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CONTENTS

Mapping and evaluation of soil macronutrient and micronutrient status in Muzaffarnagar district of India

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ABSTRACT: The study aimed to evaluate soil fertility in Muzaffarnagar district by analyzing physico-chemical properties and nutrient contents across different blocks. Soil samples were collected from representative villages in nine blocks and assessed for pH, electrical conductivity (EC), organic carbon, and the availability of macro- nutrients (N, P, K & S) and micro-nutrients (Zn, B, Cu, Fe & Mn). Standard analytical techniques were used for laboratory evaluation. Results revealed that soil pH ranged from 7.00 to 8.36, with a district average of 7.94, indicating neutral to slightly alkaline soils. EC values were generally low (0.15–0.91 dS/m), reflecting minimal salinity concerns. Organic carbon content ranged between 1.50 and 5.80 g/kg, suggesting moderate fertility levels. Macro-nutrient analysis showed nitrogen levels varying significantly (33.7–511.5 kg/ha), with phosphorus, potassium, and sulfur also displaying wide ranges, pointing to variability in soil nutrient management. Micro-nutrient availability was block-dependent, with deficiencies in zinc and boron in several areas, while iron and manganese levels were generally adequate. The study concluded that Muzaffarnagar district soils are moderately fertile but show spatial variability in nutrient availability. Balanced fertilizer applications tailored to block-specific deficiencies are recommended to improve soil health and productivity. This baseline assessment can guide sustainable soil and crop management practices in the region.

Keywords: Fertility block, organic carbon, plant nutrients, productivity, physio-chemical properties

Soil fertility is a critical determinant of agricultural productivity and ecosystem sustainability. It directly influences crop yield, making it a key factor in ensuring food security for a growing population. As food demand rises, maintaining soil fertility becomes essential for sustaining agricultural output. Fertile soil contains essential nutrients, organic matter, and microbial life that support healthy plant growth. It enhances water retention, improves soil structure, and facilitates root development. These factors collectively contribute to increased crop productivity, helping meet the nation's food requirements. The availability of essential nutrients in soil, including macronutrients such as N, P, and K, along with micronutrients like Zn, Fe, Mn, and Cu, plays a pivotal role in crop growth and yield (Nadeem *et al.*, 2018). Muzaffarnagar, situated in Uttar Pradesh, India, is an agriculturally significant district for cultivating crops like sugarcane, wheat, and rice. However, intensive agricultural practices, over-reliance on chemical fertilizers, and inadequate nutrient management strategies have led to the degradation of soil fertility. The declining soil health poses a significant challenge to sustainable agricultural development and farmers' livelihoods in the region. Macronutrients are required in large quantities and are fundamental to plant physiology. Nitrogen is crucial for vegetative growth and chlorophyll formation, phosphorus aids in root development and energy transfer, while K enhances stress resistance and crop quality (Sinha and Tandon, 2020, Wang *et al.*, 2024, and Khan *et al.,* 2023). On the other hand, micronutrients, though needed in smaller amounts, are equally indispensable. For instance, zinc plays a vital role in enzyme activation, iron is essential for chlorophyll synthesis, and manganese (Mn) and Cu contribute to various physiological and biochemical processes (Nandal and Solanki, 2021, Cakmak *et al*., 2023 and Broadley *et al.,* 2012). Deficiencies or imbalances in these nutrients can adversely affect crop productivity, reduce soil fertility, and lead to economic losses for farmers (Tan *et al*., 2005). The soils of Muzaffarnagar face multiple challenges that hinder effective nutrient management. Excessive use of N and N fertilizers has resulted in nutrient imbalances, often leading to potassium and micronutrient deficiencies (Malvi, 2011). Additionally, the declining use of organic fertilizers and poor crop residue management has led to reduced organic matter content in soils, further affecting nutrient availability (Doran and Smith, 1987). Spatial variability in soil nutrient levels, influenced by differences in land use, irrigation practices, and cropping systems, complicates the formulation of region-specific fertilizer recommendations. Moreover, the lack of widespread access to soil testing services leaves many farmers unaware of their soil's nutrient status, leading to suboptimal fertilizer application practices. Kumar *et al*. (2013) addressed soil fertility in Uttar Pradesh, there is a lack of comprehensive data specific to the macronutrient and micronutrient status of soils in Muzaffarnagar district. Existing research often fails to capture localized spatial variability, resulting in generalized recommendations that may not effectively address the region's specific needs.

The primary objective of this study is to map and evaluate the macronutrient and micronutrient status of soils in Muzaffarnagar district. Specifically, it aims to analyze the spatial distribution of essential nutrients, and provide data-driven recommendations for site-specific nutrient management. By addressing these gaps, the research seeks to promote sustainable agricultural practices and improve soil fertility in the region.

MATERIALS AND METHODS

Study area

The study area for the present investigation is Muzaffarnagar district, located in the Gird region of Uttar Pradesh, India. It lies between latitudes 29°28' N and longitudes 77°41' E, with an elevation above mean sea level ranging from 272 meters in the Doab region of the Indo-Gangetic Plain. The district falls under the agro-ecological region N8D2 (Seghal, 1996). The physiography of the area features well-drained soils with rapid to moderately rapid permeability in the surface and sub-surface layers, although it becomes poor beyond 100 cm depth due to calcium carbonate cementation. Geologically, Muzaffarnagar is part of the Indo-Gangetic alluvial plain, where soils exhibit horizon differentiation, classified into various soil orders such as Entisols, Inceptisols, and Alfisols. The district spans an area of 309,992 hectares, representing 1.28% of Uttar Pradesh's total area. Muzaffarnagar experiences a semi-arid sub-tropical climate, with hot, dry summers and cold winters. The region receives annual rainfall of 700 to 800 mm, primarily during the monsoon months from June to September. Major irrigation sources include tube wells, wells, and canals. The soils are predominantly sandy loam with varying texture, and the major crops cultivated are sugarcane, paddy, wheat, maize, potato, mustard, black gram, chickpea, arhar, and groundnut.

Collection and preparation of soil samples

For the present study, 100 surface (0-15 cm) soil samples were collected from cultivators' fields in nine blocks (Muzaffarnagar, Budhana, Baghra, Shahpur, Purkaji, Charthawal, Morna, Jansath, and Khatauli) of Muzaffarnagar district. The GPS-based details of the sample locations are provided in the appendix. Representative soil samples were collected using a soil auger, placed in properly labeled polythene bags, and transported to the laboratory. After collection, the samples were brought to the Soil Science Laboratory at C.C.S.U. Meerut (U.P.), where they were air-dried, crushed, and sieved through a 2 mm plastic sieve. The details of the soil samples from different blocks are given in Table 1, the location of the soil samples is depicted in Figure 1, and the limits of different nutrients in the soil are illustrated in Table 2.

Observation recorded

pH

The soil pH was determined using a glass electrode in a 1:2 soil-water suspension, following the method outlined by Piper (1967).

Electrical Conductivity

Electrical conductivity is an important soil property that indicates the total soluble salts present. It is used to estimate the ionized constituent concentration in the soil solution. Higher conductivity reflects greater dissolved salts and provides an indication of nutrient availability. The soil water suspension used for pH determination was allowed to settle, and the conductivity of the supernatant liquid was measured using a Systronics conductivity meter.

Organic Carbon

Organic carbon content was estimated using the Walkely and Black method (1934). In this method, organic matter in the soil is oxidized with a mixture of potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid (H_2SO_4), utilizing the heat of dilution. The unused potassium dichromate is then back-titrated with ferrous ammonium sulfate.

Available Nitrogen

Available nitrogen was determined by the alkaline permanganate method (Subbiah and Asija, 1956). 5 g soil sample was treated with 20 ml of 0.32% $KMnO_4$ solution and 20 ml of 2.5% NaOH solution in a distillation unit. The ammonia gas was collected in boric acid and titrated with 0.02 *N* H_2SO_4 after adding five drops of mixed indicator. A blank correction was made for the final calculation.

Available Phosphorus

Available phosphorus was determined using the colorimetric method by Olsen *et al*. (1954). The 2.5 g soil sample was shaken with 50 ml of 0.5*M* $NaHCO_3$ at pH 8.5 for 30 minutes and filtered. The filtrate (5 ml) was treated with ammonium molybdate and ascorbic acid solution, and the colour intensity was measured using a photoelectric colorimeter at 860 nm. The phosphorus content was calculated and expressed in kg/ha.

Available Potassium

To determine available potassium, 5 g of soil was shaken with 25 ml of neutral normal ammonium acetate in a 100 ml conical flask for 5 minutes. The extract was filtered, and the potassium content was estimated using a flame photometer (Jackson, 1973).

Available Sulphur

Available sulphur was determined by the turbidimetric method using a 0.15% $CaCl_2$ solution as an extractant, following Chesnin and Yien (1951).

Available Micronutrient Cations

The availability of micronutrients such as Zn, B, Fe, Mn, and Cu was determined using an Atomic Absorption Spectrophotometer (AAS) with DTPA (Diethylene Triamine Penta Acetic Acid) as an extractant, as described by Lindsay and Norvell (1978). Soil was shaken with a buffered DTPA solution, and the dissolved elements were measured by AAS. The solution was prepared by mixing DTPA, calcium chloride, and triethanolamine, and adjusting the pH to 7.3.

RESULTS AND DISCUSSION

pH

The analysis of soil pH in the studied area revealed a range from 7.00 to 8.36, with an average pH value of 7.74, indicating a predominantly slightly alkaline condition across different villages (Table 3). Specific village assessments within the Muzaffarnagar district displayed variable pH levels: for instance, the pH in Muzaffarnagar ranged from 7.42 to 8.19, in Budhana from 7.21 to 7.79, and in Baghra from 7.35 to 8.16. Similarly, Shahpur demonstrated pH values between 7.15 and 8.65, while Purkaji's range was from 7.50 to 7.93. Charthawal exhibited the lowest pH values, ranging from 7.00 to 7.70, in contrast to Khatauli, which recorded the highest average pH at 7.94, indicating a more alkaline soil environment. The average pH for Budhana, Baghra, Shahpur, Purkaji, Charthawal, Morna, Jansath, and Khatauli were calculated as 7.80, 7.50, 7.75, 7.40, 7.71, 7.35, 7.51, 7.60, and 7.94, respectively. Soil pH is a critical factor influencing nutrient availability and microbial activity, which directly affects agricultural productivity (Zifcakova, 2020). The slightly alkaline nature of the soils in Khatauli block could suggest a favorable condition for certain crops that thrive in such soil environments, necessitating targeted crop management strategies to optimize agricultural output in these areas (Singh *et al*., 2017).

Electrical Conductivity (dS/m)

The electrical conductivity (EC) values in the Muzaffarnagar district displayed notable variation, ranging from 0.15 to 0.91 dS/m, with an overall average of 0.53 dS/m, indicating moderate salinity levels across the region (Table 3). Within the individual blocks, the EC values demonstrated considerable variability. For example, the EC in Muzaffarnagar ranged from 0.23 to 0.88 dS/m, while in Budhana, it varied from 0.28 to 0.63 dS/m. The lowest recorded values were in Charthawal, ranging from 0.18 to 0.66 dS/m, and Jansath, with values between 0.26 and 0.49 dS/m. Conversely, the highest average EC was found in the Purkaji block, at 0.57 dS/m, suggesting a higher concentration of soluble salts in this area, which can influence crop production and soil health. Salinity, as indicated by EC levels, impacts soil structure, nutrient availability, and plant growth (Hailu and Mehari, 2021). High salinity levels can impede crop productivity by affecting water uptake and causing physiological stress to plants. The EC levels recorded in Muzaffarnagar district, particularly in Purkaji and the other blocks, emphasize the need for effective salinity management strategies to mitigate negative impacts on agriculture (Majeed and Muhammad, 2019). Conversely, the Khatauli block demonstrated a relatively lower average EC value of 0.30 dS/m, suggesting less salinity risk in that area. Understanding the spatial variability of electrical conductivity is vital for developing targeted agricultural practices and interventions aimed at improving soil health and crop yields across the district.

Organic Carbon (g/kg)

The organic carbon status in the studied area ranged between 1.50 and 4.50 g/kg, with an average value of 3.0 g/kg, reflecting the variable levels of organic carbon content across different villages (Table 3). This variability can be attributed to several factors, including differences in land use, farming practices, and soil management across the villages within the blocks of Muzaffarnagar district. Specifically, organic carbon levels varied across different blocks, with Muzaffarnagar showing the highest average organic carbon content of 5.00 g/kg, whereas Budhana had the lowest at 3.05 g/kg. This contrast between blocks suggests that local soil fertility management and agricultural practices may have a significant influence on soil organic carbon levels. These variations highlight the complex interaction of climatic, edaphic, and anthropogenic factors that influence organic carbon content in soils. For instance, areas with intensive agricultural activity tend to have lower organic carbon levels due to increased decomposition and reduced organic matter input, as indicated by similar studies in other regions (Luo *et al*., 2021). Moreover, regions with better soil management practices, including crop rotation and organic amendments, typically exhibit higher organic carbon content (Merante *et al.,* 2017). Thus, the organic carbon levels across the studied blocks emphasize the importance of localized management practices in enhancing soil fertility and carbon sequestration.

Available -- Nitrogen(kg/ha)

The status of available nitrogen (N) in the studied area of Muzaffarnagar district, as presented in Table 4, reveals significant variation in nitrogen levels across different villages, ranging from 33.7 to 511.5 kg/ha, with an average of 272.6 kg/ha. This variation is influenced by factors such as soil type, agricultural practices, and fertilizer usage. For example, Charthawal block showed the highest average nitrogen content (279.3 kg/ha), while Budhana block had the lowest (68.6 kg/ha), reflecting differences in soil management and crop practices. Within individual villages, nitrogen levels also varied widely; in Muzaffarnagar block, nitrogen ranged from 108.2 to 139.6 kg/ha, while Budhana's range was from 33.7 to 103.5 kg/ha. This suggests that nitrogen availability is affected by a combination of soil fertility, organic matter content, and local agronomic practices. Research indicates that nitrogen is often a limiting nutrient in agro-ecosystems and can be depleted by intensive farming without proper replenishment (Geremew, 2021). Low nitrogen levels in some blocks, such as Budhana, may result from inadequate fertilizer use or poor organic matter management, which are known to negatively affect soil nitrogen availability (Mehrotra *et al*., 2023-24).

Available -- Phosphorus (kg/ha)

The status of available phosphorus (P) in the studied area of Muzaffarnagar district, as presented in Table 4, shows considerable variation in phosphorus levels across different villages, ranging from 2.73 to 98.0 kg/ha, with an average of 50.36 kg/ha. This variability highlights the complex nature of soil fertility, where factors such as soil texture, pH, organic matter content, and agricultural practices influence nutrient availability. The highest average phosphorus content was found in Budhana block at 53.27 kg/ha, while Purkaji block exhibited the lowest average of 7.26 kg/ha. This significant difference reflects regional disparities in phosphorus availability within the district. In terms of individual village variations, phosphorus levels ranged from 12.25 to 24.75 kg/ha in Muzaffarnagar, 8.55 to 98.0 kg/ha in Budhana, 9.38 to 29.04 kg/ha in Baghra, and 2.73 to 11.80 kg/ha in Purkaji, among others. The wide range indicates that phosphorus is not uniformly distributed across the district. Factors such as soil amendments, crop rotation, and fertilization regimes play a significant role in determining phosphorus availability. For example, Budhana's higher phosphorus levels may be due to the use of phosphorus-rich fertilizers or better soil management practices (Schröder *et al.*, 2010). Conversely, Purkaji's lower levels could be linked to insufficient phosphorus fertilization or soil pH issues (Penn and Camberato, 2019). Many blocks with average phosphorus below 30 kg/ha could face limitations in phosphorus availability, which may adversely affect agricultural productivity. Phosphorus is vital for plant growth, and its deficiency can result in stunted growth and reduced crop yields (Malhotra *et al.*, 2018). Therefore, improving phosphorus management, such as optimizing fertilization practices and adjusting soil pH, is essential for enhancing soil fertility and ensuring sustainable agricultural production in the region.

Available --Potassium(kg/ha)

The status of available potassium (K) in the studied area of Muzaffarnagar district, as shown in Table 4, exhibited significant variation, ranging from 11.4 to 475.3 kg/ha, with an average of 243.35 kg/ha. This variation highlights the influence of several factors on potassium availability in soils, including soil type, farming practices, and fertilization regimes. The highest average potassium content (328.1 kg/ha) was found in Muzaffarnagar block, whereas the lowest (109.0 kg/ha) was observed in Charthawal block. These differences suggest that nutrient management practices vary across the district, potentially resulting in significant disparities in crop yields and long-term soil health. Potassium levels in individual villages also varied widely. In Muzaffarnagar, potassium levels ranged from 181.4 to 475.3 kg/ha, and in Budhana, the range was from 87.0 to 189.0 kg/ha. Other blocks, including Baghra, Shahpur, and Purkaji, showed similar variation. These disparities are likely influenced by local farming practices, soil texture, and organic matter content, which can significantly impact potassium availability. Potassium deficiency, often linked to intensive farming, occurs when nutrient cycling is disrupted by over-reliance on chemical fertilizers without sufficient replenishment (Singh *et al.,* 2021). The low potassium levels in blocks like Purkaji, Charthawal, and Morna may indicate depletion due to insufficient fertilization or soil amendments. Low potassium, particularly in Charthawal (11.4 kg/ha) and Khatauli (24.1 kg/ha), could affect crop growth, leading to weaker plants and reduced yields (Pettigrew, 2008). To ensure sustainable agricultural productivity, addressing potassium deficiency through proper fertilization, crop rotation, and organic amendments is crucial for maintaining soil health in the district.

Available --Sulphur (ppm)

The status of available sulfur (S) in the studied area of Muzaffarnagar district, as presented in Table 4, shows considerable variation across different villages. The available sulfur ranged from 3.20 to 192.ppm, with an average value of 98.00 ppm. This variability in sulfur levels suggests the influence of factors such as the natural sulfur content of the soil, organic matter levels, and agricultural practices. The highest average sulfur content (142.4 ppm) was observed in Muzaffarnagar block, while the lowest average (4.88 ppm) was found in Budhana block, indicating a significant disparity in sulfur availability across the district. The range of available sulfur within individual villages was also highly variable. In Muzaffarnagar, sulfur content ranged from 92.0

to 192.8 ppm, while in Budhana, it ranged from 3.84 to 5.92 ppm, suggesting severe sulfur deficiency in this region. Similarly, other blocks, such as Baghra, Shahpur, and Purkaji, exhibited wide ranges, with Baghra showing 11.4 to 158.8 ppm, Shahpur 3.20 to 52.00 ppm, and Purkaji 40.2 to 132.7 ppm. These differences highlight the impact of local soil conditions, fertilization practices, and organic amendments on sulfur availability. Sulfur deficiency in blocks like Budhana and Shahpur could be attributed to limited sulfur inputs, both from fertilizers and organic sources. Sulfur plays a key role in protein synthesis and enzyme activation (Métayer, 2008), and its deficiency can lead to poor plant growth, yellowing leaves, and reduced crop yields (Zenda, 2021). The higher sulfur content in Muzaffarnagar suggests better conditions for crop growth, while regions with low sulfur require appropriate sulfur-based fertilizers and organic amendments to ensure sustainable agricultural productivity.

Available --Zinc (ppm)

The status of available zinc (DTPA-extractable) in Muzaffarnagar district, as shown in Table 5, reveals significant variation in zinc levels across different villages, ranging from 0.26 to 95.0 ppm, with an average value of 47.63 ppm. This considerable variability indicates that zinc availability in the soil is influenced by various factors such as soil texture, pH, organic matter content, and agricultural practices. Zinc is a critical micronutrient for plants, essential for enzyme activity, protein synthesis, and the regulation of plant metabolism (Nandal and Solanki, 2021). Thus, the differences in zinc availability may impact agricultural productivity and soil fertility across the district. Zinc content in individual villages showed a wide range. For example, in Muzaffarnagar, zinc levels ranged from 1.94 to 5.38 ppm, while in Budhana, they ranged from 0.39 to 0.95 ppm. Other blocks such as Baghra, Shahpur, and Purkaji exhibited similar variability, with zinc values spanning from 0.58 to 6.24 ppm, 0.29 to 0.95 ppm, and 0.28 to 3.75 ppm, respectively. The most striking observation was in Charthawal block, where zinc levels ranged from 0.26 to 95.0 ppm, with an average of 47.63 ppm, the highest in the district. This disparity could be due to differences in soil management, fertilization history, or natural mineral content. Zinc deficiencies, often linked to high soil pH, low organic matter, or insufficient fertilization, are a concern in regions like Shahpur and Budhana, where the average levels were lower (Mousavi *et al*., 2012). Zinc deficiency can hinder crop growth, leading to poor yields and stunted development (Hafeez *et al*., 2013). To mitigate this, efficient zinc management practices, including proper fertilization and organic amendments, are essential for sustainable agricultural production.

Available -- Boron (ppm)

The available boron status in the soils of Muzaffarnagar district, as shown in Table 5, reveals considerable variation across different blocks and villages. Boron content ranged from 0.55 to 16.00 ppm, with an average of 8.27 ppm, indicating significant spatial differences in boron availability. These variations can be attributed to factors such as soil texture, pH, organic matter content, and regional agricultural practices. Boron is a vital micronutrient that plays a crucial role in cell wall formation, flowering, fruiting, and overall plant growth. The observed variation suggests that while some areas in the district have adequate boron for plant health, others may face deficiency, potentially affecting crop yields and plant development (Rashid and Rafique, 2017). For example, boron content in Muzaffarnagar ranged from 1.55 to 4.93 ppm, while in Budhana, it varied from 1.40 to 3.78 ppm. Purkaji block exhibited relatively low levels of boron, with values ranging from 0.75 to 2.73 ppm. In contrast, Morna block had the highest levels, with boron ranging from 0.63 to 16.00 ppm. Boron deficiency often leads to poor root development, reduced flowering, and poor seed set (Ahmad *et al.,* 2012).

Available -- Copper (ppm)

The available copper status in the soils of Muzaffarnagar district, as shown in Table 5, reveals significant variation in copper levels across different villages and blocks. The copper content ranged from 0.16 to 5.51 ppm, with an average value of 2.83 ppm. This variability is likely influenced by factors such as soil properties, land use practices, and

Table 1: Details of soil samples collected from different villages of different blocks of Muzaffarnagar district

S. No.	Block	Village Name	No. of samples collected	Total samples
1.	Muzaffarnagar	Sujru	5	10
		Bilaspur	5	
2.	Budhana	Kalyanpur	5	10
		Sultanpur	5	
3.	Baghra	Baghra	5	10
		Mandi	5	
4.	Shahpur	Purbaliyan	5	10
		Pura	5	
5.	Purkaji	Nurnagar	5	10
		Chhapra	5	
6.	Charthawal	Bhamela	5	15
		Manganpur	5	
		Pipalshah	5	
7.	Morna	Dhiraheri	5	15
		Belra	5	
		Bhaleri	5	
8.	Jansath	Bahadurpur	5	10
		Wazidpur Kawali	5	
9.	Khatauli	Mansoorpur	5	10
		Bhataura	5	
	Grand Total		20	100

Table 2: Limits of different nutrients for classification.

S. No.	Constituents	Limit for different categories		
		Low	Medium	High
1.	Av. N (kg/ha)	<250	250-500	>500
2.	Av. P (kg/ha)	<25	25-50	>50
3.	Av. K (kg/ha)	<125	125-300	>300
4.	Organic Carbon (%)	<0.5	0.5-0.75	>0.75
		Deficient		Sufficient
5.	S (ppm)	<10.00		>10.00
		Normal	Toward critical	Above critical
6.	pH	6.5≤7.5	7.5-8.5	>8.5
7.	E.C. (dS/m)	<0.5	0.5-1.0	>1.0
Av. Micronutrient (ppm)		Critical limits		
		Deficient		Sufficient
8.	Zn	<0.78		>0.78
9.	B	<0.50		>0.50
10.	Fe	<7.00		>7.00
11.	Cu	<0.60		>0.60
12.	Mn	<3.00		>3.00

(Source: Reddy *et al.*, 2021)

environmental conditions. Copper is an essential micronutrient for plant growth, playing key roles in photosynthesis, respiration, and enzyme activation. Deficiency or excess of copper can adversely affect plant health and productivity (Adrees *et al.*, 2015). In terms of individual blocks, copper levels showed considerable variation. In Muzaffarnagar, copper ranged from 2.02 to 4.89 ppm, while Budhana had a range of 0.32 to 0.84 ppm. Other blocks, such as Baghra, Shahpur, and Purkaji, also showed variability in copper content, with values ranging from 0.51 to 5.51 ppm, 0.35 to 0.95 ppm, and 0.21 to 3.60 ppm, respectively. The highest copper content was observed in Muzaffarnagar (3.45 ppm), while Budhana had the lowest (0.58 ppm). Low copper levels, such as those in Budhana and Shahpur, may

Table 3: Soil pH, EC and Organic carbon (%) in various villages of different blocks of Muzaffarnagar district.

S. No.	Block	Village Name	pH		EC (dS/m)		OC (g/kg)	
			Range	Mean	Range	Mean	Range	Mean
1.	Muzaffarnagar	Sujru	7.42 -7.88	7.65	0.32-0.88	0.60	4.70-5.80	5.25
		Bilaspur	8.03-8.19	8.11	0.23-0.26	0.24	4.20-5.50	4.85
			7.42-8.19	7.80	0.23-0.88	0.55	4.20-5.80	5.00
2.	Budhana	Kalyanpur	7.21-7.71	7.46	0.42-0.63	0.52	1.50-3.90	2.70
		Sultanpur	7.30-7.79	7.54	0.28-0.41	0.34	1.50-4.60	3.05
			7.21-7.79	7.50	0.28-0.63	0.45	1.50-4.60	3.05
3.	Baghra	Baghra	7.35-7.90	7.62	0.15-0.45	0.30	3.30-4.90	4.10
		Mandi	7.35-8.16	7.75	0.50-0.80	0.65	4.20-5.40	4.80
			7.35-8.16	7.75	0.15-0.80	0.47	3.30-5.40	4.35
4.	Shahpur	Purbaliyan	7.30-7.65	7.47	0.35-0.66	0.50	1.80-5.20	3.50
		Pura	7.15-7.30	7.22	0.45-0.53	0.49	2.20-3.10	2.65
			7.15-7.65	7.40	0.35-0.66	0.50	1.80-5.20	3.50
5.	Purkaji	Nurnagar	7.83-7.93	7.88	0.23-0.37	0.30	3.50-4.50	4.00
		Chhapra	7.50-7.81	7.65	0.51-0.91	0.71	3.90-4.70	4.30
			7.50-7.93	7.71	0.23-0.91	0.57	3.50-4.70	4.10
6.	Charthawal	Bhamela	7.49-7.69	7.59	0.36-0.60	0.48	3.00-4.50	3.75
		Manganpur	7.30-7.50	7.40	0.20-0.32	0.26	4.50-5.70	5.10
		Pipalshah	7.00-7.70	7.35	0.18-0.66	0.42	2.10-5.40	3.75
			7.00-7.70	7.35	0.22-0.54	0.42	2.10-5.70	3.90
7.	Morna	Dhiraheri	7.49-7.82	7.65	0.22-0.54	0.38	3.70-4.30	4.00
		Belra	7.54-7.60	7.57	0.33-0.40	0.36	2.40 -4.50	3.45
		Bhaleri	7.20-7.59	7.39	0.34-0.59	0.46	2.10-4.20	3.15
			7.20-7.82	7.51	0.22-0.59	0.40	2.10-4.50	3.30
8.	Jansath	Bahadurpur	7.60-7.66	7.63	0.26-0.31	0.28	3.40-4.50	3.90
		Wazidpur	7.32-7.88	7.60	0.35-0.49	0.42	3.00-4.00	3.50
			7.32-7.88	7.60	0.26-0.49	0.37	3.00-4.50	3.75
9.	Khatauli	Mansoorpur	7.53-8.14	7.83	0.13-0.25	0.19	4.70-5.30	5.00
		Bhataura	7.61-8.36	7.98	0.18-0.47	0.32	2.90-4.20	4.35
			7.53-8.36	7.94	0.13-0.47	0.30	2.90-5.80	4.35
	Average		7.00-8.36	7.94	0.15-0.51	0.30	1.50-4.50	3.00

indicate deficiency, which can limit crop growth and yield (Fageria *et al.*, 2002). Proper copper fertilization and soil management are essential to address deficiencies while preventing toxicity in areas with high copper levels.

Available -- Iron (ppm)

The available iron status in the soils of Muzaffarnagar district, as shown in Table 5, demonstrates considerable variation in DTPA-extractable iron (Fe) levels across different villages and blocks. Iron content ranged from 1.10 to 31.40 ppm, with an average value of 16.25 ppm. This variability indicates uneven iron availability in the district, influenced by factors like soil pH, organic matter, and redox conditions (Blundell *et al.*, 2009). Iron is a vital micronutrient for plants, crucial for photosynthesis, respiration, and chlorophyll synthesis. In Muzaffarnagar block, iron content ranged from 18.25 to 31.40 ppm, with an average of 24.82 ppm, suggesting relatively high iron availability. In contrast, Shahpur block had lower iron levels, ranging from 6.35 to 11.27 ppm, with an average of 8.81 ppm, indicating potential iron deficiency. Other blocks such as Budhana, Baghra, Purkaji, and Charthawal had varying concentrations, ranging from 4.31 to 24.08 ppm. Iron deficiency in plants leads to chlorosis, stunted growth, and reduced crop yields, particularly in crops like maize and rice (Zuo and Zhang, 2011). In areas like Shahpur and Budhana, iron fertilizers may be necessary, while in areas with higher iron levels, caution is needed to avoid toxicity. Proper iron management is essential for optimal crop health and sustainable agricultural productivity in the district.

Table 4: Status of available macro-nutrient cations (N, P, K & S) in soils of different blocks of Muzaffarnagar district.

S. No.	Block	Village Name	N (kg/ha)		P (kg/ha)		K (kg/ha)		S (mg/kg)	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean
1.	Muzaffarnagar	Sujru	118.5-139.6	129.0	16.86-24.75	41.61	344.6-475.3	409.9	137.1-192.8	164.9
		Bilaspur	108.2-139.6	123.9	12.25 —16.75	14.50	181.4-307.8	244.6	92.0-166.4	129.2
			108.2-139.6	123.9	12.25-24.75	18.50	181.4-475.3	328.1	92.0-192.8	142.4
2.	Budhana	Kalyanpur	33.7-87.7	60.7	8.55-18.45	13.50	123.0-189.0	156.0	3.84-5.92	4.88
		Sultanpur	33.7-103.5	68.6	10.35-98.00	54.17	87.0-150.0	118.5	4.48-5.76	5.12
			33.7-103.5	68.6	8.55-98.00	53.27	87.0-189.0	138.0	3.84-5.92	4.88
3.	Baghra	Baghra	74.2-125.0	99.6	9.38-16.20	12.79	110.4-404.5	257.4	11.4-132.1	71.7
		Mandi	108.2-136.9	122.5	17.89-29.04	23.46	404.3-437.9	421.1	100.7-158.8	129.7
			74.2-136.9	105.5	9.38-29.04	19.21	110.4-437.9	274.1	11.4-132.1	85.1
4.	Shahpur	Purbaliyan	40.5-117.0	78.7	12.60-14.85	13.72	126.3-189.8	158.0	3.20-9.44	6.32
		Pura	54.0-69.7	61.8	11.70-18.00	14.85	92.0-159.0	125.5	4.00-52.0	28.0
			40.5-117.0	78.7	11.70-18.00	14.85	92.0-189.8	140.9	3.20-52.0	27.6
5.	Purkaji	Nurnagar	77.9-100.5	89.9	2.73-6.74	4.73	44.4-62.1	53.2	40.2-87.0	63.6
		Chhapra	98.3-119.7	109.0	8.40-11.80	10.10	347.4-385.7	366.5	88.7-132.7	110.7
			77.9-119.7	98.8	2.73-11.80	7.26	44.4-385.7	215.0	40.2-132.7	86.4
6.	Charthawal	Bhamela	67.5-101.2	84.3	13.50-18.00	15.75	59.0-90.0	74.5	5.00-25.2	15.1
		Manganpur	101.2-128.2	114.7	13.50-22.50	18.00	64.0-99.0	81.5	18.0-80.2	49.1
		Pipalshah	47.2-511.5	279.3	5.10-27.00	16.05	11.4-206.7	109.0	3.40-16.2	9.80
			47.2-511.5	279.3	5.10-27.00	16.05	11.4-206.7	109.0	3.40-80.2	41.8
7.	Morna	Dhiraheri	94.1-109.4	101.7	7.12-16.46	11.79	63.3-303.0	183.1	9.40-32.6	21.0
		Belra	54.0-101.2	77.6	9.00-22.50	15.75	108.6-221.7	165.1	7.20- 11.2	9.20
		Bhaleri	47.2-94.5	70.8	13.50-18.00	15.75	125.4-227.3	176.3	7.00-8.90	7.95
			47.2-109.4	78.3	7.12-22.50	14.81	63.3-303.0	183.1	7.00-32.6	19.8
8.	Jansath	Bahadurpur	75.6-101.9	88.7	6.70-8.95	7.82	124.6-179.7	152.1	27.1-32.2	29.6
		Wazidpur	76.8-102.5	89.6	11.04-15.00	13.02	200.0-285.0	242.5	13.4-26.4	19.9
			75.6-102.5	89.0	6.70-15.00	10.85	124.6 -285.0	204.8	13.4-32.2	22.8
9.	Khatauli	Mansoorpur	119.7-136.1	127.9	7.52-9.58	8.55	94.0-127.8	110.9	15.3-21.2	18.2
		Bhataura	65.1-107.4	86.2	2.74-29.62	16.18	24.1-230.7	127.4	6.20-51.1	28.6
			65.1-136.1	100.6	2.73-98.00	16.18	24.1-230.7	127.4	6.20-51.1	28.6
	Whole district		33.7-511.5	272.6	2.73-98.00	50.36	11.4-475.3	243.3	3.20-192.8	98.0

Available -- Manganese (ppm)

The available manganese (Mn) status in the soils of Muzaffarnagar district, as shown in Table 5, reveals significant variability in manganese concentrations across different blocks and villages. Manganese levels ranged from 0.41 to 63.37 ppm, with an average value of 31.89 ppm. Manganese is an essential micronutrient for plants, involved in photosynthesis, enzyme activation, and metabolism (Rashed *et al.*, 2019). The variations in Mn availability can be attributed to factors like soil texture, organic matter, pH, and the presence of other elements. In Muzaffarnagar block, the average Mn content was 29.77 ppm, indicating sufficient manganese availability, which benefits crops like wheat and maize. Conversely, Budhana block had the lowest average Mn content of 7.35 ppm, indicating potential deficiency. Manganese

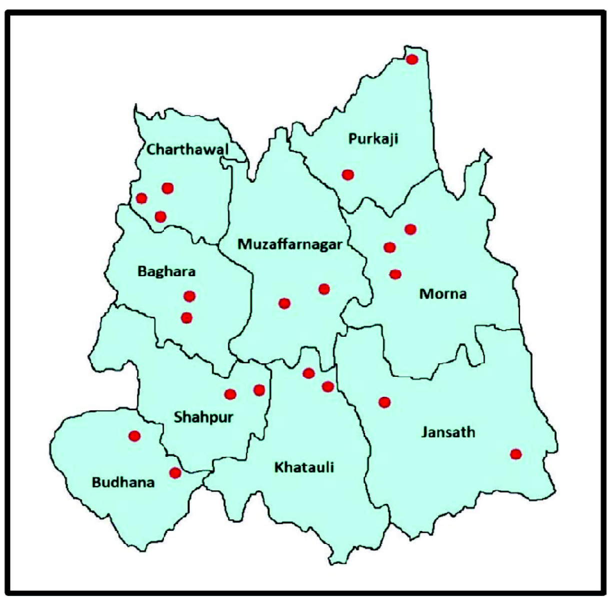

Fig. 1: Collection of soil sample at different blocks in Muzzafarnagar District

Table 5: Status of available micro-nutrient cations (Zn, B, Cu, Fe & Mn) in soils of different blocks of Muzaffarnagar district.

S. No.	Block	Village Name	Zn (ppm)		B (ppm)		Cu (ppm)		Fe (ppm)		Mn (ppm)	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
1.	Muzaffarnagar	Sujru	4.03-5.38	4.70	4.40-4.93	4.66	3.73-4.89	4.31	22.6-31.4	27.0	29.9-42.5	36.2
		Bilaspur	1.94-3.72	2.83	1.55-1.87	1.71	2.02-3.10	2.56	18.2-26.1	22.2	16.9-29.1	23.0
			1.94-5.38	3.66	1.55-4.93	3.25	2.02-4.89	3.45	18.2-31.4	24.8	16.9-42.5	29.7
2.	Budhana	Kalyanpur	0.47-0.95	0.71	2.53-3.78	3.15	0.42-0.84	0.63	8.26-14.2	11.6	9.58-12.3	10.9
		Sultanpur	0.39-0.86	0.62	1.40-2.50	1.95	0.32-0.62	0.47	8.25-10.1	9.21	2.36-9.35	5.85
			0.39-0.95	0.67	1.40-3.78	2.59	0.32-0.84	0.58	8.25-14.2	11.2	2.36-12.3	7.35
3.	Baghra	Baghra	0.58-3.40	1.99	1.12-1.40	1.26	0.51-3.10	1.80	4.31-14.6	9.48	2.39-20.3	11.3
		Mandi	4.67-6.24	5.45	3.01-3.34	3.17	4.40-5.51	4.95	15.9-20.5	18.2	39.2-50.3	44.7
			0.58-6.24	3.41	1.12-3.34	2.23	0.51-5.51	3.01	4.31-20.5	12.4	2.39-50.3	26.3
4.	Shahpur	Purbaliyan	0.29-0.95	0.62	0.58-10.8	5.73	0.62-0.95	0.78	6.35-11.2	8.81	7.26-63.3	35.3
		Pura	0.35-0.84	0.59	0.60-1.67	1.13	0.35-0.63	0.49	7.32-9.35	8.33	7.56-14.3	10.9
			0.29-0.95	0.62	0.58-10.8	5.73	0.35-0.95	0.65	6.35-11.2	8.81	7.26-63.3	21.8
5.	Purkaji	Nurnagar	0.28-0.57	0.42	0.75-1.84	1.29	0.21-0.92	0.56	1.10-4.95	3.02	1.01-4.64	2.82
		Chhapra	2.56-3.75	3.15	2.12-2.73	2.42	2.81-3.60	3.20	18.8-24.0	21.4	23.4-31.9	27.7
			0.28-3.75	2.01	0.75-2.73	1.74	0.21-3.60	1.90	1.10-24.0	12.5	1.01-31.9	16.5
6.	Charthawal	Bhamela	0.65-0.89	0.77	1.08-2.02	1.55	0.45-0.89	0.67	4.62-7.65	6.13	6.35-8.67	7.51
		Manganpur	0.62-95.0	47.81	2.01-3.23	2.62	0.48-0.71	0.59	6.32-9.95	8.08	3.35-12.2	7.81
		Pipalshah	0.26-2.23	1.24	0.95-5.40	3.17	0.52-2.30	1.41	7.60-17.9	12.7	1.69-15.1	8.43
			0.26-95.0	47.63	0.95-5.40	3.17	0.45-2.30	1.37	4.62-17.9	11.2	1.69-15.1	8.43
7.	Morna	Dhiraheri	0.82-4.42	2.62	0.63-1.50	1.06	0.49-2.47	1.48	9.88-23.7	16.8	4.78-32.9	18.8
		Belra	0.75-0.92	0.83	1.82-16.0	8.91	0.59-0.85	0.72	8.34-12.2	10.2	8.26-10.2	9.27
		Bhaleri	0.57-0.85	0.71	1.66-1.90	1.78	0.59-0.81	0.70	8.34-12.3	10.3	6.59-12.3	9.45
			0.57-4.42	2.49	0.63-16.0	8.31	0.49-2.47	1.48	8.34-23.7	16.0	4.78-32.9	18.8
8.	Jansath	Bahadurpur	0.54-0.86	0.70	0.90-2.80	1.85	0.59 0.85	0.33	4.23-5.87	5.05	0.31-0.48	0.39
		Wazidpur	2.93-6.04	4.48	0.98-1.39	1.18	0.59-0.81	2.62	14.6-18.5	16.5	6.94-22.4	14.7
			0.54-6.04	3.29	0.90-2.80	1.85	0.49-2.47	1.91	4.23-18.5	11.4	0.31-22.4	11.3
9.	Khatauli	Mansoorpur	1.12-1.70	1.41	0.55-0.67	0.61	0.16-1.87	1.01	14.7-22.3	18.5	18.6-29.3	24.0
		Bhataura	0.59-3.42	2.00	1.04-5.01	3.02	0.66-3.28	1.97	13.1-21.8	17.5	0.41-31.4	15.9
			0.59-3.42	2.00	0.55-5.01	2.78	0.16-3.28	1.72	13.1-22.3	17.7	0.41-31.4	15.9
	Whole district		0.26-95.0	47.63	0.55-16.0	8.27	0.16-5.51	2.83	1.10-31.4	16.2	0.41-63.3	31.8

deficiency can cause chlorosis and reduced growth, especially in crops like rice and soybean (Bagale, 2021). Other blocks, such as Baghra, Shahpur, and Purkaji, showed varying manganese levels, indicating that soil management practices could help optimize Mn availability. Acidic soils tend to improve Mn solubility, while alkaline soils may limit Mn availability (Rengel, 2015). The significant variation in manganese levels across the district highlights the importance of soil testing to determine manganese needs and ensure appropriate fertilization strategies, avoiding toxicity in areas with high Mn levels.

Categorization of the available nutrients

All the soil samples were categorized in low, medium and high category for available N, P, K & S and deficient and sufficient for available macronutrient on the basis of critical limit presented in Table 3.2 and the results are presented in Table 4.14 & 4.15. Under available nitrogen, about 99 % soil samples of Muzaffarnagar district were found to be under low category (< 250 kg N ha) and remaining in the category of medium (250-500 kg N/ha). Approximate 94, 4 and 2 % of the soil samples were found in low, medium and high category in respect of available phosphorus. In available potassium 36, 43 and 21 % of the soil samples were found in low, medium and high category. However, for available sulphur, about 34 and 66 % samples were found under Deficient and Sufficient category. Consider the critical limit of DTPA - Zn (0.78 ppm) Out of 100 samples, 33 and 67 % of the samples were found to be deficient and sufficient categories. Considering

0.60 ppm as critical limit for Cu deficiency, the samples were found under sufficient categories are 29 % and Deficient Categories are 71 %. Considering 7.00 ppm as critical limit for Fe deficiency, about 13 % soil samples were found under deficient and 83 % were sufficient category. Considering 3.00 ppm as critical limit for Mn deficiency, about 10 %soil samples were found under Deficient categories and 90% samples are sufficient categories.

CONCLUSION

Thus, it can be concluded that a soil fertility study in Muzaffarnagar district, Uttar Pradesh, analyzed 100 samples across nine blocks, revealing a slightly alkaline pH (7.00–8.36, avg. 7.74) and moderate salinity (EC 0.15–0.91 dS/m, avg. 0.53 dS/m). Organic carbon was low to moderate (1.50–4.50 g/kg, avg. 3.0 g/kg), notably in Budhana (3.05 g/kg). Nitrogen was critically low (<250 kg/ha) in 99% of samples (33.7–511.5 kg/ha, avg. 272.6 kg/ha), while phosphorus was deficient (<30 kg/ha) in 94% (2.73–98.0 kg/ha, avg. 50.36 kg/ha), especially in Purkaji (7.26 kg/ha). Potassium showed 36% low (<150 kg/ha), 43% medium, and 21% high (11.4–475.3 kg/ha, avg. 243.35 kg/ha), with sulfur deficient (<10 ppm) in 34% (3.20–192.8 ppm, avg. 98.00 ppm). Micronutrients varied: zinc (33% deficient, <0.78 ppm), copper (71% deficient, <0.60 ppm), iron (13% deficient, <7.00 ppm), and manganese (10% deficient, <3.00 ppm). Targeted nutrient management, including fertilization and climate-adapted practices, is essential for sustainable agriculture in this region.

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