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GPS and GIS based soil fertility assessment and mapping in Bihariganj Block of Madhepura District

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Abstract
This study examines soil chemical properties and micronutrient availability in Bihariganj block, Madhepura district, Bihar, India, using GPS and GIS technologies. Analyzing 92 soil samples from a 1 km grid, results showed a pH range of 5.6-8.5 (mostly neutral), low salinity (average EC 0.23 dS/m), and variable organic carbon (0.11-0.84%). Micronutrient analysis revealed sufficient Cu and Fe levels (with some Cu toxicity concerns), higher Mn in acidic soils, and widespread Zn deficiency. Soil pH strongly influenced micronutrient availability, with acidic soils enhancing Fe, Mn, Cu, and Zn solubility. Organic carbon showed a weak to moderate correlation with nutrient retention. The study underscores the need for integrated soil management, including pH optimization, organic matter enrichment, and targeted Zn fertilization, to improve soil health and crop productivity. Long-term monitoring and site-specific strategies are recommended for sustainable agriculture.

Keywords: DTPA-extractable micronutrients, GIS, soil mapping, sustainable agriculture

1. Introduction
Micronutrients such as iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) play critical roles in crop production, as they are essential for various physiological and biochemical processes in plants. Their importance in agriculture has been widely studied, and deficiencies in these micronutrients can significantly limit crop yield and quality. Iron (Fe) is a key component of enzymes involved in chlorophyll synthesis, photosynthesis, and respiration. It is also essential for electron transport in chloroplasts and mitochondria. Its deficiency cause chlorosis (yellowing) in young leaves, stunted growth, and reduced yield (Briat *et al*. 2015) [4]. Manganese (Mn) is essential for photosynthesis, as it is a component of the oxygen-evolving complex in Photosystem II. It also activates enzymes involved in nitrogen metabolism and antioxidant defense. Interveinal chlorosis, necrotic spots, and poor root development are the key symptoms of its deficiency. (Millaleo *et al.* 2010) [12]. Copper (Cu) is a cofactor for enzymes involved in photosynthesis, respiration, and lignin synthesis. It also plays a role in antioxidant defense and cell wall metabolism. Wilting, chlorosis, and stunted growth are the deficiency symptoms of Cu (Yruela 2005) [18]. Zinc (Zn) is vital for enzyme activation, protein synthesis, and auxin (a plant hormone) production. It also plays a role in maintaining membrane integrity and stress tolerance. In the deficiency of Zn plant get stunted, reduced leaf size, and interveinal chlorosis (Cakmak 2008) [5]. Overall the micronutrients are required in small quantities but are indispensable for optimal plant growth and development. Deficiencies can lead to reduced crop yields, poor quality produce, and increased susceptibility to diseases and environmental stresses. Soil micronutrient deficiencies are becoming more prevalent due to intensive farming practices, soil erosion, and imbalanced fertilizer use (Alloway 2008) [1, 2].
The integration of Global Positioning System (GPS) and Geographic Information System (GIS) technologies has revolutionized soil mapping, enabling precision agriculture and sustainable crop production. These tools provide accurate spatial data, facilitate efficient resource management, and support decision-making processes for optimizing agricultural practices. GPS technology provides precise location data (latitude, longitude, and elevation) for soil sampling and mapping.

It enables the collection of geo-referenced soil data, which is critical for creating accurate soil maps (Zhang *et al*. 2002) [19]. GIS is a powerful tool for analyzing, visualizing, and interpreting spatial data. It integrates GPS-collected soil data with other layers of information (e.g., topography, climate, and land use) to create detailed soil maps and models. It also identifying soil fertility zones and nutrient deficiencies, predicting crop suitability and yield potential, and planning sustainable land use and conservation practices (McBratney *et al.* 2003) [11]. The combination of GPS and GIS allows for the creation of high-resolution soil maps, which are essential for site-specific management practices. This integration supports sustainable agriculture by reducing input costs (e.g., fertilizers, pesticides, and water), minimizing environmental impacts (e.g., nutrient runoff and soil erosion), enhancing crop productivity and resource use efficiency (Stafford 2000) [14]. GPS-guided soil sampling combined with GIS analysis helps identify nutrient-deficient zones, enabling targeted fertilizer application, GIS models (e.g., RUSLE) use GPS data to assess soil erosion risks and plan conservation measures, GIS-based soil maps help farmers select suitable crops for specific soil types, improving yield and sustainability (Tagarakis *et al.* 2013) [16].

Bihariganj Block is one of the administrative blocks in the Madhepura district of Bihar, India. It is located in the Kosi Division of Bihar and is known for its agricultural economy and rural lifestyle. Bihariganj block is situated in the northern part of Bihar, within the Madhepura district at 25.75° N latitude and 86.85° E longitude. The region is part of the fertile Gangetic plains, with flat terrain and alluvial soil, making it suitable for agriculture. The Kosi River, often referred to as the "Sorrow of Bihar," flows near the region, influencing the agricultural and socio-economic conditions.

2. Materials and Methods

The soil samples were collected at 1 km grid points from 0-15 cm topsoil after harvesting Rabi crops with the help of Garmin GPS device and soil auger and collected in a clean polythene bag. A total 92 soil samples were taken on grid points in the block of Bihariganj. The topographic maps of 1:50000 scale procured from the Survey of India were used as a base map. For GIS software, ArcGIS was used to map and analyze soil data. Label the sample bags and keep soil samples in a cool, dry place to prevent contamination or degradation. Analyze the soil sample for different parameter in soil testing laboratory and transfer the GPS coordinates and sample details to a spreadsheet as well as GPS software to create a map of sampling points for visualization and analysis (McBratney *et al*. 2003) [11].

The soil samples were ground and sieved through a 2-mm mesh, after which they were analyzed for their chemical properties and micronutrients (e.g. Fe, Mn, Zn, and Cu). Soil pH and electrical conductivity (EC) were measured in a 1:2.5 soil-water suspension using a pH meter and EC meter. Organic carbon content in the soil was estimated using the rapid titration method described by Walkley and Black, 1934. The DTPA-extractable micronutrients (Fe, Mn, Zn, and Cu) were determined following the procedure given by Lindsay and Norvell, 1978 [9]. The concentrations of Fe, Mn, and Cu were quantified using an atomic absorption spectrophotometer. Based on established rating limits, the soil samples were categorized as either deficient or sufficient in these micronutrients.

3. Results and Discussion

Chemical Properties of Soils

Data about chemical properties of soil viz., pH, EC, organic carbon of soils of Bihariganj block of Madhepura is presented in Table 1. The soil pH data summary is as follows: A total of 92 samples were analyzed, with pH values ranging from 5.6 to 8.5. The average pH across all samples was approximately 6.8. The most frequently occurring pH values were 6.5, 6.6, 6.8, 7.0, 7.2, 7.6, 7.7, 8.1, and 8.4. In terms of distribution, 32 samples were classified as acidic (pH < 6.5), 48 samples fell within the neutral range (pH 6.5-7.5), and 20 samples were alkaline (pH > 7.5).

The soil EC (electrical conductivity) values ranged from 0.10 to 0.61 dS/m and the average EC value across all samples was approximately 0.23 dS/m. The most frequently occurring EC values were 0.18, 0.24, and 0.26 dS/m. The majority of the samples (approximately 70%) had EC values below 0.30 dS/m, indicating low salinity levels (Non-saline soil) suitable for most crops. However, a few samples (e.g., 0.40, 0.43, 0.45, 0.48, 0.59, and 0.61 dS/m) showed higher salinity levels, which may require management practices to mitigate potential impacts on plant growth. Overall, the data suggest that most of the soil samples have low to moderate salinity, with a small proportion exhibiting elevated EC levels.

The soil organic carbon (SOC) data ranged from 0.11% to 0.84%, with an average value of 0.47%. The majority of the values fell within the range of 0.30% to 0.60%, indicating moderate organic carbon content in the soil. However, some samples exhibited very low SOC levels, such as 0.11%, 0.16%, and 0.18%, suggesting potential degradation or poor soil health in those areas. Conversely, higher SOC values, such as 0.75%, 0.77%, and 0.84%, were observed in certain samples, indicating healthier soil conditions with better organic matter retention. These variations in SOC levels highlight the spatial heterogeneity of soil properties, which can be influenced by factors such as land use, management practices, and environmental conditions (Lal, 2004 and Six *et al*., 2002) [8, 13].

DTPA-extractable Micronutrients

A wide range of spatial distribution of DTPA extractable micronutrients was noticed in soils of Bihariganj block of Madhepura district (Table 1). The criteria for assessment of micronutrient status in soils and plants were mentioned in Table 2.

- **Available Copper (Cu)**

The available copper (Cu) levels in the soil samples range from 0.70 to 6.86 ppm, with an average of approximately 1.85 ppm. Most samples fall within the sufficiency range for Cu (1-5 ppm), as defined by Lindsay and Norvell (1978) [9]. However, a few samples exhibit elevated Cu levels (> 5 ppm), which may indicate potential toxicity risks in those soils. This finding is supported by Lindsay and Norvell (1978) [9], who established critical levels for Cu availability in soils, with 1-5 ppm considered sufficient for most crops.

- **Available Iron (Fe)**

The available iron (Fe) levels range from 7.76 to 69.68 ppm, with an average of approximately 38.50 ppm. Fe availability is generally sufficient, as most samples exceed the critical level of 4.5 ppm, as per Lindsay and Norvell (1978) [9]. However, some samples show very high Fe levels (> 50 ppm), which may indicate reducing conditions or excessive Fe availability, particularly in acidic soils. This observation aligns with Lindsay and Norvell (1978) [9], who highlighted that Fe availability is strongly influenced by soil pH, with acidic soils favoring higher Fe solubility.

- **Available Manganese (Mn)**

The available manganese (Mn) levels range from 2.22 to 81.60 ppm, with an average of approximately 22.50 ppm. Mn availability is highly variable, with some samples showing very high levels (> 50 ppm), particularly in acidic soils. This variability is consistent with the findings of Fageria *et al.* (2011) [6], who noted that Mn availability increases significantly in acidic conditions. They also emphasized the impact of soil pH on Mn solubility, with acidic soils favouring higher Mn availability.

- **Available Zinc (Zn)**

The available zinc (Zn) levels range from 0.12 to 2.84 ppm, with an average of approximately 1.30 ppm. Zn availability is generally low, with many samples falling below the critical level of 1.0 ppm, as established by Lindsay and Norvell (1978) [9]. This suggests potential Zn deficiency in these soils, which could limit crop productivity. Lindsay and Norvell (1978) [9] also noted that Zn availability is strongly influenced by soil pH, with alkaline soils reducing Zn solubility.

Interrelationships between Micronutrients:

- **Fe and Mn:** A positive correlation is observed between Fe and Mn availability, particularly in acidic soils. This is consistent with the findings of Marschner (2012) [10], who noted that both Fe and Mn availability increases under acidic conditions due to reduced precipitation and oxidation.
- **Cu and Zn:** There is a weak positive correlation between Cu and Zn availability, likely due to their similar chemical behavior in soils. However, Zn availability is more strongly influenced by soil pH compared to Cu. Alloway (2008) [1, 2]: Focused on Zn dynamics and its interactions with Cu, emphasizing pH effects.

Correlation between soil properties and DTPA-extractable Micronutrients

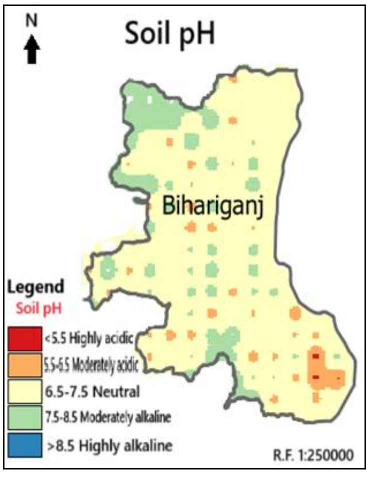
Data in Table 4 showed the correlation between micronutrients and chemical properties of soil. The correlation analysis between soil pH, organic carbon (OC%), and micronutrients (Fe, Mn, Cu, and Zn) reveals the following relationships:

Soil pH and Micronutrients

- **Copper (Cu):** Cu availability shows a weak negative correlation with soil pH. Acidic soils tend to have slightly higher Cu availability, though the relationship is less pronounced compared to Fe and Mn. This is supported by Marschner (2012) [10], who noted that Cu availability is influenced by pH but is also strongly affected by organic matter and soil mineralogy.
- **Iron (Fe):** There is a negative correlation between soil pH and available Fe. Lower pH (acidic soils) is associated with higher Fe availability, as observed in the data where acidic soils (pH < 6.5) consistently show higher Fe levels. This aligns with the findings of Lindsay and Norvell (1978) [9], who demonstrated that Fe solubility increases in acidic conditions due to reduced precipitation and increased ion exchange.
- **Manganese (Mn):** Similar to Fe, Mn availability shows a negative correlation with soil pH. Acidic soils (pH < 6.5) exhibit higher Mn availability, while alkaline soils (pH > 7.5) show reduced Mn levels. This is consistent with the research by Fageria *et al.* (2011) [6], which highlights that Mn availability decreases in alkaline soils due to oxidation and precipitation.
- **Zinc (Zn):** Zn availability exhibits a strong negative correlation with soil pH. Acidic soils (pH < 6.5) show significantly higher Zn availability, while alkaline soils (pH > 7.5) have lower Zn levels. This is consistent with the findings of Lindsay and Norvell (1978) [9], who reported that Zn solubility decreases in alkaline soils due to adsorption and precipitation.

Organic Carbon (OC%) and Micronutrients

- **Copper (Cu):** A weak positive correlation exists between OC% and Cu availability. Organic matter can form stable complexes with Cu, increasing its availability in the soil. This is consistent with the research by Marschner (2012) [10], who noted that organic matter plays a key role in Cu chelation.
- **Iron (Fe):** There is a weak positive correlation between OC% and Fe availability. Higher organic carbon content tends to enhance Fe availability, likely due to the formation of organic complexes that prevent Fe precipitation. This is supported by Stevenson (1994), who highlighted the role of organic matter in chelating Fe and increasing its availability.
- **Manganese (Mn):** OC% shows a moderate positive correlation with Mn availability. Soils with higher organic carbon content tend to have higher Mn levels, as organic matter can reduce Mn oxidation and enhance its solubility. This aligns with the findings of Brady and Weil (2016) [3], who emphasized the role of organic matter in micronutrient availability.
- **Zinc (Zn):** OC% shows a weak positive correlation with Zn availability. Higher organic carbon content tends to enhance Zn availability, likely due to the formation of organic-Zn complexes. Lindsay and Norvell (1978) [9] supported this, highlighting the importance of organic matter in Zn solubility.



Interactions Between pH and OC%

The combined effect of pH and OC% on micronutrient availability is evident in the data. Acidic soils with higher organic carbon content tend to have the highest availability of Fe, Mn, Cu, and Zn. This is consistent with the findings of Brady and Weil (2016) [3], who emphasized that both pH and organic matter are critical factors influencing micronutrient availability.

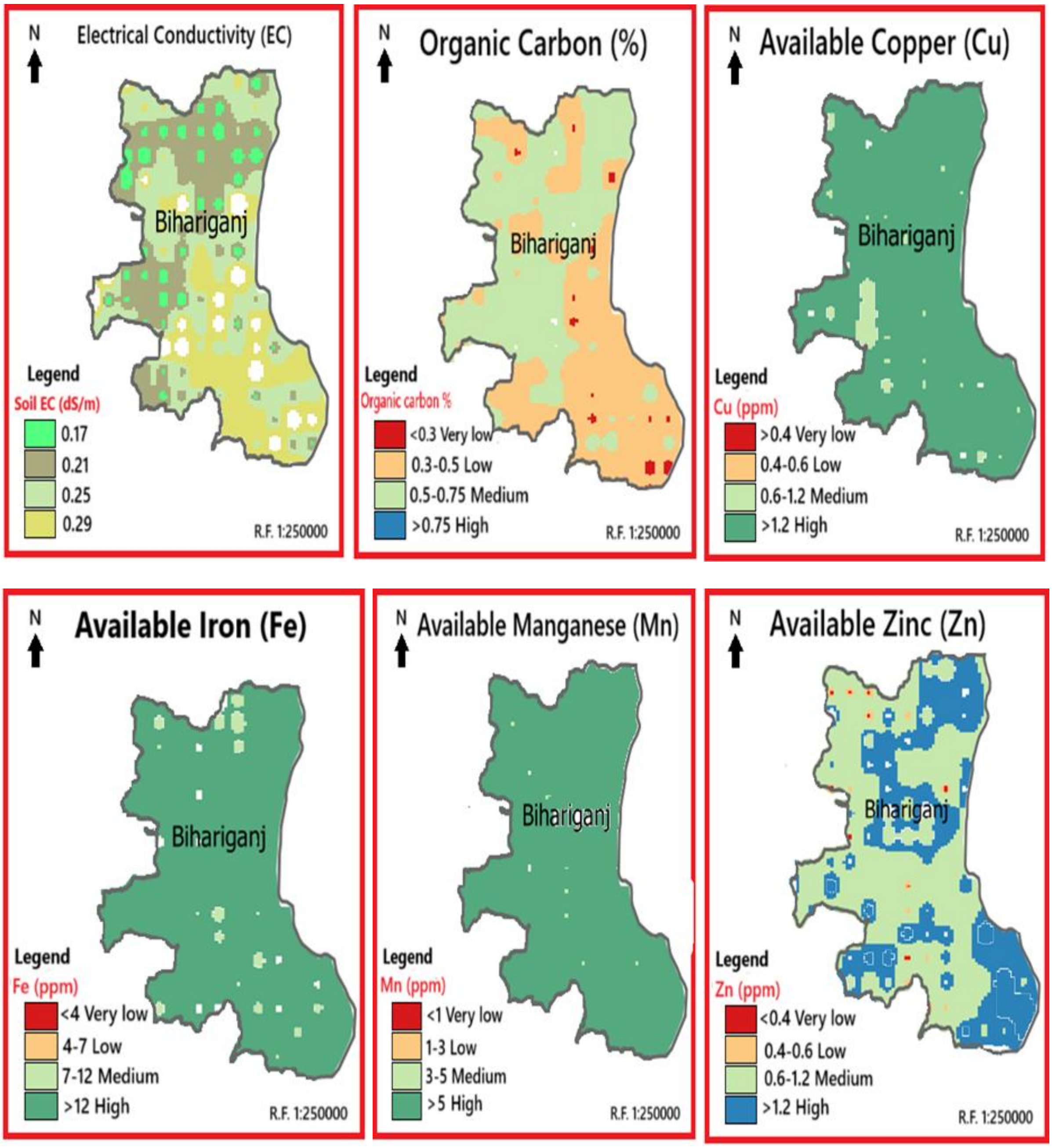


Fig 1: Map showing status of soil properties and DTPA-extractable micronutrients

Table 1: Status of chemical properties and DTPA extractable micronutrients in soils of Bihariganj block of Madhepura (Bihar)

	pH	EC (dSm^{-1})	OC (%)	DTPA-extractable micronutrients			
				Cu	Fe	Mn	Zn
				(PPM)			
Village Panchayat: Babhangama							
Min	5.8	0.2	0.6	1.4	12.2	4.2	0.4
Max	8.4	0.3	0.7	2.5	40.1	18.0	2.3
Mean	7.2	0.2	0.7	1.8	26.8	10.4	1.4
Village Panchayat: Bihariganj							
Min	5.7	0.1	0.2	0.9	30.6	5.7	0.7
Max	7.8	0.4	0.5	2.5	64.7	16.8	2.6
Mean	7.1	0.3	0.4	1.7	45.1	9.9	1.2
Village Panchayat: Gamail							
Min	5.6	0.1	0.2	1.1	24.1	5.6	0.2
Max	8.2	0.5	0.7	3.9	62.4	17.0	2.4

Mean	6.8	0.2	0.5	2.1	42.3	10.5	1.5
Village Panchayat: Hatiaundha							
Min	7.9	0.2	0.7	1.7	47.2	3.3	0.3
Max	8.0	0.6	0.8	2.4	67.2	3.6	0.7
Mean	8.0	0.3	0.8	2.2	58.2	3.5	0.5
Village Panchayat: Lachhmipur							
Min	5.6	0.1	0.2	0.7	7.8	2.2	0.8
Max	7.7	0.5	0.7	3.6	58.5	16.1	2.8
Mean	6.4	0.3	0.4	1.8	32.8	11.7	1.7
Village Panchayat: Madhukar Chak							
Min	5.6	0.2	0.2	0.9	23.0	3.7	0.1
Max	8.5	0.5	0.7	2.9	58.4	16.7	2.8
Mean	7.0	0.3	0.4	1.8	44.1	9.4	1.1
Village Panchayat: Mohanpur							
Min	6.5	0.1	0.5	1.6	33.9	5.7	0.6
Max	7.6	0.2	0.8	6.9	51.2	18.4	2.1
Mean	7.3	0.1	0.6	4.0	46.0	12.0	1.0
Village Panchayat: Pararia							
Min	5.8	0.2	0.4	1.1	18.9	8.5	0.5
Max	8.4	0.3	0.5	2.7	66.3	11.9	1.6
Mean	7.2	0.2	0.5	1.7	40.2	10.4	1.1
Village Panchayat: Rajganj							
Min	6.4	0.1	0.2	0.7	26.3	20.5	0.5
Max	8.3	0.3	0.6	1.6	50.5	60.5	2.8
Mean	7.0	0.2	0.4	1.2	34.0	48.1	1.7
Village Panchayat: Shekhpura							
Min	5.6	0.1	0.1	1.0	23.6	6.2	0.2
Max	8.1	0.6	0.8	2.1	69.7	69.9	2.4
Mean	6.8	0.2	0.5	1.5	41.3	30.7	1.4
Village Panchayat: Tulsia							
Min	5.9	0.1	0.3	1.2	14.7	11.0	0.6
Max	8.5	0.3	0.8	1.8	46.7	81.6	2.5
Mean	7.2	0.2	0.6	1.4	33.9	46.0	1.3
Overall							
Min	5.6	0.1	0.1	0.7	7.8	2.2	0.1
Max	8.5	0.6	0.8	6.9	69.7	81.6	2.8
Mean	6.9	0.2	0.5	1.8	38.9	18.9	1.4

Table 2: Criteria for assessment of DTPA-extractable micronutrient status in soils

Micronutrients	Very low	Low	Medium	High
DTPA-Cu (ppm)	< 4	4-7	7-12	> 12
DTPA-Fe (ppm)	< 1	1-3	3-5	> 5
DTPA-Mn (ppm)	< 0.4	0.4-0.6	0.6-1.2	> 1.2
DTPA-Zn (ppm)	< 0.4	0.4-0.6	0.6-1.2	> 1.2

Table 3: Percentage of samples falling in different categories of micronutrients

Micronutrients	Very low	Low	Medium	High
DTPA-Cu	0	0	18.5	81.5
DTPA-Fe	0	0	1.0	99.0
DTPA-Mn	0	1.0	7.6	91.4
DTPA-Zn	7.6	7.6	33.7	51.1

Table 4: Correlation between DTPA-extractable micronutrients and chemical properties of soils

Soil properties	DTPA-Cu	DTPA-Fe	DTPA-Mn	DTPA-Zn
pH	-0.12219934	-0.15722	-0.05427	-0.811
EC	-0.18738318	-0.15744	-0.06361	-0.21544
OC	0.20552579	-0.02279	0.233333	-0.14351

4. Conclusion

The study on the chemical properties and micronutrient status of soils in Bihariganj block, Madhepura district, revealed significant variability in soil pH, electrical conductivity (EC), organic carbon (OC%), and micronutrient availability. Soil pH ranged from 5.6 to 8.5, with most samples being neutral (pH 6.5-7.5), though acidic and alkaline soils were also present, necessitating targeted pH management. EC values were generally low (average 0.23 dS/m), indicating non-saline conditions suitable for crops, with a few samples requiring salinity management.

Soil organic carbon (SOC) ranged from 0.11% to 0.84% (average 0.47%), with low SOC levels in some areas indicating potential degradation and the need for organic matter enrichment. Micronutrient analysis showed sufficient Cu and Fe levels, though some samples had elevated Cu, posing toxicity risks. Mn availability varied, with higher levels in acidic soils, while Zn deficiency was widespread, potentially limiting crop productivity. Soil pH strongly influenced micronutrient availability, with acidic soils favoring higher Fe, Mn, Cu, and Zn solubility. Organic carbon showed a weak to moderate positive correlation with micronutrient availability, highlighting its role in nutrient retention.

The findings underscore the need for integrated soil management, including pH optimization, organic matter enrichment, and Zn fertilization, to improve soil health and agricultural productivity. Future research should focus on long-term monitoring and tailored management practices to address spatial variability and ensure sustainable crop production in the region.

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