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Soil Fertility and Micronutrient Analysis in Different Agroecosystems of Vidarbha Region, Maharashtra, India

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ABSTRACT

This study evaluates the physico-chemical properties and micronutrient composition of soils collected from three distinct agricultural sites in the Vidarbha region of India. The selected sites represent varied land uses: A cotton field in Sunna (Pandharkawda) located in Yavatmal district, a soybean field in Ashoknagar in Amravati district, and garden soil from Naurewal Parsodi in Chandrapur district. Comprehensive soil analyses were conducted to determine key parameters such as pH, electrical conductivity, moisture content, water holding capacity, organic and inorganic carbon, as well as the availability of primary nutrients (nitrogen, phosphorus and potassium) and secondary micronutrients (magnesium, zinc, ferrous, manganese, boron, calcium, sulfur, copper and sodium). The soil pH values recorded were slightly alkaline at the cotton and soybean sites (7.78 and 7.87 respectively) and slightly acidic to neutral at the garden soil site (6.1), which may influence nutrient solubility and microbial activity. Electrical conductivity was moderate across all sites, indicating balanced ionic concentrations without excessive salinity stress. Although the moisture content ranged modestly between 2.07% and 3.85%, all samples demonstrated a high water holding capacity (71.74% to 74.92%), highlighting their potential for adequate water retention. However, the low organic carbon and organic matter content observed in all samples suggest a possible depletion due to intensive agricultural practices. The analysis of primary macronutrients revealed that nitrogen levels varied between 294 and 410.81 kg/ha, with the cotton field showing the lowest content. Phosphorus availability was also lowest at the cotton site (20.18 kg/ha) and highest in garden soil (42.56 kg/ha), while potassium levels were moderate to high across the stations. Secondary micronutrient assessments indicated that magnesium, manganese, copper and sodium were consistently available at high levels, though discrepancies were noted in ferrous and boron content among the sites. These spatial variations underscore the necessity for site-specific nutrient management strategies. The results of this study, corroborated by extensive literature, underscore the critical need for continuous soil monitoring and the adoption of tailored soil management practices to enhance soil fertility and promote sustainable agricultural production in the Vidarbha region.

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INTRODUCTION

Agriculture serves as a cornerstone of India's economy, supporting over 65% of the population and significantly contributing to the nation's GDP (Wagh & Dongre 2016). Soil quality plays a crucial role in sustaining agricultural productivity, as it directly influences crop yield and long-term soil fertility (Wankhede *et al*. 2021). Assessing the physico-chemical properties and nutrient composition of soil is essential for determining its fertility and optimizing land use for sustainable farming (Shanmugasundaram *et al.* 2019). Effective soil management, including balanced fertilization and organic matter conservation, enhances carbon sequestration and improves productivity across diverse agro-climatic conditions (Bhattacharyya *et al.* 2009).

Soil health is determined by several interrelated factors, including pH, organic matter content, organic carbon levels, electrical conductivity, moisture retention capacity, and water-holding ability (Lehmann *et al.* 2020). These factors influence nutrient availability and overall soil fertility. Macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) are essential for plant growth, while secondary and micronutrients, including magnesium (Mg), zinc (Zn), iron (Fe), manganese (Mn), boron (B), calcium (Ca), sulfur (S), copper (Cu), and sodium (Na), play a vital role in sustaining crop productivity and maintaining soil stability (Radulov & Berbecea 2024). Research by Gudla *et al.* (2023) highlights the strong correlations between primary macronutrients and soil properties, particularly the role of organic carbon in nutrient cycling and fertility management. The decomposition of plant and animal matter contributes to soil organic matter, transforming into humus that enhances soil structure, nutrient retention, and water-holding capacity (Lehmann *et al*. 2020). Maintaining an optimal balance of these nutrients is crucial for ensuring long-term agricultural sustainability and ecological stability (Radulov & Berbecea 2024).

The productivity of soil is significantly influenced by the availability and balance of macro- and micronutrients, which are essential for plant growth, development, and overall resilience. Any imbalance, whether due to deficiencies or excesses, can disrupt essential physiological and metabolic processes in plants, increasing their susceptibility to diseases and environmental stressors. Martín-Cardoso and San Segundo (2025) emphasize that nutrient stress not only hampers plant growth but also weakens natural defense mechanisms, making crops more vulnerable to pathogens. Consequently, improper nutrient management can lead to soil degradation, declining fertility, and reduced agricultural yields. Ensuring a well-balanced nutrient supply is therefore imperative for sustaining soil health and maximizing crop productivity.

In India, where a significant portion of the population depends on agriculture and forestry, maintaining soil health is crucial for sustainable farming practices. Regular soil monitoring and nutrient assessment are essential for formulating effective soil management strategies that ensure long-term agricultural productivity. The Government of India introduced the Soil Health Card (SHC) Scheme to enhance soil fertility and optimize fertilizer use. According to Singh *et al*. (2022), farmers who implemented SHC-based recommendations experienced increased crop yields and reduced input costs, leading to higher net incomes. The study demonstrated notable improvements in soil fertility through balanced nutrient applications, ultimately boosting agricultural productivity. Furthermore, the Food and Agriculture Organization (FAO 2023) underscores the importance of integrated soil and water management in achieving food security, particularly in rainfed regions that contribute nearly 40% of India's food production. Sustainable soil management practices, such as maintaining organic matter and improving water retention, are vital for ensuring agricultural resilience.

The Vidarbha region of eastern Maharashtra is a significant agricultural hub with diverse soil types and varying climatic conditions, necessitating region-specific soil management strategies. A recent study by Rahangdale *et al.* (2024) analyzed soil samples from sweet orange orchards in the Saoner and Kalmeshwar areas of Nagpur district, revealing variations in soil pH (7.2 to 8.1), electrical conductivity (0.102 to 0.257 dS m^{-1}), organic carbon (4.4 to 5.9 g kg^{-1}), and calcium carbonate content (2.3 to 4.8%). The study also identified optimal nutrient levels, including nitrogen (312.4 to 336.1 kg ha^{-1}), phosphorus (19.9 to 30.4 kg ha^{-1}), and potassium (414.14 to 429.45 kg ha^{-1}), along with essential micronutrients. These findings emphasize the importance of targeted soil conservation measures and nutrient management strategies to enhance agricultural productivity in the region (Rahangdale *et al.* 2024).

Soil serves as a foundation for plant growth, hosting diverse microorganisms and supporting essential biological processes (Dasgupta & Brahmaprakash 2021). It comprises various mineral components that form distinct layers, each characterized by unique physical, chemical, and morphological properties (Usharani *et al.* 2019). In addition to anchoring plant roots, soil functions as a reservoir for essential nutrients such as nitrogen, phosphorus, potassium, calcium, sulfur, and other micronutrients critical for plant development (Sagwal *et al*. 2023). Soil productivity is governed by its physico-chemical and biological characteristics, which influence its fertility and ecological significance (Chen *et al.* 2020).

Soil quality is shaped by multiple interacting factors, including texture, pH, organic matter content, microbial activity, and irrigation practices. These factors regulate nutrient cycling and determine plant nutrient uptake, ultimately influencing soil fertility (Schröder *et al.* 2016). While macronutrients are frequently supplemented through fertilizers, micronutrients are naturally replenished through biological and geochemical processes (Schröder *et al.* 2016). Soil organic matter plays a pivotal role in improving nutrient retention, water conservation, and soil structure (Lal 2020). A higher organic matter content enhances soil aeration, promotes microbial activity, and strengthens long-term soil productivity (Bhadha *et al.* 2017).

However, agricultural intensification, excessive land use, nutrient depletion, and soil erosion continue to pose significant threats to soil fertility, underscoring the need for consistent soil assessment and sustainable nutrient management practices (Shelke *et al.* 2024, Devatale *et al*. 2024). Given India's heavy reliance on agriculture, soil quality assessment is essential for ensuring long-term agricultural viability, particularly in regions like Vidarbha, where soil properties and land-use patterns vary widely. Recent studies in Maharashtra have identified variations in soil fertility, with some areas exhibiting neutral to strongly alkaline soils and differing levels of organic carbon, nitrogen, phosphorus and potassium, necessitating region-specific conservation strategies (Shelke *et al.* 2024, Devatale *et al*. 2024). Understanding soil characteristics and nutrient composition across different agricultural lands facilitates the implementation of effective conservation measures, ensuring optimal crop yields while preserving soil health for future generations.

This study aims to investigate the physico-chemical properties and micronutrient composition of soils from three different locations in the Vidarbha region. Through systematic soil analysis, the research will provide valuable insights into soil fertility assessment, sustainable soil management, and improved agricultural practices.

MATERIALS AND METHODS

Study area

The study was conducted in three distinct agricultural sites within the Vidarbha region, chosen for their varied soil types and land-use patterns. These sites were selected to analyze the physico-chemical characteristics and micronutrient composition of the soil. The first site was located in Yavatmal district, specifically in Kelapur Taluka at Sunna (Pandharkawda), where the primary crop cultivated is cotton. The second site was in Amravati district, in Dhamangaon Railway Taluka at Ashoknagar, which is primarily used for soybean cultivation. The third site was in Chandrapur district, in Nagbhid Taluka at Naurewal Parsodi, classified as garden soil. Soil samples were collected by digging a V-shaped pit up to a depth of 30 cm from the surface. The collected soil from each location was thoroughly mixed to ensure a representative sample before proceeding with laboratory analysis.

The soil sample from Yavatmal district, Kelapur

Taluka at Sunna (Pandharkawda), was from a cotton field, a major crop in this region. Cotton cultivation requires significant water and often involves fertilizers and pesticides to enhance yield. The second sample, from Amravati district, Dhamangaon Railway Taluka at Ashoknagar, was from a soybean farm. Soybean plants grow up to two meters and have self-fertilizing flowers, with commercially grown varieties typically having brown or tan seeds. The third sample, from Chandrapur district, Nagbhid Taluka at Naurewal Parsodi, was garden soil, which is deep, porous, and loamy, providing good moisture retention and aeration, making it suitable for horticulture.

Methods of soil analysis

To analyze the soil samples collected from three different stations in the Vidarbha region, various laboratory techniques were employed. The following methodologies were used to determine the physico-chemical characteristics and micronutrient content of the soil samples.

pH determination

Soil pH is a measure of the hydrogen ion concentration in the soil, influencing the solubility of minerals and nutrient availability for plant growth. It was determined using a glass electrode pH meter. For analysis, 20 g of soil sample were mixed with 100 mL of distilled water. The suspension was allowed to settle, and the leachate was filtered before measuring the pH using the electrode (Weil & Brady 2017).

Nitrogen estimation (Kjeldahl method)

Nitrogen, a primary macronutrient, is mainly present in organic and ammonium forms. The Kjeldahl method was used to determine total nitrogen content. One gram of soil sample (sieved through a 2 mm sieve) was mixed with 10 mL of distilled water and left to stand for 30 minutes. The mixture was digested with 20 g of catalyst digestion mixture and 10 mL of concentrated sulfuric acid (H_2SO_4) for 1.5 hours. After cooling, the digest was diluted to 100 mL with distilled water. Twenty milliliters of this solution were distilled with 20 mL of 40% sodium hydroxide (NaOH) and a few pieces of zinc. The releazed ammonia was absorbed in boric acid and titrated with 0.1N hydrochloric acid (HCl) (Fageria 2009).

Available phosphorus (modified truog method)

Phosphorus availability in the soil was analyzed using the Modified Truog method. One gram of soil sample was extracted with 200 mL of 0.002 N sulfuric acid (H_2SO_4) by shaking for 30 minutes. The filtrate was treated with ammonium molybdate and $SnCl_2$ solution to develop a blue color, which was measured at 690 nm using a spectrophotometer (Rashmi *et al.* 2016).

Organic carbon and organic matter (walkley and black method)

Organic matter in the soil was determined using the Walkley and Black method. One gram of soil sample was reacted with 10 mL of 1N potassium dichromate ($K_2Cr_2O_7$) and 20 mL of concentrated sulfuric acid (H_2SO_4). The reaction was allowed to proceed for 30 minutes, followed by dilution with 200 mL of distilled water. After adding 10 mL of o-phosphoric acid and 1 mL of diphenylamine indicator, the sample was titrated with 0.4N ferrous ammonium sulfate (FAS) until the endpoint turned brilliant green (Post *et al.* 1982).

Potassium determination (flame photometry)

Exchangeable potassium was determined using ammonium acetate extraction followed by flame photometry. Fifty grams of air-dried soil were treated with 100 mL of 40% ethanol and filtered through Whatman No. 50 filter paper. The filtrate was further leached with 1N ammonium acetate solution, and the potassium concentration was measured using a flame photometer (Deshmukh 2012).

Electrical conductivity

Electrical conductivity (EC) of soil is an indicator of its salinity and is measured using a conductivity meter. A standard method involves preparing a 1:5 soil-to-water suspension, stirring it for 30 minutes, and filtered before measuring EC in dS/m (FAO 2021).

Moisture content

Soil moisture content was determined using the gravimetric method. A known weight of fresh soil was dried in an oven at 105°C for 24 hrs, and the weight loss was calculated to determine moisture content (Aiswarya *et al*. 2024).

Water holding capacity

Water holding capacity was assessed by saturating a known amount of soil with water, allowing drainage, and then measuring the retained water (Govindasamy *et al.* 2022).

Magnesium, zinc, iron, manganese, boron, calcium, sulfur, copper and sodium

Micronutrients were analyzed using atomic absorption spectrophotometry (AAS). Soil samples were digested with diethylene triamine penta acetic acid (DTPA) solution and filtered before analyzing the concentrations of magnesium (Mg), zinc (Zn), iron (Fe), manganese (Mn), boron (B), calcium (Ca), sulfur (S), copper (Cu), and sodium (Na) (Sunitha *et al.* 2015).

Statistical analysis

Mean, standard error and significance are calculated by using Statistical Package for Social Sciences (SPSS 10.0). All graphs in this study were drawn using Microsoft Excel Software.

RESULTS

The soil analysis results for pH, electrical conductivity, moisture content, water holding capacity, organic and inorganic carbon, as well as the availability of primary, secondary, and other micronutrients for the three selected stations—Sunna (Pandharkawda), Ashoknagar, and Naurewal Parsodi—are presented in graphical format to illustrate variations across locations. Table 1 shows the availability of primary micronutrients along with various soil properties at the three stations, while Table 2 presents the availability of secondary micronutrients (in PPM) across all sites.

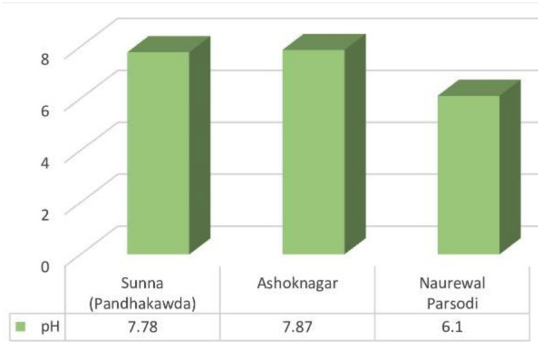

Fig. 1. Showing pH at three different stations.

Soil pH

Soil pH is crucial for root development and nutrient availability, typically ranging from 1 to 14, with most plants thriving in a range of 5.5 to 7.5. In this study, the pH values recorded were 7.78 for Sunna, 7.87 for Ashoknagar, and 6.1 for Naurewal Parsodi. The results indicate that the first two locations have slightly alkaline soils, whereas Naurewal Parsodi has a slightly acidic to neutral soil. The pH of soil for all three locations is represented in Fig. 1.

Electrical conductivity

Electrical conductivity (EC) influences soil salinity

Table 1. Showing the availability of primary micronutrients and properties of soil at three stations.

Sampling site	pH	EC ds/m	Moisture %	Organic carbon %	Inorganic carbon %	Water holding capacity %	Nitrogen kg/ha	Phosphorus kg/ha	Potassium kg/ha
Sunna (Pandhakawda)	7.78	0.84	3.24	0.874	2.34	74.92	294	20.18	217.28
Ashoknagar	7.87	0.42	2.07	0.901	1.54	71.74	410.81	30.91	293.17
Naurewal Parsodi	6.1	0.1	3.85	1.02	1.37	73.25	380.2	42.56	266.4

Table 2. Showing availability of secondary micronutrient in PPM.

Secondary micronutrient in PPM	Sunna (Pandhakawda)	Remark	Ashoknagar	Remark	Naurewal Parsodi	Remark
	Sampling stations					
Magnesium	495.7	High	505.2	High	285	High
Zinc	1	Low	4.29	Moderate	4	Moderate
Ferrous	2.3	Low	11.74	High	64	Very high
Manganese	8.78	High	9.67	High	39	High
Boron	0.51	High	0.42	Moderate	1	High
Calcium	762	Moderate	601	Moderate	1650	Moderate
Sulfur	43.23	High	19.91	Low	11	Moderate
Copper	8.87	High	11.59	High	1.4	High
Sodium	4.9	High	5.6	High	15	High

and nutrient solubility. Across all three sampling sites, EC values were within the moderate range, varying from 0.1 to 0.84 dS/m, indicating adequate ionic concentration without excessive salinity. EC values show that Sunna (0.84 ds/m) has the highest electrical conductivity, followed by Ashoknagar (0.42 ds/m), while Naurewal Parsodi has the lowest (0.1 ds/m), suggesting varying levels of soil salinity. The electrical conductivity values are illustrated in Fig. 2.

Moisture content, organic and inorganic carbon, and water holding capacity

Moisture content in the soil samples ranged from 2.07% to 3.85%, with the highest value recorded in Naurewal Parsodi. Organic and inorganic carbon percentages were consistently low across all sites. Naurewal Parsodi has the highest moisture content (3.85%), followed by Sunna (3.24%), while Ashoknagar has the lowest (2.07%).

Organic carbon is highest in Naurewal Parsodi

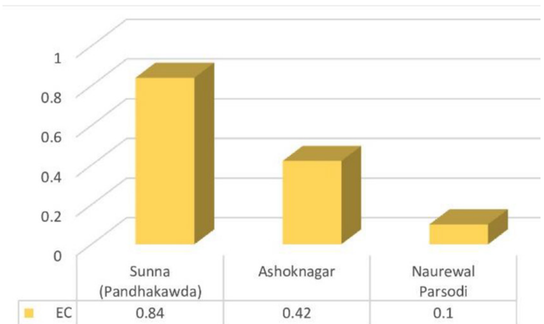

Fig. 2. Showing EC in ds/m at three different stations.

(1.02%), followed by Ashoknagar (0.901%) and Sunna (0.874%), indicating differences in soil fertility.

Sunna (Pandhakawda) has the highest inorganic carbon content (2.34%), indicating a significant presence of carbonate minerals, which could contribute to its slightly alkaline pH (7.78). Ashoknagar has a moderate inorganic carbon level (1.54%), aligning with its slightly alkaline pH (7.87). In contrast, Naurewal Parsodi has the lowest inorganic carbon content (1.37%), which corresponds with its slightly acidic pH (6.1).

The water holding capacity of all three samples was ranging between 71.74% and 74.92%, reflecting good soil porosity and retention potential. The soils at all three sites have high water-holding capacity, with Sunna (74.92%) having the highest, followed by Naurewal Parsodi (73.25%) and Ashoknagar (71.74%).

The moisture content, Organic and Inorganic Carbon for the three locations are depicted in Fig. 3 and water holding capacity is represented in Fig. 4.

Availability of nitrogen, phosphorus and potassium

Ashoknagar has the highest nitrogen content (410.81 kg/ha), followed by Naurewal Parsodi (380.2 kg/ha), while Sunna has the lowest (294 kg/ha). In terms of phosphorus, Naurewal Parsodi has the highest content (42.56 kg/ha), followed by Ashoknagar (30.91 kg/ha), while Sunna has the lowest (20.18 kg/ha). For potassium, Ashoknagar again records the highest value (293.17 kg/ha), followed by Naurewal Parsodi

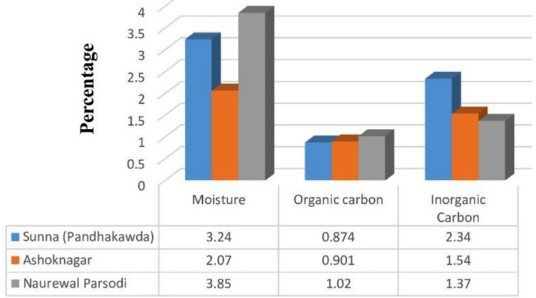

Fig. 3. Showing moisture content, organic and inorganic carbon at three different stations.

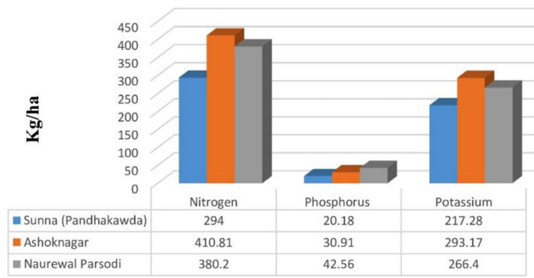

Fig. 5. Showing N, P, K content at three different stations in kg/ha.

(266.4 kg/ha), with Sunna having the lowest (217.28 kg/ha). These variations in nutrient levels indicate differences in soil fertility across the three stations, with Ashoknagar showing the highest nitrogen and potassium levels, while Naurewal Parsodi leads in phosphorus content. The nitrogen, phosphorus, and potassium concentrations are shown in Fig. 5.

Secondary and other micronutrients

The secondary micronutrient analysis showed high availability of magnesium, manganese, copper, and sodium in all soil samples. Ferrous content was low in Sunna but significantly higher in Ashoknagar and extremely high in Naurewal Parsodi. Boron levels were high in Sunna and Naurewal Parsodi, while moderate in Ashoknagar. Calcium was moderately available in all samples, whereas sulfur was found in high concentrations in Sunna, low in Ashoknagar, and moderate in Naurewal Parsodi.

The availability of secondary micronutrients in soil varies across the three sampling stations: Sunna (Pandhakawda), Ashoknagar, and Naurewal Parsodi (Table 2). Magnesium levels are high at all three sites, with values of 495.7 PPM at Sunna, 505.2 PPM at Ashoknagar, and 285 PPM at Naurewal Parsodi. Zinc is low at Sunna (1 PPM) but moderate at Ashoknagar (4.29 PPM) and Naurewal Parsodi (4 PPM). Ferrous content is low in Sunna (2.3 PPM), high in Ashoknagar (11.74 PPM), and very high in Naurewal Parsodi (64 PPM). Manganese levels are consistently high, with Sunna at 8.78 PPM, Ashoknagar at 9.67 PPM, and Naurewal Parsodi at 39 PPM. Boron is high in Sunna (0.51 PPM) and Naurewal Parsodi (1 PPM) but moderate in Ashoknagar (0.42 PPM). Calcium content is moderate across all stations, with Sunna at 762 PPM, Ashoknagar at 601 PPM, and Naurewal Parsodi at 1650 PPM. Sulfur is high in Sunna (43.23 PPM), low in Ashoknagar (19.91 PPM), and moderate in Naurewal Parsodi (11 PPM). Copper is high across all stations, with values of 8.87 PPM at Sunna, 11.59 PPM at Ashoknagar, and 1.4 PPM at Naurewal Parsodi. Sodium is also consistently high, with Sunna at 4.9 PPM, Ashoknagar at 5.6 PPM, and Naurewal Parsodi at 15 PPM. These variations indicate differences in soil composition, influencing nutrient availability and plant growth potential across the three locations.

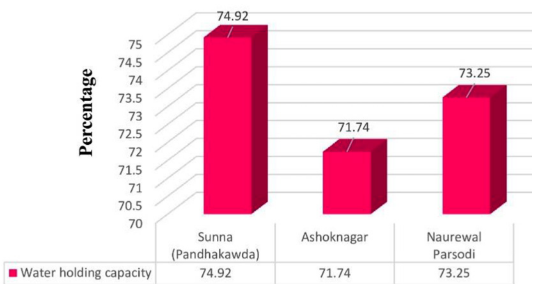

Fig. 4. Showing water holding capacity at three different stations.

These findings provide a comprehensive understanding of soil fertility across the three stations in the Vidarbha region and can assist in the development of effective soil management strategies for enhanced agricultural productivity.

DISCUSSION

The findings of this study highlight significant spatial variability in soil fertility across three distinct agricultural sites in the Vidarbha region. The variation in soil pH, moisture content, organic carbon, and primary and secondary nutrient availability underscores the influence of land use practices, climatic conditions, and inherent soil characteristics on soil health. These results align with previous studies that emphasize the necessity for region-specific soil management practices to maintain sustainable agricultural productivity (Rahangdale *et al.* 2024, Shang *et al*. 2014).

The pH values observed across the sites—ranging from slightly acidic (6.1) in Naurewal Parsodi to slightly alkaline in Ashoknagar (7.87) and Sunna (7.78) directly impact nutrient availability. Previous research indicates that optimal pH levels promote microbial activity and nutrient solubility, whereas extreme pH values can lead to deficiencies or toxicities of essential elements (Schröder *et al.* 2016, O'Kennedy 2022). The moderate electrical conductivity (EC) values across all sites suggest balanced ionic concentrations, avoiding excessive salinity stress, which can impair root function and hinder nutrient uptake (Chen *et al.* 2020).

Organic carbon content, a key indicator of soil fertility, was consistently low across all samples. This finding aligns with previous studies indicating that intensive agricultural practices and reduced organic matter inputs contribute to soil carbon depletion (Lal 2020, Tong *et al.* 2022). Given that organic matter enhances soil structure, water retention, and microbial diversity, strategies such as organic amendments and conservation tillage should be promoted to mitigate carbon loss and improve soil health (Bhattacharyya *et al.* 2009, Busari *et al.* 2015).

The availability of primary macronutrients-nitrogen, phosphorus and potassium varied across the study sites. The lowest nitrogen content was observed in Sunna (294 kg/ha), which could be attributed to high cropping intensity and inadequate nitrogen replenishment. Research by Gudla *et al.* (2023) suggests that nitrogen availability is closely linked to soil organic carbon content, emphasizing the importance of organic inputs for sustaining soil fertility. The phosphorus levels in Sunna were also the lowest (20.18 kg/ha), reinforcing the need for phosphorus-based fertilization strategies, as phosphorus is crucial for root development and energy transfer in plants (Shanmugasundaram *et al*. 2019, Gong *et al*. 2022). In contrast, potassium levels were moderate to high across the sites, supporting previous findings that potassium availability in Indian soils is relatively stable due to inherent mineral reserves (Shelke *et al.* 2024).

Secondary and micronutrient analysis revealed significant differences in availability across the sites. High magnesium, manganese, copper, and sodium levels suggest that these elements are not limiting factors in the region. However, the low ferrous content in Sunna (2.3 ppm) raises concerns, as iron deficiency can impair chlorophyll synthesis and reduce crop yields (Sagwal *et al.* 2023, Singh 2008). The study by Martín-Cardoso and San Segundo (2025) also underscores the impact of micronutrient imbalances on plant health and disease resistance, highlighting the need for integrated soil fertility management.

The study's results underscore the importance of site-specific nutrient management strategies tailored to the unique soil characteristics of each location. The Soil Health Card (SHC) initiative in India has demonstrated the benefits of targeted fertilization in enhancing crop yields while reducing input costs (Singh *et al*. 2022, Reddy 2017). By integrating soil testing with precision nutrient management, farmers can optimize fertilizer use efficiency and prevent excessive nutrient depletion.

Sustainable soil management practices, such as crop rotation, organic amendments, and conservation tillage, should be encouraged to improve soil structure, enhance microbial diversity, and sustain long-term agricultural productivity (FAO 2023, Hou 2021). Furthermore, water management strategies should be optimized, as moisture retention plays a critical role in nutrient availability and uptake (Bhadha *et al.* 2017, Rastogi *et al.* 2024).

Overall, the findings of this study contribute valuable insights into the physico-chemical and nutrient properties of soil in Vidarbha, offering a foundation for improved agricultural planning and sustainability. Future research should focus on the long-term impact of different land-use practices on soil health, with an emphasis on climate change adaptation strategies to ensure resilient agroecosystems in the region.

CONCLUSION

The present study reveals significant spatial variability in the physico-chemical properties and nutrient content of soils across three diverse agricultural sites in the Vidarbha region. The marked differences in soil pH, moisture content, organic carbon, and the availability of both primary (nitrogen, phosphorus and potassium) and secondary micronutrients (magnesium, manganese, copper, among others) underscore the complex interplay of Factors Governing soil fertility. Such variability necessitates tailored nutrient management strategies that address local soil conditions and environmental factors to optimize crop performance. Moreover, the findings of this study, in conjunction with the current literature, highlight the importance of continuous soil monitoring and the incorporation of organic amendments to mitigate nutrient imbalances. These insights provide a comprehensive baseline for future research and practical interventions aimed at preventing soil degradation and promoting sustainable land use practices in the Vidarbha region.

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