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MACRO AND MICRO NUTRIENT PROFILING IN TEHSIL HAZRO SOILS: INSIGHTS INTO SPATIAL VARIABILITY

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Abstract

Understanding the nutrient status of agricultural soils is essential for optimizing crop growth and maximizing yields. Plants require 18 essential nutrients to grow and survive, classified by their importance into macronutrients (C, H, O, N, P, K, Ca, Mg, S) and micronutrients (B, Cu, Fe, Mn, Zn, Mo, Cl, Co, Ni). The adequate concentrations and proper balance of these nutrients are key to achieve the maximum agricultural yields. However, intensive agricultural practices have led to the depletion of both macro and micronutrients from soil. To assess soil nutrient depletion, the Agricultural Extension Department of Punjab initiated a Cluster Program, collecting 140 soil samples from 11 villages (Haroon 16, Ghourghushti 4, Nartopa 8, Malikmala 14, Khagwani 18, Jalalia 12, Shadi Khan 10, Formali 14, Shamsabad 22, Hameed 12, Bahadar Khan 10, soil samples, respectively) in Tehsil Hazro, District Attock. Analysis revealed that none of the samples were affected by soil salinity or sodicity, with electrical conductivity (EC) values ranging from 0.11-0.55 dS m^{-1} (mean 0.22 dS m^{-1}) and pH values ranging from 7.5-8.2 (mean 7.78). Soil saturation percentage varied from 26% to 54% (mean 40%), indicating soil textures of sandy loam, loam, and clay loam. Soil organic matter (SOM) levels ranged from 0.10%- 1.61%, with a mean of 0.72%, showing 67% of samples were deficient in SOM. Available phosphorus (P2O5) levels were critically low, ranging from 1-6 mg P Kg^{-1}, with 100% of samples showing P2O5 deficiency. Extractable potassium (K2O5) levels were sufficient, ranging from 120-360 mg K Kg^{-1}, with a mean of 177 mg K Kg^{-1}. Micronutrient analysis showed varying levels of zinc (Zn) (0.10-0.74 mg Kg^{-1}, mean 0.35 mg Kg^{-1}), copper (Cu) (0.02-1.40 mg Kg^{-1}, mean 0.54 mg Kg^{-1}), iron (Fe) (0.2-1.9 mg Kg^{-1}, mean 0.77 mg Kg^{-1}), and manganese (Mn) (0.00-0.62 mg Kg^{-1}, mean 0.12 mg Kg^{-1}). Based on these findings, site-specific fertilizer recommendations were provided to farmers to improve soil fertility management. These findings provide critical insights for targeted soil fertility management, enabling farmers to optimize nutrient application for improved crop productivity.

Keywords: *Crop productivity, Macro-nutrients, Micro-nutrients, Rainfed, Soil fertility*

INTRODUCTION

The assessment of soil fertility status and the determination of soil physicochemical properties is vital for ensuring maximum crop yield. Researchers have consistently demonstrated the significance of essential plant nutrients and the importance of their adequate supply to the soil. However, the development and breeding of high-yielding crop varieties and intensive land use have led to the depletion of essential nutrients in the soil, increasing the need for nutrient top-dressing to sustain productivity. Thus, understanding the chemical, biological, and physical relationships within the soil-plant system is critical for maintaining optimal nutrient availability, as nutrient balance is a key component for increasing crop yields (1).

The presence of humus in the topsoil serves as a reservoir for these essential elements, supporting soil fertility, biological activity, and soil water retention (2). Consequently, maintaining sufficient levels of SOM is essential for preserving soil productivity. Unfortunately, Pakistani soils generally have low SOM content due to limited water availability and extreme temperatures, which contributes to low productivity. To sustain agricultural output, it is crucial to maintain adequate SOM levels through repeated applications and proper management of SOM return (3). Soil fertility depends on the interaction of physical, chemical, and biological characteristics, including soil texture, pH, lime content, electrical conductivity, organic matter, and available plant nutrients such as macronutrients (N, P, and K) and micronutrients (Fe, Mn, Zn, and Cu). These properties are prerequisites for establishing soil fertility, which directly influences productivity. Although micronutrients are critical for soil health, they often receive less attention from farmers in rural areas who are unaware of their importance for sustainable crop production. Given the limited potential to expand cultivated land, future agricultural demands must be met through intensified, sustainable practices. This objective can only be achieved by maintaining soil fertility through the incorporation of essential nutrients, as intensive cultivation and high-yielding crop varieties continue to deplete the soil's nutrient reserves.

The deficiencies of micronutrients including Zn, Fe, and B in Pakistan's rainfed areas have extensively reported by many researchers previously. These deficiencies are attributed to alkaline soil pH and calcareousness (4, 5, 6). The intensive agricultural practices employed in these soils have resulted in reduced crop production, particularly in rainfed areas, where the nutrient budget shows a negative balance (7). Rainfall also plays a significant role in determining cropping systems and overall agricultural productivity in Pakistan's rainfed regions. Plant analysis has shown deficiencies in 50% of samples for N and P, and 80% of samples for Zn (8). This highlights the reality that plants exhaust substantial quantities of nutrients, particularly N, P, and K, from the soil. Therefore, meeting soil fertility requirements is essential to sustain healthy crop production. Accurate information about the nutrient status of a region is crucial for improving agricultural productivity, sustainability, and fertility management. This necessitates the analysis of data to enhance the productivity of soils, which often display high spatial variability due to the combined effects of physical, chemical, and biological processes. Soil sampling and testing provide an assessment of the soil's ability to supply sufficient nutrients, helping to address deficiencies and formulate precise recommendations (9).

This study aimed to gather accurate information about nutrient needs for different crops to provide judicious and economical recommendations for macronutrients (N, P, and K) and micronutrients (Fe, Mn, Zn, and Cu) in the main hubs (villages) of Tehsil Hazro, District Attock, Pakistan.

MATERIALS AND METHODS

LOCATION AND DESCRIPTION OF THE PROJECT AREA

Tehsil Hazro is situated in the north-west of Pakistan in District Attock. It lies between Peshawar and Islamabad (33.9097 °N to 72.4928 °E, at elevation of 361 m above the sea level). The mean annual rainfall is about 750 mm, predominately in monsoon (70%). The temperature varies between an average maximum of 28.9 °C and average minimum of 14.7°C (en.wikipedia.org/wiki/Hazro Tehsil). The soils are mainly medium to coarse textured. The soil fertility is very poor and changes with cropping pattern and management practices. In Pakistan, entire soils are almost nutrient deficient (10). The major crops of the area are wheat, gram, maize and groundnut while a substantial area is used for citrus, guava and apricot orchards. The trend of growing grapes is also increasing. Tehsil Hazro is well known for its vegetable production. Rainfall is prime source of water for irrigation however; wells and tube wells also exist in the area.

Total eleven Hubs namely, Haroon (33.9574 °N to 72.4446 °E), Ghourghushti (33.9447 °N to 72.5519 °E), Nartopa (33.9142 °N to 72.5186 °E), Malikmala (33.9300 °N to 72.4200 °E), Khagwani (33.8901°N to 72.5029 °E), Jalalia (33.9700°N to 72.5400°E), Shadi Khan (33.5435 °N to 72.4900 °E), Formali (33.9120 °N to 72.3900 °E), Shamsabad (33.8965 °N to 72.4192 °E), Hameed (33.9300 °N to 72.4500 °E) and Bahadar Khan (33.8772 °N to 72.4648 °E) were selected and from each Hub, various soil samples were collected from different locations.

Total 140 samples (Haroon 16, Ghourghushti 4, Nartopa 8, Malikmala 14, Khagwani 18, Jalalia 12, Shadi Khan 10, Formali 14, Shamsabad 22, Hameed 12, Bahadar Khan 10, soil samples, respectively) were collected.

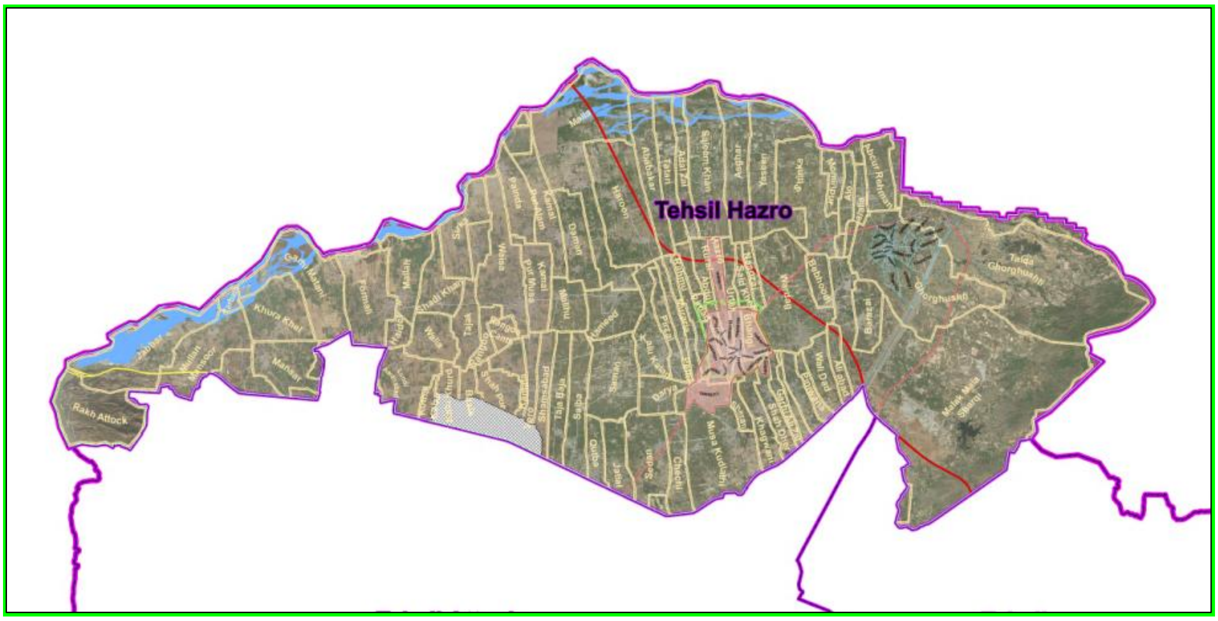

Fig. 1. Map of Tesil Hazro, Attock District

ANALYTICAL DETAILS OF SOIL SAMPLES

In this study 140 soil samples were collected from 11 villages (Haroon 16, Ghourghushti 4, Nartopa 8, Malikmala 14, Khagwani 18, Jalalia 12, Shadi Khan 10, Formali 14, Shamsabad 22, Hameed 12, Bahadar Khan 10, soil samples, respectively) in Tehsil Hazro, District Attock from (0-15 and 15-30 cm) depths by using soil augar (Table III-XIII). After collection, soil samples were labelled and stored in polythene bags brought to Soil and Water Testing Laboratory, Attock for analysis. To analyze, soil samples were air dried, crushed in mortar and pestle, and passed through 2 mm sieve. The stored soil samples were then subjected to analyses for soil texture, soil reaction (pH), electrical conductivity (EC), SOM, P_2O_5, K_2O and micronutrients (Zn, Cu, Fe, Mn) at the aforementioned laboratory. Soil pH was determined by using a soil-to-water ratio of 1:1, while EC was measured at a ratio of 1:10 soil to water. SOM content was assessed via titration method, P_2O_5 was extracted using 0.5 M $NaHCO_3$ and K_2O was extracted with 1 M CH_3COONH_4. Samples prepared for P_2O_5 and K_2O were analyzed using a spectrometer and flame-photometry, respectively. The concentration of extractable micronutrients (Zn, Cu, Fe and Mn) in soil was determined by the Diethylene Triamine Pentaacetic Acid (DTPA) solution. The references of methods used are given in Table 1. Statistical analysis of the data was performed using the MS Excel package.

Table I. Generalized guidelines used for interpretation of soil analysis data in Pakistan

Nutrient	Soil test	Unit	Low	Satisfactory	Adequate	Reference
O.M.	Walkley and Black	%	< 0.86	0.86-1.29	> 1.29	FAO (11)
P	$NaHCO_3$	mg kg^{-1}	< 10	10-15	> 15	Ahmad et al. (12)
K	NH_4OAc	mg kg^{-1}	< 60	60-120	> 120	Wahab (13)
Zn	DTPA	mg kg^{-1}	< 0.5	0.5-1.0	> 1.0	Martin and Lindsay (14)
Cu	DTPA	mg kg^{-1}	< 0.2	-	> 0.2	Martin and Lindsay (14)
Fe	DTPA	mg kg^{-1}	< 4.5	-	> 4.5	Martin and Lindsay (14)
Mn	DTPA	mg kg^{-1}	< 1.0	1.0-2.0	> 2.0	Martin and Lindsay (14)

RESULTS AND DISCUSSION

SOIL pH AND EC

The pH portrays the ratio of H^+ and OH^- ions in the soil solution. Soil solution possessing excess of H^+ leaves soil acidic while the dominance OH^- leads to alkaline soil condition. The equal concentrations of both these ions develop neutral conditions. The pH range 6.5-7.5 is the most appropriate for proper nutrient availability (21). Data presented in (Table 1) showed that soil pH of these villages was 7.5- 8.2 with an average value of 7.7, showed that all tested samples are alkaline in nature but no sample exceeded the critical limit (>8.5). Soil pH was slightly higher in surface soil (0-15 cm) compared with sub-surface soil (15-30 cm). The small variation in soil pH values could be attributed to variability of calcium carbonate, soil organic matter and in leaching of bases (22). This alkaline pH could also be due to the reaction of applied fertilizer material with soil colloids, which may have resulted in the reaction of basic cations on the exchangeable complex of the soil. The soils of Attock area are slight to strongly calcareous with neutral to strongly alkaline reaction and this situation is similar in almost all soils. These results are supported by the findings of earlier researchers (23). Such alkaline calcareous soils are generally favorable to nutrient deficiencies, particularly those of P, Zn and Fe (24).

The soil EC was 0.11-0.55 dS m^{-1} with an average of 0.22 dS m^{-1}. These results indicated that soil EC of these soils was normal which may be ascribed to leaching of salts to lower horizons. Earlier it was reported that these soils have low content of soluble salts and there is no danger of salinity (25). Similarly it was also investigated that the drainage water is characterized by its alkalinity, which allows reduction in the solubility of heavy metals (26). The results suggested that these soils were low (<2-4 dS m^{-1} at 25 °C) in electrolyte concentration due to leaching induced by heavy rainfall pattern (Table I). This low EC value is a matter of concern with respect to maintain the required level of bases on sustainable basis indicating the susceptibility of soils to nutrient leaching in the absence of adequate organic matter.

ORGANIC MATTER CONTENT

Data analysis reported that SOM in this region was 0.10-1.61% while average of all samples was 0.72%. It was concluded that only 6% samples possesses the adequate concentration of soil organic matter. Out of total, 70% samples were deficient (<0.86%) and 24% were in satisfactory range (0.86-1.29%). Such deficiency of soil organic matter have reported previously as well (1). These variations in the SOM might be due to the addition of different quantities of organic wastes. Low SOM might be due to limited addition of organic materials and their rapid mineralization due to warmer climate. The fact that largest source of SOM is crop residue but unfortunately in Pakistan and many other developing countries, negligible amount of crop residue is left in fields after crop harvest which is either used to feed animals, to make paper or used as a fuel (27).

SOIL PARTICLE SIZE DISTRIBUTION

The analysis of collected samples revealed that the texture of soils varied from sandy loam to clay loam. The presented results of particle soil analysis showed that the soils generally contained large proportion of silt followed by sand and very small proportion of clay. Majority of soils were loam (80%). These results suggested that the soils are generally medium textured. The particle size being loamy in nature suited to all kinds of agricultural crops and fruit trees. However, being well drained in nature, the chances of nutrient leaching are always more, if the level of organic matter is not maintained. Thus, it is very important to add organic and chemical fertilizer to maintain adequate fertility status of these soils.

MACRONUTRIENTS

All soil samples showed very low availability of P_2O_5. Phosphorous ranged from 1.0-6.0 mg Kg^{-1} with an average of 3.10 mg Kg^{-1}. P_2O_5 was found deficient in 94% samples, satisfactory 6% samples while no soil sample was found with adequate concentration (Table II). Standard deviation was 1.24 showing a wide range of variations in samples. Factors such as different parent material, low SOM and high sand and silt contents might be responsible for deficiency of P concentration (6, 10).

Status of K_2O in the soils was 120- 360 mg Kg^{-1} with an average of 177 mg Kg^{-1}. Most of the soil samples (64 %) were found in adequate range while 31% soil samples were found at satisfactory level having no deficiency of K. It might be due to the presence of sufficient mica (biotite and muscovite) in soil. The sand fraction of the alluvial soils of Pakistan is mainly composed of quartz; feldspars and biotite mica. The less weathered alluvial soils contain the highest K both in sand and silt. Most of the researchers reported the adequacy of K in Pakistani soils except some clayey soils (28).

Table II. Classification of soil samples on the basis of analysis

Category	EC (dS m^{-1})	pH	O.M. (%)	Av. P. (mg Kg^{-1})	Saturation (%)	Av. K (mg Kg^{-1})	Zn (mg Kg^{-1})	C u (mg Kg^{-1})	Fe (mg Kg^{-1})	Mn (mg Kg^{-1})
Average	0.22	7.78	0.72	3.10	39.59	177	0.35	0.54	0.77	0.12
Maximum	0.55	8.20	1.61	6.00	54.00	360	0.74	1.40	1.90	0.62
Minimum	0.11	7.50	0.10	1.00	26.00	120	0.10	0.02	0.20	0.00
St. Dev.	0.060	0.133	0.361	1.242	5.698	52.16	0.181	0.257	0.311	0.157

MICRONUTRIENTS

The value of zinc content ranges from 0.10 to 0.74 mg Kg^{-1} with an average of 0.35 mg Kg^{-1} in different soil samples. Copper content ranged from 0.02 to 1.40, with average: 0.54 mg Kg^{-1}. The deficiency of Fe was found to be ranged from (0.20 to 1.90, Average: 0.77 mg Kg^{-1}) in different soil samples whereas, soil analysis showed that Mn ranged from 0.0 to 0.62 mg Kg^{-1} with an average of 0.12 mg Kg^{-1} in all soil samples. Zn, Cu, Fe and Mn were found deficient in 74, 68, 20 and 24% samples, respectively. There are 26, 0, 48 and 46% samples of Zn, Cu, Fe and Mn was in satisfactory range. The adequacy of Zn, Cu, Fe and Mn were only in 0, 32, 34 and 28% soil samples. A great deficiency of these micronutrients particularly Zn and Fe could be due to low organic matter, high calcareousness and high soil pH (1).

The data analysis of 329 soil samples collected from various depths during the period of 7 months had marked widespread deficiency of Zn, B followed by Fe (29). The availability of soil micronutrients is very sensitive to environmental change and further organic matter, soil pH, lime content and particle size distribution interfere with their availability. Most coarse textured soils like in study areas are deficient in micronutrients since the clay content is relatively lesser in these soils (30).

Table III: Soil characterization of Haroon

Site	Depth (cm)	EC (dS m^{-1})	pH	O. M. (%)	Av. P. (mg Kg^{-1})	Av. K (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	Fe (mg Kg^{-1})	Mn (mg Kg^{-1})	Texture
1	0-15	0.23	8.0	1.27	4.5	240	0.1	0.46	0.98	0	Sandy Loam
	15-30	0.18	7.8	0.86	4.0	260	0.46	0.58	0.72	0	
2	0-15	0.19	7.9	0.86	3.5	220	0.14	0.62	0.84	0	Loam
	15-30	0.18	7.9	0.62	3.0	280	0.20	0.50	0.90	0	
3	0-15	0.18	7.9	0.96	4.0	320	0.14	0.54	0.64	0.1	Loam
	15-30	0.19	7.8	0.70	3.5	340	0.18	0.70	0.34	0	
4	0-15	0.17	8.0	0.72	3.2	360	0.16	1.40	0.36	0	Loam
	15-30	0.19	7.9	0.49	3.0	340	0.16	1.02	0.50	0	
5	0-15	0.20	7.8	1.17	5.0	320	0.12	0.50	0.76	0	Loam
	15-30	0.18	7.7	0.96	4.5	340	0.20	0.10	1.24	0	
6	0-15	0.20	7.9	1.30	5.0	180	0.36	0.26	1.12	0	Loam
	15-30	0.20	7.9	1.06	4.5	160	0.32	0.04	1.36	0.18	
7	0-15	0.25	7.7	1.30	5.0	220	0.28	0.34	1.34	0	Loam
	15-30	0.26	7.8	0.99	4.2	240	0.40	0.58	1.00	0	
8	0-15	0.21	7.7	0.72	3.5	260	0.34	0.10	0.48	0	Loam
	15-30	0.15	7.8	0.44	3.0	220	0.16	0.34	0.98	0	

Table IV. Soil Soil characterization Ghourghushti

Site	Depth (cm)	EC (dS m^{-1})	pH	O.M (%)	Av. P. (mg Kg^{-1})	Av. K (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	Fe (mg Kg^{-1})	Mn (mg Kg^{-1})	Texture
1	0-15	0.18	7.9	0.57	1.2	270	0.46	1.12	0.90	0	Sandy Loam
	15-30	0.20	7.9	0.27	1.0	240	0.28	0.04	0.52	0.04	
2	0-15	0.21	7.9	0.57	1.2	220	0.42	0.02	0.74	0	Clay Loam
	15-30	0.21	7.8	0.26	1.0	240	0.18	0.46	0.82	0	

Table V. Soil Soil characterization of Nartopa

Site	Depth (cm)	EC (dS m-1)	pH	O.M (%)	Av. P. (mg Kg-1)	Av. K (mg Kg-1)	Zn (mg Kg-1)	Cu (mg Kg-1)	Fe (mg Kg-1)	Mn (mg Kg-1)	Texture
1	0-15	0.18	7.8	1.33	5.2	160	0.34	0.08	1.44	0.22	Loam
	15-30	0.17	7.7	1.19	4.5	180	0.36	0.30	0.42	0	
2	0-15	0.23	7.6	1.37	6.0	140	0.38	0.74	0.76	0	Loam
	15-30	0.19	7.7	0.88	4.5	160	0.39	0.70	0.88	0	
3	0-15	0.23	7.7	0.96	4.8	180	0.31	0.62	0.78	0	Loam
	15-30	0.24	7.8	0.78	4.2	160	0.33	0.46	1.22	0	
4	0-15	0.24	7.9	1.35	5.5	180	0.41	0.44	0.86	0.10	Loam
	15-30	0.21	7.9	1.12	5.0	140	0.42	0.16	0.64	0	

Table VI. Soil characterization of Malikmala

Site	Depth (cm)	EC (dS m-1)	pH	O.M. (%)	Av. P. (mg Kg-1)	Av. K (mg Kg-1)	Zn (mg Kg-1)	Cu (mg Kg-1)	Fe (mg Kg-1)	Mn (mg Kg-1)	Texture
1	0-15	0.55	7.8	0.96	3.5	120	0.28	0.30	0.76	0	Loam
	15-30	0.24	7.9	0.65	3.0	160	0.24	0.42	0.62	0	
2	0-15	0.18	7.7	1.4	5.5	160	0.32	0.86	0.90	0	Loam
	15-30	0.15	7.6	0.99	5.0	180	0.16	0.74	0.68	0	
3	0-15	0.21	8.0	0.46	1.5	140	0.30	0.76	0.76	0	Clay Loam
	15-30	0.18	7.9	0.16	1.0	120	0.42	0.50	0.54	0	
4	0-15	0.25	7.7	0.83	3.2	180	0.46	0.62	0.64	0	Loam
	15-30	0.28	7.7	0.44	3.0	160	0.28	0.08	0.42	0	
5	0-15	0.23	7.9	0.41	1.0	240	0.10	0.16	0.50	0	Loam
	15-30	0.23	7.8	0.10	150	220	0.10	0.34	0.62	0.04	
6	0-15	0.24	7.9	0.49	150	280	0.40	0.60	0.70	0	Clay Loam
	15-30	0.26	7.8	0.23	150	240	0.34	0.46	0.56	0	
7	0-15	0.21	7.9	0.99	150	240	0.28	0.76	1.28	0	Loam
	15-30	0.13	7.9	0.59	150	180	0.18	0.64	0.70	0	

Table VII. Soil characterization of Khagwani

Site	Depth (cm)	EC (dS m-1)	pH	O.M. (%)	Av. P. (mg Kg-1)	Av. K (mg Kg-1)	Zn (mg Kg-1)	Cu (mg Kg-1)	Fe (mg Kg-1)	Mn (mg Kg-1)	Texture
1	0-15	0.34	8	1.37	4.0	220	0.16	0.02	0.86	0.20	Loam
	15-30	0.24	7.9	1.17	3.5	120	0.22	0.62	0.64	0	
2	0-15	0.34	8.2	0.33	1.5	180	0.36	0.22	0.70	0	Loam
	15-30	0.27	8.0	0.16	1.0	140	0.14	0.04	0.78	0	
3	0-15	0.23	7.9	0.44	2.8	120	0.18	0.72	0.80	0	Loam
	15-30	0.20	7.9	0.17	1.5	160	0.14	0.64	0.74	0	
4	0-15	0.50	8	1.04	3.8	140	0.32	0.82	1.20	0.12	Loam
	15-30	0.30	7.9	0.52	3.2	180	0.30	0.78	1.16	0.10	
5	0-15	0.17	7.6	0.68	3.2	160	0.40	0.48	1.18	0	Loam
	15-30	0.21	7.7	0.31	2.0	120	0.28	0.42	1.10	0	
6	0-15	0.18	7.7	0.62	2.5	140	0.36	0.72	0.90	0.14	Loam
	15-30	0.26	7.7	0.28	2.0	180	0.32	0.68	0.76	0.10	
7	0-15	0.24	7.8	1.43	4.2	140	0.42	0.90	0.84	0	Loam
	15-30	0.17	7.7	0.96	3.5	120	0.36	0.82	0.82	0	
8	0-15	0.23	7.8	1.32	4.0	140	0.46	0.64	0.98	0.16	Loam
	15-30	0.23	7.8	0.91	3.2	140	0.40	0.62	0.90	0.16	
9	0-15	0.24	7.8	0.54	2.5	180	0.38	0.60	1.40	0.12	Clay Loam
	15-30	0.23	7.8	0.26	2.0	160	0.26	0.58	1.20	0.10	

Table VIII. Soil characterization of Jalalia

Site	Depth (cm)	EC (dS m-1)	pH	O.M. (%)	Av. P. (mg Kg-1)	Av. K (mg Kg-1)	Zn (mg Kg-1)	Cu (mg Kg-1)	Fe (mg Kg-1)	Mn (mg Kg-1)	Texture
1	0-15	0.21	7.9	0.6	3	180	0.46	1.10	0.78	0	Clay Loam
	15-30	0.21	7.9	0.28	2.5	150	0.32	0.98	0.72	0	
2	0-15	0.19	7.8	0.49	1.2	160	0.48	0.90	0.34	0.18	Loam
	15-30	0.17	7.9	0.26	1.0	170	0.36	0.72	0.20	0.10	
3	0-15	0.24	7.9	0.88	3.2	180	0.30	0.66	0.62	0.14	Loam
	15-30	0.21	7.9	0.62	3.0	150	0.22	0.60	0.60	0.12	
4	0-15	0.32	7.9	1.61	4.5	160	0.40	0.74	0.70	0.12	Loam
	15-30	0.33	7.8	1.30	4.0	180	0.34	0.70	0.40	0.10	
5	0-15	0.24	7.8	0.49	1.0	160	0.28	0.62	0.60	0	Clay Loam
	15-30	0.22	7.8	0.18	1.0	180	0.18	0.60	0.46	0	
6	0-15	0.24	7.8	0.60	3.0	120	0.40	0.44	0.84	0	Loam
	15-30	0.22	8.0	0.31	2.4	160	0.32	0.36	0.70	0	

Table IX. Soil characterization of Shadi Khan

Site	Depth (cm)	EC (dS m^{-1})	pH	O.M. (%)	Av. P. (mg Kg^{-1})	Av. K (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	Fe (mg Kg^{-1})	Mn (mg Kg^{-1})	Texture
1	0-15	0.22	7.8	0.91	4.5	180	0.36	0.28	0.62	0	Loam
	15-30	0.21	7.8	0.68	3.2	260	0.30	0.20	0.62	0	
2	0-15	0.22	7.7	1.24	4.5	280	0.50	0.48	0.84	0.22	Loam
	15-30	0.19	7.7	0.99	4.0	320	0.46	0.42	0.74	0.12	
3	0-15	0.2	7.6	0.57	3.0	180	0.60	0.66	0.48	0	Loam
	15-30	0.13	7.5	0.44	2.5	160	0.52	0.62	0.72	0	
4	0-15	0.14	7.5	0.52	2.8	180	0.48	1.12	0.86	0.14	Loam
	15-30	0.19	7.6	0.41	2.5	160	0.40	0.92	0.80	0.12	
5	0-15	0.18	7.7	0.80	3.5	160	0.44	0.62	1.16	0.18	Loam
	15-30	0.16	7.7	0.65	3.2	180	0.32	0.60	1.12	0.14	

Table X. Soil characterization of Formali

Site	Depth (cm)	EC (dS m^{-1})	pH	O.M. (%)	Av. P. (mg Kg^{-1})	Av. K (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	Fe (mg Kg^{-1})	Mn (mg Kg^{-1})	Texture
1	0-15	0.23	7.7	0.55	3	150	0.40	0.44	0.90	0.32	Loam
	15-30	0.25	7.7	0.46	2.6	180	0.32	0.36	0.84	0.34	
	0-15	0.24	7.6	0.6	2.8	120	0.38	0.64	0.48	0.32	Loam
	15-30	0.20	7.7	0.39	2.5	150	0.32	0.60	0.42	0.24	
2	0-15	0.23	7.8	1.24	5.0	160	0.46	0.28	1.40	0.30	Loam
	15-30	0.22	7.8	0.80	4.5	120	0.40	0.20	1.32	0.30	
	0-15	0.22	7.8	1.22	4.8	150	0.48	0.14	0.72	0.38	Loam
	15-30	0.22	7.8	0.57	4.2	160	0.40	0.10	0.70	0.32	
3	0-15	0.29	7.6	0.68	3.0	160	0.46	0.16	1.90	0.30	Loam
	15-30	0.25	7.6	0.31	2.0	180	0.38	0.12	1.72	0.20	
4	0-15	0.29	7.6	1.09	3.5	150	0.40	0.18	0.74	0	Loam
	15-30	0.49	7.6	0.52	2.5	170	0. 40	0.16	0.62	0	
5	0-15	0.21	7.8	0.65	3.0	120	0. 26	0.72	1.68	0	Loam
	15-30	0.28	7.7	0.36	2.0	160	0. 18	0.62	1.60	0	

Table XI. Soil characterization of Shamsabad

Site	Depth (cm)	EC (dS m^{-1})	pH	O.M. (%)	Av. P. (mg Kg^{-1})	Av. K (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	Fe (mg Kg^{-1})	Mn (mg Kg^{-1})	Texture
1	0-15	0.19	7.5	1.58	4.5	150	0.28	0.90	0.76	0.18	Loam
	15-30	0.11	7.6	1.22	3.5	120	0.28	0.80	0.72	0.14	
2	0-15	0.23	7.9	1.06	4.0	160	0.18	1.0	1.30	0	Loam
	15-30	0.24	7.9	0.88	3.0	150	0.16	1.0	1.14	0	
3	0-15	0.17	7.5	0.60	3.0	120	0.22	0.74	0.46	0.36	Loam
	15-30	0.17	7.5	0.52	2.8	160	0.16	0.68	0.42	0.32	
4	0-15	0.17	7.6	0.59	3.0	150	0.62	0.72	0.96	0	Loam
	15-30	0.18	7.7	0.46	2.6	160	0.18	0.66	0.82	0	
5	0-15	0.20	7.5	0.68	3.2	120	0.34	0.82	0.78	0.48	Loam
	15-30	0.21	7.6	0.55	3.0	160	0.30	0.78	0.66	0.40	
6	0-15	0.16	7.5	0.70	3.5	180	0.48	0.72	0.86	0	Loam
	15-30	0.15	7.5	0.36	3.0	120	0.36	0.64	0.82	0	
7	0-15	0.21	7.8	1.35	5.6	160	0.32	0.50	0.56	0.54	Loam
	15-30	0.22	7.8	1.12	5.0	180	0.28	0.42	0.42	0.46	
8	0-15	0.19	7.7	1.27	4.2	120	0.62	0.66	0.44	0.16	Loam
	15-30	0.20	7.8	1.04	3.8	160	0.56	0.42	0.32	0.12	
9	0-15	0.19	7.8	0.68	3.0	150	0.48	0.70	0.48	0	Loam
	15-30	0.21	7.8	0.50	2.6	160	0.40	0.62	0.42	0	
10	0-15	0.18	7.9	0.49	1.2	160	0.44	0.48	0.88	0.10	Sandy Loam
	15-30	0.19	7.8	0.13	1.0	220	0.32	0.40	0.74	0.10	
11	0-15	0.23	7.9	0.60	2.8	200	0.50	0.44	0.90	0.48	Loam
	15-30	0.18	8.0	0.33	1.5	150	0.44	0.36	0.84	0.42	

Table XII. Soil textural class, pH, EC and organic matter content of Hameed

Site	Depth (cm)	EC (dS m^{-1})	pH	O.M. (%)	Av. P. (mg Kg^{-1})	Av. K (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	Fe (mg Kg^{-1})	Mn (mg Kg^{-1})	Texture
1	0-15	0.14	7.6	0.7	3.4	160	0.34	0.70	0.50	0.56	Loam
	15-30	0.14	7.7	0.42	3.0	170	0.32	0.62	0.44	0.52	
2	0-15	0.16	7.7	0.65	3.2	120	0.26	0.72	0.48	0.60	Loam
	15-30	0.13	7.8	0.39	3.0	160	0.20	0.62	0.42	0.34	
3	0-15	0.18	7.7	0.85	3.2	180	0.18	0.68	0.60	0.14	Loam
	15-30	0.21	7.7	0.65	3.0	160	0.14	0.64	0.46	0.12	
4	0-15	0.18	7.6	0.87	4.0	150	0.34	0.46	0.72	0.10	Loam

	15-30	0.15	7.6	0.59	3.5	160	0.30	0.44	0.64	0.10	
5	0-15	0.2	7.7	1.27	4.6	170	0.48	0.48	0.76	0.32	Loam
	15-30	0.21	7.7	0.8	4.0	120	0.40	0.40	0.72	0.26	
6	0-15	0.19	7.7	1.11	4.2	160	0.24	0.34	0.80	0	Clay Loam
	15-30	0.18	7.7	0.78	3.5	120	0.22	0.26	0.74	0	

Table XIII. Soil characterization of Bahadar Khan

Site	Depth (cm)	EC (dS m^{-1})	pH	O.M. (%)	Av. P. (mg Kg^{-1})	Av. K (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	Fe (mg Kg^{-1})	Mn (mg Kg^{-1})	Texture
1	0-15	0.18	7.8	0.44	1.2	140	0.66	0.72	0.78	0.62	Sandy Loam
	15-30	0.17	7.9	0.20	1.0	160	0.54	0.56	0.66	0.54	
2	0-15	0.21	7.9	0.39	1.0	140	0.70	0.42	0.72	0.24	Loam
	15-30	0.21	8	0.18	1.0	180	0.62	0.36	0.46	0.20	
3	0-15	0.20	7.9	0.39	1.2	120	0.66	0.52	0.42	0	Sandy Loam
	15-30	0.20	7.8	0.21	1.0	140	0.60	0.40	0.54	0	
4	0-15	0.23	7.8	0.65	3.0	160	0.74	0.52	0.46	0.18	Sandy Loam
	15-30	0.23	7.9	0.31	2.8	180	0.66	0.40	0.32	0.14	
5	0-15	0.20	7.8	1.14	3.5	160	0.70	0.70	0.34	0.30	Sandy Loam
	15-30	0.21	7.8	0.70	3.0	120	0.68	0.62	0.28	0.24	

CONCLUSION

On the basis of results of this study we concluded that the pH of all soil samples was found to be alkaline, but no visible symptoms of salinity or sodicity were observed in any of the hub villages. SOM was critically low, with 70% of the samples categorized as inadequate. A widespread deficiency of P_2O_5 was evident, with 94% of the soil samples lacking adequate levels. In contrast, K_2O levels were sufficient across all samples. Micronutrient analysis revealed significant deficiencies of DTPA-extractable Zn and Fe, at 74% and 68% respectively. However, Cu and Mn levels were largely adequate, with deficiencies noted in only 20% and 24% of the samples. These findings underscore the urgent need for tailored soil fertility management in the study area. It is recommended to adopt variable-rate fertilization, particularly focusing on P, Zn, and Fe, while ensuring a sufficient supply of SOM to improve soil health and productivity. Regular soil testing should be implemented to monitor fertility trends and facilitate informed decision-making for sustainable soil management in the future.

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