



Soil fertility appraisal for Palwal district of Haryana using geospatial tools

ANKUSH DHANDA^{1*}, SONIA RANI¹, RITAMBHARA¹, VIKAS¹, DEEPIKA RATHI¹, SUSHIL¹,
DEV RAJ¹ and ROHTASH KUMAR¹

Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana 125 004, India

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ABSTRACT

Understanding the spatial variability of soil fertility is vital for site-specific nutrient management and precise fertiliser recommendations. A study was carried out during 2022–23 across blocks of Palwal District, Haryana to assess and map the fertility status of soils with respect to nutrients (NPK) using GPS and GIS techniques. A total of 228 geo-referenced surface soil samples (0–15 cm) were collected and analysed for nutrient content, and thematic maps were prepared based on standard fertility ratings. Results showed marked variability in soil fertility across the district. Approximately 64% and 45% of the area fell in the high fertility category for P and K, respectively, whereas no sample recorded a high nitrogen status. Medium fertility classes accounted for 3, 24, and 50% of the samples for N, P, and K, respectively. In contrast, low fertility was widespread for nitrogen (97%), affecting the majority of soils, while only 12% and 5% of samples were low in P and K. Block-wise variation indicated that Parithala had the highest mean nitrogen content, Palwal had highest phosphorus, and Hodal had highest potassium. The calculated soil fertility index (SFI) for the district was 1.79, placing soils under the medium fertility category overall. Correlation matrix and PCA analysis revealed that spatial variation in fertility was mainly influenced by organic matter status and macronutrient availability. Three distinct fertility groups were identified, underscoring the importance of organic matter enrichment and balanced nutrient application in sustaining soil productivity. The widespread nitrogen deficiency, continuous K depletion and overall medium fertility calls for organic matter enrichment and balanced fertilisation.

Keywords: Fertility map, GPS, Macronutrients, Palwal, Soil testing

Soil performs vital ecosystem services providing a growth medium for plants, and serving as habitats for diverse soil biota (Creamer *et al.* 2022). In order to secure food, water, environmental stability, and livelihood security, a science-based approach to soil and crop management is critical (Evangelista *et al.* 2023). This approach should integrate the best available soil data to empower producers in making informed, farm-level decisions. Digital Soil Mapping (DSM), which employs model-informed maps to reveal soil variability and function (Richiedei *et al.* 2024), represents a promising technique for optimizing soil management practices (Arrouays *et al.* 2021, Moharana and Dharumarajan 2022). Global concerns about the reduction of fertile land exacerbated by factors such as intensive cultivation, overgrazing, deforestation, poor irrigation, indiscriminate mining, and increasing urbanization (Thakur 2020) that further highlight the pressing need to counteract processes like vegetation degradation, erosion, waterlogging, salinisation, and nutrient depletion that contribute to desertification (Gupta 2019).

In the specific context of India, approximately 228 Mha of the total 328 Mha geographical area is characterised by dry conditions (Anonymous 2010). Studies have shown that about 57% of India's land has been degraded to some extent, with cultivated lands being the most affected, followed by grazing lands and forests (Sehgal and Abrol 1994). Low soil fertility, aggravated by intensive cultivation practices of high-yield varieties, the diminishing use of organic manures, and inadequate crop residue recycling, poses a significant barrier to achieving high agricultural productivity (Das *et al.* 2022). By delineating soil constraints and fertility zones, soil surveys facilitate efficient input utilisation, balanced nutrient management, and conservation-oriented practices. In the long term, they contribute to climate-resilient agriculture, continuous soil health assessment, and sustainable land resource planning. GIS and GPS play a crucial role in understanding the spatial variability of soil fertility by providing georeferencing and spatial data analysis. These technologies enable accurate mapping, monitoring and delineation of soil fertility zones when combined with field observations and analytical data (Mitran *et al.* 2021). Combining soil testing with GIS mapping, therefore, enables a more accurate depiction of fertility status in the study area.

¹College of Agriculture, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana. *Corresponding author email: ankushdhanda@hau.ac.in

MATERIALS AND METHODS

Study area: The study was carried out in Palwal district (28°10'–28°25'N, 76°35'–77°10'E) of south-eastern Haryana. The area of district is 1359 km². It experiences a semi-arid subtropical climate, receiving 600–700 mm rainfall annually. The mean temperature ranges from 5°C in winter to 45°C in summer. Major cropping systems include pearl millet-wheat, cotton-wheat and paddy-wheat rotations, supported by canal and tube well irrigation. In this investigation, geo-referenced soil samples were collected from nearly all villages of the district during the 2022–23 period. However, the samples were collected exclusively from agricultural fields, with a sampling density of 0.16 samples/km², adequately representing the cultivated area of the district. Specifically, soil samples (0–15 cm depth) were collected from harvested and cleaned fields following a multistage stratified random sampling method, ensuring a comprehensive spatial representation. At each sampling site, geographic coordinates (latitude and longitude) were precisely recorded using a GPS device (Garmin HCX Model). Subsequent analyses focused on determining the available nitrogen, phosphorus, and potassium (NPK) in these soil samples, thereby establishing a critical foundation for evaluating soil fertility within the district.

Soil sample analysis: After collection, the soil samples were air-dried, ground using a wooden pestle and mortar, and sieved through a 2 mm mesh (or a 0.2 mm sieve for organic carbon analysis), then carefully labelled and stored. Subsequently, the samples were analysed for various chemical parameters: pH and electrical conductivity (EC) were determined following Jackson (1973) method, organic carbon (OC) was assessed using the method of Walkley and Black (1934), available nitrogen (N) was measured according to Subbiah and Asija (1956), available phosphorus (P) was analysed as per Olsen *et al.* (1954), and available potassium (K) was also determined following Jackson (1973). The analytical results for each soil sample were then categorized into low, medium, and high levels for each macronutrient. Based on the distribution of samples across these categories, the percentage of samples in each category and the corresponding nutrient index values (NIV) were computed using the formulas provided below.

Nutrient index and fertility rating: Nutrient index value (NIV) was calculated from the proportion of soils under low, medium and high available nutrient categories, as represented by:

$$NIV = \frac{[(PH \times 3) + (PM \times 2) + PL \times 1]}{100}$$

Where NIV, Nutrient index value; PL, PM and PH are the percentage of soil samples falling in the category of low, medium and high nutrient status and given weightage of one, two and three, respectively (Ramamoorthy and Bajaj 1969). The index values are rated into various categories viz. low (<1.67), medium (1.67–2.33) and high (>2.33) for OC and available N, P and K. The district was categorized into different fertility ratings based on per cent sample category and NIV.

Generation of thematic soil fertility maps: Firstly, data based on available nutrient status was generated using Excel software and to delineate the spatial distribution of soil nutrients, the analysed data from each sampling site were first incorporated into GIS as point-based, geo-referenced information via table management. The study utilised ArcGIS software to manage and process the data. Based on the level of adequacy of each nutrient for plants, the individual units within these vector maps were aggregated into low, medium, and high categories for the macronutrients (NPK), providing a comprehensive spatial understanding of soil fertility distribution.

Soil fertility index (SFI): Soil fertility status was evaluated using the SFI approach considering six parameters; pH, EC, OC, AN (Available nitrogen), AP (Available phosphorus), and AK (Available potassium). Each parameter was classified into low, medium, and high categories based on standard critical limits and assigned scores of 1, 2, and 3, respectively. For pH, values between 6.5–7.5 were rated as optimum (score 3), while acidic (<6.5) and basic (>7.5) soils were rated poor (score 1). EC <0.8 dS/m was considered non-saline (score 3), while higher values were saline (score 1). The SFI for each sample was calculated as the mean of individual parameter scores (Malo and Saha 2025):

$$SFI = \frac{\sum(S_i)}{n}$$

Where S_i, Score of the soil parameter (pH, EC, OC, AN, AP, AK) and n, Number of parameters included in the calculation. Soils were finally grouped as low (<1.5), medium (1.5–2.5), and high fertility (>2.5). The district SFI was obtained from the mean of all samples, and the distribution of soils across fertility classes was computed.

Statistical analysis: Descriptive statistics and correlation analysis were performed to examine relationships among soil properties. For district statistics, data were screened for accuracy, and outliers were removed using the Interquartile Range (IQR) method, wherein data points lying below Q1 - 1.5 × IQR or above Q3 + 1.5 × IQR were considered extreme and excluded from analysis (Tukey 1977). A scatterplot correlation matrix was generated with significance levels to visualize pairwise associations. Principal component analysis (PCA) was conducted on standardised data to identify the major factors governing soil fertility variation, and k-means clustering was applied to classify soils into fertility groups. All statistical analyses were carried out in R studio (Version 2025.05.1+513s, Posit) using the packages GGally, FactoMineR, and factoextra.

RESULTS AND DISCUSSION

Descriptive statistic: Soil texture of the Palwal district varied from sandy loam to loamy textural class. The soil pH and electrical conductivity (Table 1) of the surface soil ranged from 7.20–8.80 and 0.10–2.20 dS/m with a mean of 8.1 and 0.92 dS/m, respectively. The samples were found to be alkaline which might be due to the higher degree of base saturation (Chinchmalatpure *et al.* 2016). High soil pH in

Table 1 Fertility status of Palwal district soils

Parameter	Status			CV (%)	Nutrient index values (NIV)	Fertility rating
	Range	Mean	Median			
pH (1:2)	7.2–8.8	8.1 ± 0.3	8.00	3.70	-	-
EC (dS/m)	0.1–2.2	0.92 ± 0.4	0.85	43.50	-	-
OC (%)	0.08–1.05	0.52 ± 0.18	0.50	34.60	2.07	Medium
Available nitrogen (kg/ha)	67.72–313.60	143.31 ± 22.77	139.20	39.84	1.03	Low
Available phosphorus (kg/ha)	4–90	25.4 ± 12.1	23.60	47.60	2.52	High
Available potassium (kg/ha)	120–650	330.2 ± 80.4	325.50	24.40	2.52	High

Ranges and means are based on cleaned data after outlier removal (interquartile range; IQR method).

Palwal results from the interaction of a semi-arid climate, poor-quality irrigation water (high EC, bicarbonate/carbonate alkalinity, sodium), fluctuating groundwater, which together drive capillary rise and sodium build-up in the root zone (Prakash *et al.* 2023). The variability in EC values points to non-uniform salinity levels across the district. Elevated salinity and moderate salinity may result from improper field management and over fertiliser use, which can lead to salt accumulation in the root zone (Eswar *et al.* 2021). Elevated salinity levels indicated the presence of localised salinity hotspots, which may have developed due to topographic depressions or low-lying areas within the field where salts tend to accumulate (Mondal *et al.* 2020). Organic carbon is a key indicator of soil health, it improves soil structure, nutrient retention, and microbial activity (Sur *et al.* 2010, Sharma *et al.* 2014). The observed moderate OC level (mean 0.52%) which might be due to textural difference and little or partial organic matter addition to the fields and the corresponding NIV of 2.07 suggested that while the soils have a medium fertility status, there is room for improvement. The data indicated that Palwal district soils are moderately fertile but face challenges related to high pH and salinity. Addressing these issues through improved management practices such as better irrigation strategies, balanced fertiliser applications, and increased organic matter inputs could enhance nutrient availability and crop productivity in the region (Nogiya *et al.* 2024).

Available nitrogen: The sampling points and N fertility status maps are depicted in Fig. 1. In Palwal, the overall

available nitrogen (N) in the soil ranged from 67.72–313.60 kg/ha, with a mean value of 143.31 kg/ha and CV 25.10% (Table 1). Approximately 97% of the samples were classified as deficient in available N, while only 3% fell into the medium category (Fig. 2). Notably, none of the samples

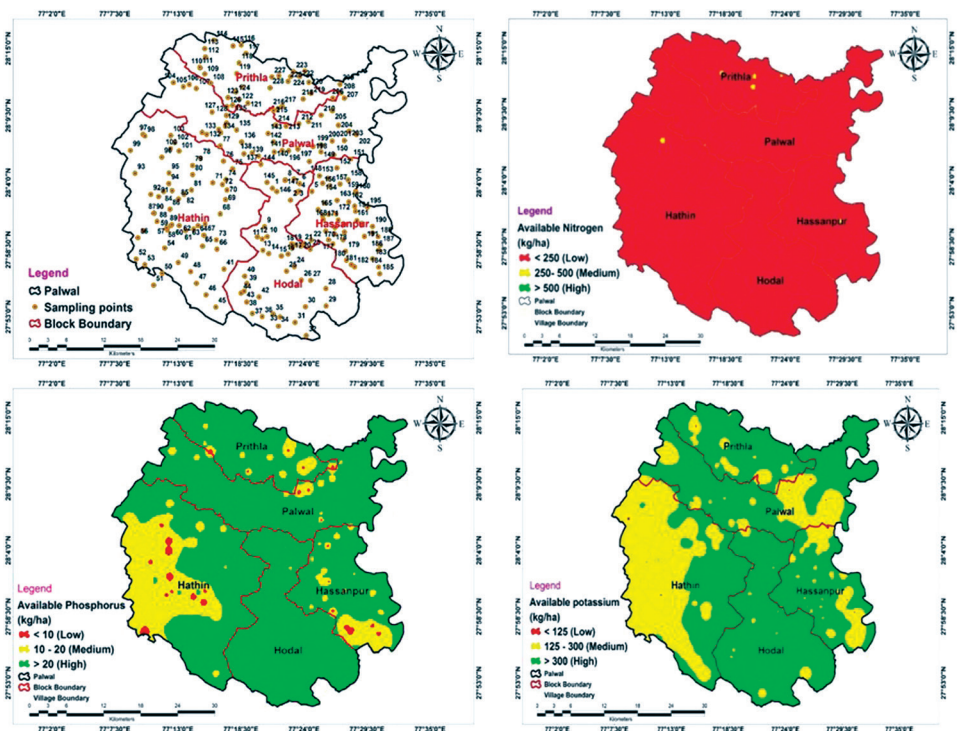


Fig. 1 Sampling points and fertility status map of Palwal district.

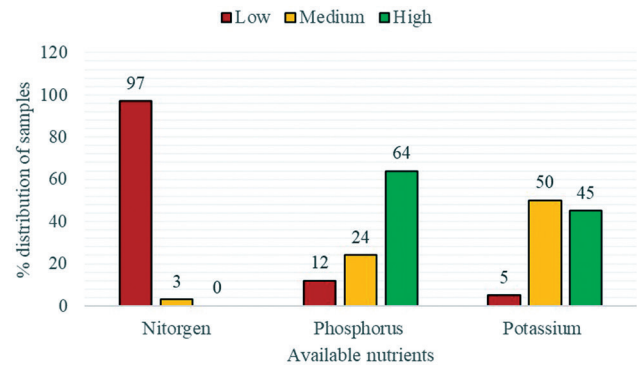


Fig. 2 Percentage distribution of soil samples in Palwal district.

reached the high category. The NIV for available N was found to be 1.03, indicating an overall low fertility rating for this nutrient in the district. The pronounced deficiency of available nitrogen in Palwal soils can be attributed to several factors. First, the generally high pH favours the volatilization loss of nitrogen to atmosphere, while salinity reduces solubility, creates osmotic stress, inhibits nitrification and mineralization process, subsequent lowering the availability of nitrogen to plants (Singh and Singh 2022). Second, the injudicious use of fertilisers; notably those that are not balanced or optimized may result in significant losses through volatilisation, leaching, or denitrification, further

reducing the N pool available for uptake (Giordano *et al.* 2021). Although soil surveys provide valuable information on fertility status, their accuracy is often limited by low sampling density, temporal variability, and sampling bias.

In Palwal district, nearly all blocks exhibited a widespread deficiency in available nitrogen (Table 2). The mean nitrogen availability across blocks was in the order (Fig. 3): Parithala (156.3 kg/ha) > Hodal (147.4 kg/ha) > Hathin (145.4 kg/ha) > Hassanpur (139.3 kg/ha) > Palwal (131.9 kg/ha). Although Parithala recorded the highest mean N, all blocks fell within the low fertility category (<250 kg/ha), indicating widespread nitrogen deficiency

Table 2 Status of available nitrogen, phosphorus and potassium (kg/ha) in soils of Palwal district

	Blocks	Nutrients	Mean	Median	Skewness	Kurtosis	Categorization of samples (%)	Interpretation (Antil <i>et al.</i> 2002)
Palwal District	Hodal	Nitrogen (kg/ha)	147.39	141.12	0.86	0.40	Low- 100	Low- <250 kg/ha
	Hathin		145.42	133.28	1.13	1.87	Low- 97 Medium- 3 High- 00	Medium- 250–500 kg/ha High- > 500 kg/ha
	Palwal		131.90	125.44	0.61	0.90	Low- 100	
	Hassanpur		139.28	133.28	0.93	1.71	Low- 98 Medium- 2	
	Parithla		156.30	141.12	0.98	0.27	Low- 85 Medium- 15	
	Hodal		Phosphorus (kg/ha)	33.35	34.80	-0.23	0.01	Low- 2 Medium- 8 High- 90
	Hathin	20.16		17.40	1.28	2.08	Low- 16 Medium- 38 High- 46	
	Palwal	38.73		27.00	1.89	4.93	Low- 6 Medium- 14 High- 80	
	Hassanpur	24.30		20.50	1.47	1.90	Low- 19 Medium- 30 High- 51	
	Parithla	23.52		22.40	0.86	-0.28	Low- 15 Medium- 30 High- 55	
	Hodal	Potassium (kg/ha)		447.73	409.59	2.02	0.62	Medium- 22 High- 78
	Hathin		270.41	220.22	2.62	7.88	Low- 5 Medium- 70 High- 25	
	Palwal		359.32	312.18	1.98	4.66	Low- 6 Medium- 39 High- 55	
	Hassanpur		362.82	258.94	1.66	1.58	Low- 8 Medium- 60 High- 32	
	Parithla		397.55	296.45	1.88	2.90	Low- 4 Medium- 48 High- 48	

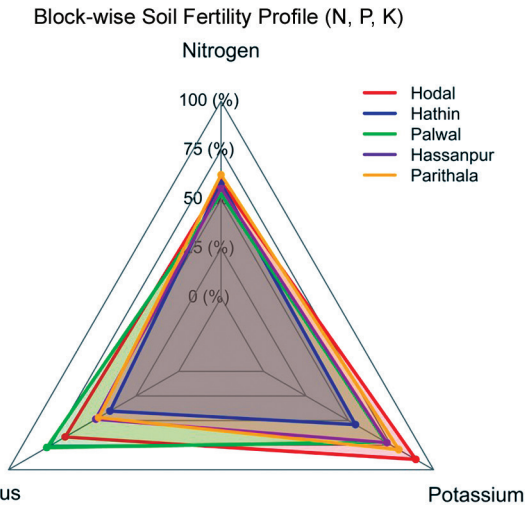


Fig. 3 Radar chart showing block-wise soil fertility profile of Palwal district based on mean values of available nitrogen, phosphorus, and potassium.

in the district. Notably, the lowest available nitrogen levels were observed in areas such as Karna and Barka villages, while the highest levels were found in Jorkhera village.

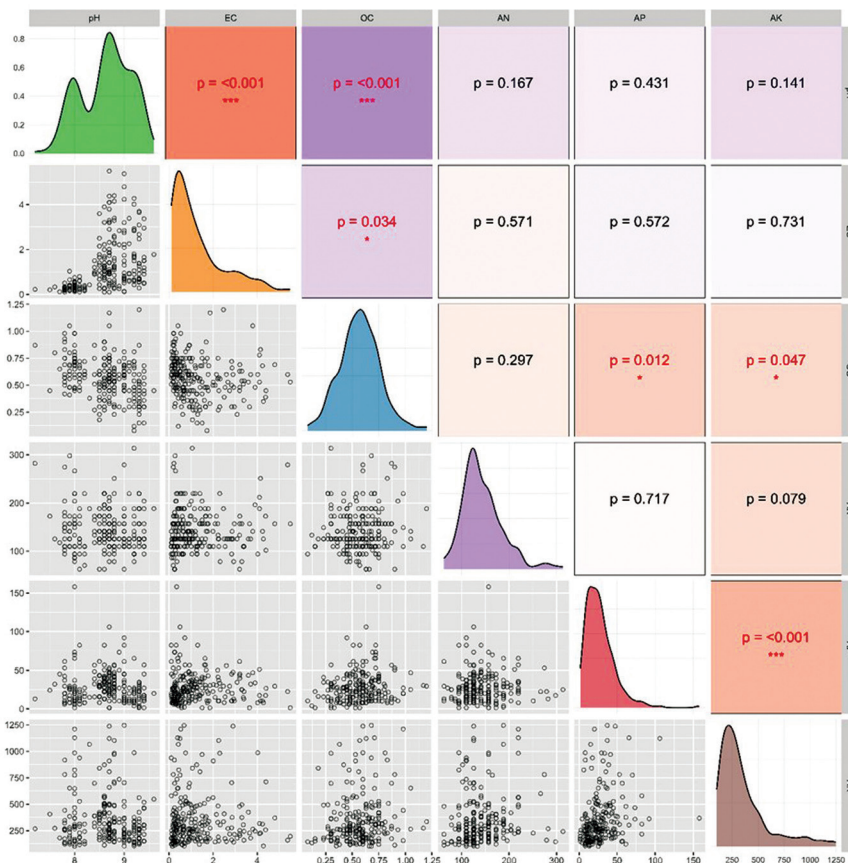


Fig. 4 Scatterplot matrix showing pairwise relationships among soil properties (pH, EC, OC, AN, AP, and AK) across the district. The diagonal illustrates variable distributions, while scatterplots depict pairwise patterns. Coloured backgrounds (blue to red) correspond to the strength and direction of correlations. EC, Electrical conductivity; OC, Organic carbon; AN, Available nitrogen; AP, Available phosphorus; AK, Available potassium.

The categorization of soil samples indicated that 100% of the samples in Hodal and Palwal, 97% in Hathin, 98% in Hassanpur, and 85% in Prithala are classified as nitrogen deficient, with only 3% (in Hathin) and 15% (in Prithala) falling into the medium category; no sample could have reached the high category. Improving nitrogen availability in Palwal could involve adopting more balanced fertiliser strategies, including the use of organic amendments to boost soil organic matter and microbial activity, which in turn enhances N mineralization.

Available phosphorus: The Olsen’s P ranged from 4.00–90.00 with a mean value of 25.40 kg/ha in the overall Palwal district. About 64% of the studied area lied under high category and 24% area under medium category (Fig. 2). Whereas, the district has 12% deficit area that has low-available soil phosphorus. The sampling points and P fertility status maps are however depicted in Fig. 1. The NIV for available phosphorus was found to be 2.52, indicating an overall high fertility rating for this phosphorus in the district. This elevated status is likely attributable to the continuous application of phosphorus-rich fertilisers such as DAP or SSP, which have progressively built up the soil phosphorus levels over time. Phosphorus from

phosphate fertilisers is less mobile in soils because it tends to bind strongly with clay minerals and organic matter. Over successive cropping cycles, even if crops remove some of the applied phosphorus, the remaining fraction gradually accumulates in the soil's exchangeable pool (Barrow and Debnath 2014). This build-up results in elevated P, indicating that the input of phosphorus exceeds the amount taken up by the crops and natural replenishment processes (Brar 2022).

The ranking of mean phosphorus availability was (Table 2), Palwal (38.7 kg/ha) > Hodal (33.4 kg/ha) > Hassanpur (24.3 kg/ha) > Parithala (23.5 kg/ha) > Hathin (20.2 kg/ha). Palwal block showed the highest P availability, with 80% of soils in the high category, while Hathin had the lowest mean P and a greater proportion of medium-fertility soils. Overall, district soils were medium to high in phosphorus. The lowest available phosphorus was found in Janchauli and Dudaal villages, whereas the highest was found in Chand hut village of Palwal district. The percent deficient, medium and high category available phosphorus were found i.e. 2, 8 and 90; 16, 38 and 46; 6, 14 and 80; 19, 30 and 51; 15, 30 and 55% in Hodal, Hathin, Palwal, Hassanpur and Prithala

blocks of the Palwal district, respectively (Table 2). The spatial variability in phosphorus distribution can be partly explained by non-uniform land-use patterns and management interventions, which likely influenced nutrient inputs, crop uptake, and subsequent soil P dynamics across the area.

Available potassium: The sampling points and the corresponding K fertility status maps are depicted in Fig. 1. In Palwal district, available soil potassium values ranged from 120–650 kg/ha, with an average of 325.50 kg/ha (Table 1). Approximately 50% of the sampled area is classified under the high potassium category, while 45% falls within the medium range (Fig. 2), and only 5% of the area shows a deficiency with low potassium availability. The nutrient index value for available potassium was determined to be 2.52, which indicated an overall high fertility rating for potassium in the district. However, when comparing these findings to the previous map generated in 2011, there is a noticeable shift: areas that were previously classified as high in potassium now fall into the medium category. This shift suggested that the neglect in potassium fertilisation over time has contributed to a gradual depletion of soil potassium levels in Palwal district. Crop mining of K has started appearing in the soils which is a matter of concern.

In Palwal district, the block-wise order of mean potassium was (Table 2): Hodal (447.7 kg/ha) > Parithala (397.6 kg/ha) > Hassanpur (362.8 kg/ha) > Palwal (359.3 kg/ha) > Hathin (270.4 kg/ha). Hodal block recorded the highest mean K, with 78% soils in the high category, whereas Hathin was dominated by medium fertility (70%). In general, soils of the district were adequate to high in potassium. The percent deficient, medium and high category available potassium were found i.e. 00, 22 and 78; 5, 70 and 25; 6, 39 and 55; 8, 60 and 32; 4, 48 and 48% in Hodal, Hathin, Palwal, Hassanpur and Prithala blocks of the Palwal district, respectively. The lowest available potassium was found in village Atar Chatta, whereas the highest was found in Dundasa village of the Palwal district. The observed potassium availability in Palwal soils can be attributed to several factors like inherent soil properties such as its texture (ranging from sandy loam to loam) and the presence of K-bearing minerals that provide an initial pool of available potassium. However, the shift from high to medium category potassium levels over time suggests that continuous crop removal without adequate replenishment through fertilisation has gradually depleted the soil's exchangeable potassium pool. In other words, the natural weathering of parent material and inputs from irrigation water are insufficient to compensate for the removal by crops (Das *et al.* 2019). Inadequate or neglected potassium fertilisation can further exacerbate this depletion, highlighting the importance of balanced nutrient management practices to maintain long-term soil fertility.

It is noteworthy that the CV of different soil properties exhibited distinct magnitudes, indicating considerable differences in the degree of variability among the studied soil parameters (Vimalashree and Sathish 2025). Among soil parameters, the greatest variation was observed in

phosphorus (47.60%) followed by EC (43.50%) whereas, the smallest variation was in soil pH (3.70). It is important to note that the present soil survey represents a single-time assessment, which may not capture temporal changes in nutrient availability influenced by management and climatic factors. The sampling density and spatial variability may also limit the precision of fertility zoning, contributing to intra-block differences in available N and P. Therefore, periodic resurvey and GIS-based temporal monitoring are essential to refine fertility mapping and support site-specific nutrient management in the district.

Soil fertility index: SFI calculated from 228 soil samples revealed a mean value of 1.79 ± 0.27 , placing the district soils in the medium fertility category. The distribution of samples showed that 9.5% of soils were low fertility, 83.1% medium fertility, and 7.4% high fertility. The fertility gradient across Palwal district followed the order: Palwal (1.93) > Hassanpur (1.90) > Prithala (1.89) > Hodal (1.77) > Hathin (1.56). This sequence indicates a gradual decline in soil fertility from the southern and central parts of the district toward the northern blocks. The comparatively higher SFI values in Palwal, Hassanpur, and Prithala (≈ 1.9) reflect fertile soils with balanced nutrient availability, moderate organic carbon content, and favourable chemical properties. In contrast, Hodal and Hathin recorded lower mean SFI values (1.77 and 1.56, respectively), suggesting medium to low fertility conditions that may be associated with lighter soil texture, reduced organic matter, and relatively higher pH and EC levels. While most soils across district exhibited adequate pH and potassium levels, the overall fertility index was constrained primarily by salinity ($EC > 0.8$ dS/m in several samples) and nitrogen deficiency, with additional influence from low to medium organic carbon content. These results indicate that site-specific nutrient management focusing on organic matter addition and balanced N and P fertilisation is essential for improving soil fertility in the district.

Correlation structure of soil properties: The correlation matrix (Fig. 4) revealed distinct relationships among soil properties across the district. Soil pH exhibited a significant positive correlation with electrical conductivity ($r = 0.44$, $p < 0.001$), implying that alkaline soil reaction is strongly influenced by the presence of soluble salts. This is consistent with salt-affected soils where elevated ionic strength contributes to both higher EC and pH values (Ankush *et al.* 2020). In contrast, pH showed a significant negative association with organic carbon ($r = -0.35$, $p < 0.001$), which might be due to accelerated decomposition of organic matter under alkaline conditions, limited biomass return in semi-arid alkaline soils, and the influence of calcareous/sodic conditions that restrict organic matter stabilization (Liao *et al.* 2016). Organic carbon also displayed weak but significant negative correlations with electrical conductivity ($p = 0.034$), and positive with available phosphorus ($p = 0.012$), and available potassium ($p = 0.047$). Salinity stress constrained biomass return and microbial activity, leading to reduced organic matter content (Ankush *et al.* 2020). These associations indicate the role

of organic matter in improving soil nutrient retention. However, the density plots on the diagonal showed that soil pH followed a bimodal distribution, while EC and AK were approximately normally distributed. Organic carbon and available phosphorus were positively skewed, indicating that most soils had low to moderate levels, with fewer enriched samples. Available nitrogen was near-normally distributed, reflecting relatively uniform levels across the district.

Principal component analysis (PCA): PCA grouped the soils into three distinct fertility clusters (Supplementary Fig. 1). PC1 was mainly influenced by organic carbon, while PC2 was dominated by available macronutrients (N, P, K). Cluster 1 (blue) comprised soils with relatively high nutrient availability, Cluster 2 (yellow) represented soils with higher organic matter content, and Cluster 3 (grey) included soils low in both nutrients and organic matter. The alignment of AP and AK vectors indicated a strong positive relationship, whereas OC was largely independent of nutrient availability. These results demonstrate that soil fertility variation in the district is primarily governed by organic matter status and nutrient availability gradients. The biplot (Supplementary Fig. 2) distinctly separated soils of Hathin and Hodal with higher OC and AK loadings, whereas Palwal, Hassanpur, and Parithla showed greater variation along PC2 due to differences in N and P availability. The scree plot confirmed that these two components effectively summarised the major spatial variation i.e. PC1 and PC2 explained 26% and 22.7% of the total variance, respectively, together accounting for 48.7% of the overall variability in soil properties.

Soils of Palwal district were found to be consistently deficient in nitrogen, with all blocks falling in the low category. In contrast, phosphorus was generally adequate to high with Palwal and Hodal blocks showing dominance. Potassium was sufficient across the district, with Hodal richest and Hathin comparatively weaker. SFI of the district was 1.79 placing it in the medium fertility category. Together correlation matrix and PCA analyses indicated that variation in soil fertility across the district is mainly controlled by organic matter status and macronutrient availability, while pH and EC play a secondary role. From a management perspective, the results emphasize the need to improve organic matter content in depleted soils and to ensure balanced application of phosphorus and potassium to sustain fertility. This information can be utilised for more precise fertiliser application, leading to better resource management and enhanced crop yields across the district.

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