731^*$) and clay ($r = -0.736^*$), indicating that an increase in the coarse fraction is associated with a corresponding decrease in finer soil particles. Such relationships are characteristic of soil textural composition and have important implications for soil structure, water retention, aeration, and nutrient-holding capacity. Coarse-textured soils generally possess lower water and nutrient retention compared to fine-textured soils. Similar strong negative correlations between sand and finer fractions have been reported by Bharné (2021) ^[1] in Ratlam district, Madhya Pradesh, and by Subhash *et al.* (2025) ^[31] in the Vertisols of central India.

3.1.2 Bulk Density and Porosity Relationship

Bulk density and porosity exhibited a perfect and highly significant negative correlation ($r = -1.000^*$), confirming the inverse relationship between soil compaction and pore space. As bulk density increases, soil pores decrease, thereby restricting water infiltration, gaseous exchange, and root penetration. This finding is consistent with Haruna *et al.* (2023) ^[14], who reported a very strong negative correlation ($r = -0.978$) between bulk density and porosity in agricultural farmlands around Zaria, Nigeria, indicating that continuous cultivation and soil compaction significantly degrade soil quality. Similarly, Yeboah *et al.* (2022) ^[35] observed strong positive correlations between bulk density and clay content ($r = 0.45^{***}$) and negative correlations with soil organic carbon in the Guinea Savanna zone of northern Ghana.

Bulk density also showed a significant positive correlation with soil pH ($r = 0.226^{**}$), suggesting that compact soils tend to exhibit relatively higher pH values, possibly due to reduced leaching and greater accumulation of exchangeable basic cations.

3.1.3 Soil pH, Organic Carbon and Electrical Conductivity

Soil reaction (pH) demonstrated a highly significant negative correlation with organic carbon ($r = -0.440^{***}$), indicating that soils rich in organic matter tend to be comparatively acidic. This may be attributed to the release of organic acids during decomposition and mineralization processes. Similar negative correlations between pH and organic carbon have been reported by Kumar *et al.* (2022) ^[8] in Shahjahanpur district ($r = -0.757$) and by Choudhary *et al.* (2024) ^[6] in Tonk district, Rajasthan, where pH showed negative correlations with nitrogen and phosphorus.

Electrical conductivity (EC) exhibited a weak but significant positive correlation with organic carbon ($r = 0.176^*$), suggesting that decomposition of organic residues may increase the concentration of soluble salts in soil solution. Comparable observations were made by Harshitha and Prakash (2026) ^[13] in Tumakuru district, Karnataka, where EC showed strong positive correlations with phosphorus ($r = 0.57$), calcium ($r = 0.43$), and sulphur ($r = 0.41$).

3.1.4 Organic Carbon as a Central Regulator of Nutrient Availability

Organic carbon emerged as one of the most influential parameters affecting nutrient availability and soil fertility. A very strong and highly significant positive correlation was observed between organic carbon and available nitrogen ($r = 0.903^*$), highlighting the role of soil organic matter as a major reservoir of nitrogen. This relationship indicates that nitrogen mineralization is strongly dependent on the organic matter content of soils. This finding corroborates the work of Prajapat *et al.* (2023) ^[23] in Indore district, Madhya Pradesh, who reported a highly significant positive correlation between organic carbon and nitrogen ($r = 0.927$). Similarly, Kumar *et al.* (2022) ^[8] observed a strong positive correlation ($r = 0.956$) between organic carbon and available nitrogen in KVK farm soils of Shahjahanpur.

Organic carbon also exhibited strong positive correlations with exchangeable calcium ($r = 0.700^*$) and magnesium ($r = 0.368^*$), suggesting that soils enriched with organic matter possess improved nutrient retention and cation exchange capacity. Gopan *et al.* (2022) ^[11] in Kollam district, Kerala, similarly reported positive correlations between organic carbon and CEC ($r = 0.451^*$) and calcium ($r = 0.446^*$). Dodia *et al.* (2025) ^[8] also observed positive correlations of organic carbon with phosphorus ($r = 0.46$), potassium ($r = 0.51$), calcium ($r = 0.33$), and magnesium ($r = 0.63$) in semi-arid soils of Kachchh district, Gujarat.

3.1.5 Cation Exchange Capacity and Texture

Cation exchange capacity (CEC), an important indicator of soil fertility and nutrient retention, showed a highly significant positive correlation with clay content ($r = 0.696^*$), emphasizing the role of fine soil particles in enhancing nutrient-holding capacity. Conversely, CEC exhibited a significant negative correlation with sand content ($r = -0.516^*$), indicating comparatively lower nutrient retention in coarse-textured soils. These findings clearly demonstrate the influence of soil texture on nutrient dynamics and soil fertility. Similar results were reported by Srinidhi *et al.* (2020) ^[29] in Chittoor district, Andhra Pradesh, where clay content showed positive associations with nutrient retention, and by Rahaman and Saha (2025) ^[24] in Jalpaiguri district, West Bengal, where CEC was positively correlated with silt content.

3.1.6 Phosphorus and Potassium Dynamics

Available phosphorus showed weak to moderate negative correlations with organic carbon ($r = -0.147^*$) and available nitrogen ($r = -0.189^{**}$), suggesting possible phosphorus fixation processes or reduced mobility under certain soil conditions. In contrast, available potassium showed mostly weak and non-significant correlations with other soil parameters, indicating its relatively independent behavior within the soil system. This finding aligns with Surjeet *et al.* (2025) ^[32], who reported that in the semi-arid Bundelkhand region, organic carbon and nutrients (N, P, K) showed significant spatial variability due to land use and management practices, with phosphorus and potassium exhibiting relatively independent distribution patterns.

3.1.7 Exchangeable Calcium and Magnesium Relationships

Exchangeable calcium exhibited strong positive correlations with organic carbon ($r = 0.700^*$) and available nitrogen ($r = 0.695^*$), indicating that soils rich in organic matter generally possess higher calcium availability.

Table 2: Correlation matrix of physico-chemical properties of soils of Pilibhit district, Uttar Pradesh

Variable	SAND	SILT	CLAY	BD	POROSITY	pH	EC	OC	CEC	N	P	K	Ca	Mg	S	Zn	B	Fe	Mn	Cu
SAND	1																			
SILT	-0.731***	1																		
CLAY	-0.736***	0.077	1																	
BD	-0.120	0.049	0.126	1																
POROSITY	0.120	-0.049	-0.126	-1.000***	1															
pH	-0.120	0.085	0.089	0.226**	-0.226**	1														
EC	0.044	-0.015	-0.050	-0.109	0.109	-0.154*	1													
OC	-0.035	0.024	0.027	-0.227**	0.227**	-0.440***	0.176*	1												
CEC	-0.516***	0.059	0.696***	0.075	-0.075	-0.005	-0.038	0.121	1											
N	-0.094	0.076	0.062	-0.220**	0.220**	-0.395***	0.171*	0.903***	0.113	1										
P	0.014	0.032	-0.053	-0.070	0.070	0.034	0.022	-0.147*	-0.113	-0.189**	1									
K	0.006	0.037	-0.044	0.021	-0.021	-0.065	-0.116	0.076	-0.046	0.052	-0.093	1								
Ca	0.077	-0.031	-0.082	-0.197**	0.197**	-0.464***	0.194**	0.700***	0.026	0.695***	-0.107	0.252***	1							
Mg	0.072	-0.063	-0.042	-0.138	0.138	-0.214**	0.086	0.368***	0.047	0.373***	-0.053	0.188**	0.653***	1						
S	-0.050	0.059	0.016	0.017	-0.017	-0.050	-0.059	0.147*	-0.030	0.122	-0.067	0.057	0.149*	0.070	1					
Zn	-0.038	-0.047	0.101	0.005	-0.005	-0.013	-0.093	0.126	0.096	0.124	-0.126	0.156*	0.146*	0.174*	-0.005	1				
B	-0.003	0.002	0.003	-0.008	0.008	-0.019	-5.230×10 ⁻⁴	0.150*	0.062	0.143*	-0.104	-0.056	0.063	0.113	0.120	0.006	1			
Fe	-0.055	-0.033	0.112	-0.071	0.071	-0.060	-0.011	0.011	0.193**	-0.017	0.042	-0.118	0.037	0.048	-0.075	0.296***	0.082	1		
Mn	0.090	-0.088	-0.043	-0.116	0.116	0.026	-0.115	-0.203**	-0.115	-0.206**	-0.003	-0.124	-0.108	-0.035	0.062	0.022	-0.186**	-0.028	1	
Cu	0.079	-0.041	-0.075	-0.228**	0.228**	-0.122	0.085	0.256***	-0.009	0.223**	-0.086	-0.024	0.180*	0.209**	0.029	0.211**	0.087	0.067	-0.040	1

Magnesium also exhibited a strong positive correlation with calcium ($r = 0.653^*$), reflecting their complementary role in maintaining soil chemical balance and plant nutrition. Similar findings were reported by Choudhary *et al.* (2024) ^[6], who observed a strong positive correlation between magnesium and nitrogen ($r = 0.804$), and by Renuka *et al.* (2026) ^[25], who noted that exchangeable cations are strongly influenced by soil pH and organic carbon under different land use systems in Rajouri district, Jammu & Kashmir.

3.1.8 Micronutrient Interrelationships

Among micronutrients, zinc showed significant positive correlations with potassium ($r = 0.156^*$) and calcium ($r = 0.146^*$), indicating its association with nutrient-rich soil environments. Iron exhibited a highly significant positive correlation with zinc ($r = 0.296^{***}$), suggesting their co-occurrence in soil mineral fractions. This is consistent with Dodia *et al.* (2025) ^[8], who reported an extremely high positive correlation between copper and zinc ($r = 0.97$) in semi-arid soils, indicating a common mineralogical source or similar adsorption behavior. Renuka *et al.* (2026) ^[25] also observed that Zn showed positive correlations with sand, clay, organic carbon, and available N, P, and K, but negative correlations with pH and EC. In contrast, manganese showed significant negative correlations with organic carbon ($r = -0.203$) and nitrogen ($r = -0.206$), indicating that higher organic matter content may reduce manganese availability through complexation or redox-mediated reactions. Sarkar (2024) ^[27] in Darjeeling district, West Bengal, also reported seasonal variations in micronutrient availability, with complex interactions between organic matter and metal ions.

Copper exhibited significant positive correlations with organic carbon ($r = 0.256^*$) and nitrogen ($r = 0.223$), highlighting the role of soil organic matter in improving micronutrient availability through chelation and adsorption mechanisms. This finding suggests that soils with higher organic matter content are more efficient in retaining and supplying micronutrients to plants. Jena *et al.* (2022) ^[17] similarly reported that organic carbon and terrain attributes significantly influence micronutrient distribution in the north-eastern Himalayan region. Saraswat *et al.* (2023) ^[26] also emphasized that land-use practices such as continuous cropping, fertilization, and irrigation play a significant role in determining micronutrient availability in Firozabad district, Uttar Pradesh.

Overall, the correlation analysis clearly demonstrates that soil fertility is governed by a dynamic interaction among physical properties, organic matter, and nutrient elements. Among all the parameters studied, organic carbon emerged as the central factor regulating nutrient availability and soil health. The results emphasize the importance of adopting integrated soil management practices that enhance soil organic matter for sustaining long-term agricultural productivity under different land use systems.

4. Conclusion

The present study revealed significant spatial variability and interrelationships among soil physico-chemical properties under different land use systems in Pilibhit district, Uttar Pradesh. The soils were predominantly loam and sandy loam in texture, with moderate to high variability observed in organic carbon, cation exchange capacity, and available nutrients. Correlation analysis indicated that organic carbon plays a central role in regulating soil fertility and nutrient availability, showing strong positive relationships with available nitrogen, calcium, and magnesium.

Clay content was positively associated with cation exchange capacity, while sand content negatively influenced nutrient retention. The study also identified nitrogen and zinc as the major limiting nutrients in the region. The findings emphasize the importance of integrated and site-specific nutrient management practices, including balanced fertilization and organic matter addition, for maintaining soil health and sustainable agricultural productivity. GIS-based spatial variability assessment can further support precision farming and efficient soil resource management in the Terai region.

References

1. Bharné S. Evaluation of physico-chemical properties and nutrient status of soil of Ratlam district of Madhya Pradesh [master's thesis]. Gwalior: Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya; 2021.
2. Bingham FT. Boron. In: Page AL, editor. Methods of soil analysis: Part 2. 2nd ed. ASA-SSSA; 1982. p. 431-447.
3. Black CA, editor. Methods of soil analysis: Part 1. American Society of Agronomy; 1965.
4. Bouyoucos GJ. Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal*. 1962;54(5):464-465.
5. Chesnin L, Yien CH. Turbidimetric determination of available sulphates. *Soil Science Society of America Journal*. 1950;14:149-151.
6. Choudhary R, Diwakar AK, Meena AK, Shukla S, Prakash C. Assessment of fertility status of soils under different cropping patterns in rainfed semi-arid eastern plain of Rajasthan, India. *International Journal of Environment and Climate Change*. 2024;14(5):192-204.
7. Danielson RE. Porosity. In: Klute A, editor. Methods of soil analysis: Part 1. 2nd ed. ASA-SSSA; 1986. p. 443-461.
8. Dodia K, Bhanushali U, Kher G, Tandel R, Sorathia K. Assessment of soil fertility status and nutrient mapping in the semi-arid Nakhtrana Taluka, Kachchh District, Gujarat. 2025.
9. Doran JW, Safley M. Defining and assessing soil health and sustainable productivity. In: Pankhurst C, Doube BM, Gupta VVSR, editors. Biological indicators of soil health. CAB International; 1997. p. 1-28.
10. Ghosh AB, Hasan R. Soil fertility map of India. Indian Agricultural Research Institute; 1980.
11. Gopan GM, Hasan A, Thomas T, David AA, Reddy IS. Correlation of physico-chemical parameters of soil and soil nutrient index status of Kollam district, Kerala, India. *International Journal of Plant and Soil Science*. 2022;34(20):270-276.
12. Hanway JJ, Heidel H. Soil analysis methods. Iowa State College; 1952.
13. Harshitha CT, Prakash KL. Chemical analysis of soils to evaluate the soil fertility status of semi-arid region of three taluks of Tumakuru District, Karnataka, India. *Asian Journal of Soil Science and Plant Nutrition*. 2026;12(2):69-77.
14. Haruna UJ, Ahmed A, Ayuba MS, Ajobunu SI, Abdulhakim HW. Analysis of physico-chemical parameters of soils as determinants of soil degradation in Zaria, Nigeria. *FUDMA Journal of Sciences*. 2023;7(5):185-191.
15. Havlin JL, Tisdale SL, Nelson WL, Beaton JD. Soil fertility and fertilizers. 8th ed. Pearson Education; 2010.
16. Jackson ML. Soil chemical analysis. Prentice Hall of India; 1973.
17. Jena RK, Bandyopadhyay S, Pradhan UK, Moharana PC,

- Kumar N, Sharma GK, *et al.* Geospatial modelling for delineation of crop management zones using local terrain attributes and soil properties. *Remote Sensing*. 2022;14(9):2101.
18. Kumar V, Kumar S, Yadav PK, Singh V, Verma S, Kumar M. Study of soil fertility status in KVK Farm, Shahjahanpur, Uttar Pradesh, India. *International Journal of Plant and Soil Science*. 2022;34(22):117-124.
 19. Lindsay WL, Norvell WA. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal*. 1978;42(3):421-428.
 20. Munsell Color Company Munsell Color Company. Munsell soil color book. 2009.
 21. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No. 939; 1954.
 22. Padbhushan R, Kumar U, Sharma S, Rana DS, Kumar R, Kohli A, *et al.* Impact of land-use changes on soil properties and carbon pools in India: A meta-analysis. *Frontiers in Environmental Science*. 2022;9:794866.
 23. Prajapat V, Singh YV, Bharteey PK, Sarvajeet, Singh K, Sharma S, *et al.* Assessment of soil fertility status of different villages of Depalpur block of Indore district, Madhya Pradesh, India. *Environment and Ecology*. 2023;41(1A):191-196.
 24. Rahaman S, Saha S. Physico-chemical properties of soil and their implications for agriculture in Jalpaiguri Sadar Block, West Bengal, India. *Geographical Thoughts*. 2025;23:57-87.
 25. Renuka, Sarabdeep K, Vikas S, Meenakshi G, Divya S, Rajeev B, *et al.* Assessment and GIS mapping of DTPA-extractable cationic micronutrients and hot water-soluble boron in soils of Rajouri District, Jammu and Kashmir, India. *Plant Science Today*. 2026;13:9167.
 26. Saraswat A, Ram S, AbdelRahman MAE, Raza MB, Golui D, HC H, *et al.* Combining fuzzy, multicriteria and mapping techniques to assess soil fertility for agricultural development: A case study of Firozabad district, Uttar Pradesh, India. *Land*. 2023;12(4):860.
 27. Sarkar L. Physico-chemical characteristics of soils of Phansidewa village of Darjeeling in perspective of seasonal variation, statistical distribution and correlation matrix. *Ecology, Environment and Conservation*. 2024;30(Suppl Issue):S1-S13.
 28. Sparks DL, editor. *Methods of soil analysis: Part 3. Chemical methods*. SSSA; 1996.
 29. Srinidhi P, Singh YV, Sharma PK, Singh RK, Latore AM, Srinath I, *et al.* Physico-chemical analysis of soils in Madanapalle block, Chittoor district of Andhra Pradesh. *International Journal of Chemical Studies*. 2020;8(3):154-158.
 30. Subbiah BV, Asija GL. A rapid procedure for the determination of available nitrogen in soils. *Current Science*. 1956;25:259-260.
 31. Subhash M, Sinha NK, Kumar J, Mohanty M, Sahoo RN, Jayaraman S, *et al.* Spatial variability of soil physicochemical properties in soybean wheat belts in Vertisols of central India. *Scientific Reports*. 2025;15(1):33830.
 32. Surjeet, Chaube AK, Kant S, Yadav RK, Nishad S, Pal A, *et al.* Status of chemical properties of soil in semi-arid region of Bundelkhand, Uttar Pradesh. *International Journal of Advanced Biochemistry Research*. 2025;9(3):686-690.
 33. Wilding LP. Spatial variability: Its documentation, accommodation and implication to soil surveys. In: Nielsen DR, Bouma J, editors. *Soil spatial variability*. Pudoc; 1985. p. 166-194.
 34. Wilding LP, Lin H. Advancing the frontiers of soil science towards a geoscience. *Geoderma*. 2006;131(3-4):257-274.
 35. Yeboah SO, Amponsah IK, Kaba JS, Abunyewa AA. Variability of soil physicochemical properties under different land use types in the Guinea savanna zone of northern Ghana. *Cogent Food and Agriculture*. 2022;8(1):2105906.