



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(6): 177-181
Received: 05-03-2026
Accepted: 08-04-2026

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Assessment of soil fertility status and nutrient relationships in agricultural soils of Sangli District, Maharashtra, India

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6Sc.5737>

Abstract

Soil fertility assessment is essential for sustainable nutrient management and improved agricultural productivity. The present study evaluated the fertility status and relationships among key soil properties in Sangli district of Maharashtra using a dataset of 341 geo-referenced surface soil samples obtained from the Soil Bank of Mahatma Phule Krishi Vidyapeeth, Rahuri. Soil samples were analyzed for pH, electrical conductivity (EC), soil organic carbon (SOC), available nitrogen (N), phosphorus (P), and potassium (K), and Pearson's correlation analysis was performed. The soils were predominantly alkaline, with 89.15% of the samples classified as slightly to moderately alkaline. Most soils (90.62%) were non-saline, although a few samples exhibited elevated EC values, indicating localized salinity. Soil organic carbon status was generally moderate to high. Available nitrogen was predominantly low, with 95.60% of the samples falling in the low category, identifying nitrogen deficiency as the major fertility constraint. Available phosphorus was mainly low to moderate, whereas available potassium was high to very high in most soils. Correlation analysis revealed positive associations of SOC with available N, P, and K, while soil pH showed negative relationships with SOC, N, and P. The study highlights the importance of nitrogen management, maintenance of soil organic matter, and efficient phosphorus management for sustaining soil fertility and crop productivity in Sangli district.

Keywords: Soil fertility, soil organic carbon, nitrogen, phosphorus, potassium, salinity, Sangli district

1. Introduction

Soil health is essential for agricultural productivity, as it supports nutrient cycling and carbon storage, both of which are crucial for stable crop yields (Shahane & Shivay, 2021) [20]. In India, the drive to increase food production has led to intensive farming and the overuse of chemical fertilizers, which often harms soil fertility and reduces how efficiently crops use nutrients (Bhattacharyya *et al.*, 2015) [4]. For regions like Sangli in Maharashtra, with varied cropping patterns and climates, understanding how nutrients are distributed across the landscape is critical for developing site-specific nutrient management (Akhil *et al.*, 2025) [1]. However, detailed, local data on the current soil fertility status and the complex relationships between nutrients in Sangli's agricultural lands remain limited, complicating efforts to create effective agricultural policies (Hadole *et al.*, 2024; Sharma *et al.*, 2022) [9, 21]. This gap in localized information limits our ability to optimize fertilizer use and prevent soil degradation, which is a growing concern. Therefore, this study aims to evaluate the soil fertility status and analyse the interactions between different soil parameters in Sangli. By providing these essential insights, the research will help support sustainable land management practices, enhance regional agricultural productivity, and guide future efforts to maintain long term soil health.

2. Materials and method

The present study was conducted for Sangli district of Maharashtra, India. Sangli district is situated in the southern part of Maharashtra and lies between 16°43' to 17°38' north latitude and 73°41' to 75°41' east longitude.

It is characterized by a semi-arid tropical climate with predominantly black soils derived from basaltic parent material. Agriculture is the major land use in the district, with sugarcane, soybean, sorghum, wheat, and horticultural crops being commonly cultivated.

The study was based on soil fertility data obtained from the Soil Bank, Department of Soil Science and Agricultural Chemistry, Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra. The database comprised geo-referenced total 341 surface soil samples (0-20 cm depth) collected from different locations across Sangli district.

The dataset included soil reaction (pH), electrical conductivity (EC), organic carbon (OC), available nitrogen (N), available phosphorus (P), and available potassium (K). Soil reaction (pH) and electrical conductivity (EC) were determined in a 1:2.5 soil-water suspension following the procedure of Jackson (1973) ^[11]. Soil organic carbon was estimated by the wet oxidation method of Nelson and Sommers (1982) ^[15]. Available nitrogen was determined by the alkaline permanganate method (Subbiah and Asija, 1956) ^[22]. Available phosphorus was estimated by the

Olsen method (Watanabe and Olsen, 1965) ^[24], while available potassium was determined by flame photometry after extraction with neutral normal ammonium acetate (Jackson, 1973) ^[11].

The fertility status of soil organic carbon (OC), available nitrogen (N), available phosphorus (P), and available potassium (K) was classified into very low, low, moderate, moderately high, high, and very high categories according to the criteria suggested by Patil and Mali (1999) ^[19]. Soil pH and electrical conductivity (EC) were classified following the guidelines of Bangar and Zende (1978) ^[2].

Pearson's correlation analysis was performed to examine the relationships among soil properties, namely pH, EC, organic carbon, available nitrogen, available phosphorus, and available potassium. The correlation matrix was generated using Python software to determine the strength and direction of association among the soil fertility parameters.

3. Results and discussion

3.1 Descriptive statistics of soil properties

Table 1: Descriptive Statistics of Soil Properties in Sangli District (n = 341)

Statistic	pH	EC (dS m ⁻¹)	SOC (%)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)
Mean	7.96	0.34	0.62	207.26	15.88	439.94
Median	8.13	0.18	0.58	200.70	14.54	392.00
Minimum	5.76	0.04	0.10	103.48	1.02	112.00
Maximum	8.96	2.82	1.56	482.94	35.97	996.80
Standard Deviation (SD)	0.62	0.44	0.28	41.91	8.63	236.73
Coefficient of Variation (CV%)	4.85	57.02	44.64	20.22	54.36	53.81

The descriptive statistics of soil properties in Sangli district are presented in table 1. The mean soil pH was 7.96, indicating that the soils were predominantly neutral to moderately alkaline. The mean EC was 0.34 dS m⁻¹, suggesting that most soils were non-saline. The average SOC content was 0.62%, which indicated a moderate level of soil organic carbon. The mean available N, P, and K contents were 207.26, 15.88, and 439.94 kg ha⁻¹, respectively. The results showed that available nitrogen and phosphorus were generally low, whereas potassium was

comparatively high. The coefficient of variation was lowest for pH (4.85%), indicating relatively low variability among the samples. The EC, available P, and available K showed higher variability, reflecting differences in soil properties and nutrient status across the study area.

3.2 Soil properties distribution status

3.2.1 Soil pH

Table 2: Distribution of soil pH in Sangli District

Soil pH Class	pH Range	Samples (n)	Percentage (%)
Extremely acidic	< 4.5	0	0.00
Strongly acidic	4.6-5.5	0	0.00
Moderately acidic	5.6-6.5	18	5.28
Slightly acidic	6.6-6.9	14	4.11
Neutral	7.0	5	1.47
Slightly alkaline	7.1-8.0	113	33.14
Moderately alkaline	8.1-9.0	191	56.01
Strongly alkaline	9.1-10.0	0	0.00
Very strongly alkaline	10.1-11.0	0	0.00
Total	—	341	100.00

The distribution of soil pH classes revealed that the soils of Sangli district were predominantly alkaline in nature (Table 2). The samples (56.01%) were classified as moderately alkaline (pH 8.1-9.0), followed by 33.14% under the slightly alkaline category (pH 7.1-8.0). Small proportion of soils were moderately acidic (5.28%), slightly acidic (4.11%), and neutral (1.47%). No samples belonged to the extremely acidic or strongly alkaline categories. The predominance of alkaline soils may be attributed to the semi-arid climate, limited leaching due to low rainfall, and the accumulation of exchangeable basic cations such as calcium and magnesium in the soil (Weil and

Brady 2017) ^[25]. These results indicate that soil reaction in the district is generally favourable for crop production; however, alkaline conditions may reduce the availability of phosphorus and micronutrients such as iron, zinc, and manganese (Havlin, 2014) ^[10].

The predominance of alkaline soils observed in the present study is consistent with earlier reports from Sangli district. Patil *et al.* (2017) ^[18] recorded slightly to moderately alkaline soils in Kadegaon tehsil, with pH ranging from 7.09 to 8.21. Similar alkaline soil conditions have also been reported in other parts of Maharashtra (Hadole *et al.*, 2024; Jagtap *et al.*, 2018) ^[9, 13].

3.2.2 Electrical conductivity

Table 3: Soil Electrical Conductivity (EC) Classification of Sangli District (n = 341)

EC Class	EC Range (dS m ⁻¹)	Samples (n)	Percentage (%)
Normal	0-1	309	90.62
Poor seed emergence	1-2	26	7.62
Harmful to some crops	2-3	6	1.76
Harmful to most crops	>3	0	0.00
Total	—	341	100.00

The distribution of soil electrical conductivity (EC) classes in Sangli district is presented in table 3. The majority of soil samples (90.62%) were classified as normal (0-1 dS m⁻¹), indicating that salinity is generally not a major constraint in the district. However, 7.62% of the samples observed under the poor seed emergence category (1-2 dS m⁻¹), while 1.76% were classified as harmful to some crops (2-3 dS m⁻¹). These findings indicate that most agricultural soils are suitable for crop production, although localized salinity problems exist in a few areas, which may affect seed germination and crop growth if not managed properly. The occurrence of localized salinity in the area may be attributed to limited rainfall, the buildup of soluble salts in the soil profile, low-lying topographic positions that favour salt accumulation, and the use of irrigation water containing elevated salt concentrations (Gedam *et al.*, 2021) ^[5]. The presence of a few samples with elevated EC values suggests minor salinity variations within the district. Comparable EC ranges have been reported from Satara (Hadole *et al.*, 2024) ^[9], Kolhapur (Kumar *et al.*, 2020) ^[14] and other parts of western Maharashtra (Ghodke *et al.*, 2016) ^[6], where most soils were

non-saline but occasional samples showed relatively higher EC values.

3.2.3 Soil organic carbon

The distribution of soil organic carbon (SOC) classes is presented in table 4 and figure 1. The majority of soil samples were distributed in the moderate (24.34%), high (25.51%), and moderately high (20.23%) categories. Low and very low SOC classes accounted for 21.99% and 5.28% of the samples, respectively, whereas only 2.64% of the samples were classified as very high. The results indicate a moderate to high organic carbon status in most soils of Sangli district, which may be attributed to crop residue incorporation and organic matter accumulation.

The organic carbon status observed in the present study is consistent with previous reports from Maharashtra. Similar organic carbon levels were reported by Hadole *et al.* (2024) ^[9] and Surwase *et al.* (2024) ^[23], indicating variability in soil organic carbon across agricultural soils of the region.

Table 4: Six-Tier Fertility Classification of Organic Carbon, Available Nitrogen, Phosphorus and Potassium in Sangli District (n = 341)

Fertility Class	Organic Carbon (%)	Available Nitrogen (kg ha ⁻¹)	Available Phosphorus (kg ha ⁻¹)	Available Potassium (kg ha ⁻¹)
Very Low	18 (5.28)	3 (0.88)	68 (19.94)	0 (0.00)
Low	75 (21.99)	326 (95.60)	103 (30.21)	18 (5.28)
Moderate	83 (24.34)	12 (3.52)	73 (21.41)	31 (9.09)
Moderately High	69 (20.23)	0 (0.00)	66 (19.35)	42 (12.32)
High	87 (25.51)	0 (0.00)	30 (8.80)	30 (8.80)
Very High	9 (2.64)	0 (0.00)	1 (0.29)	220 (64.52)
Total	341 (100)	341 (100)	341 (100)	341 (100)

Note: Values in parentheses indicate the percentage of total samples.

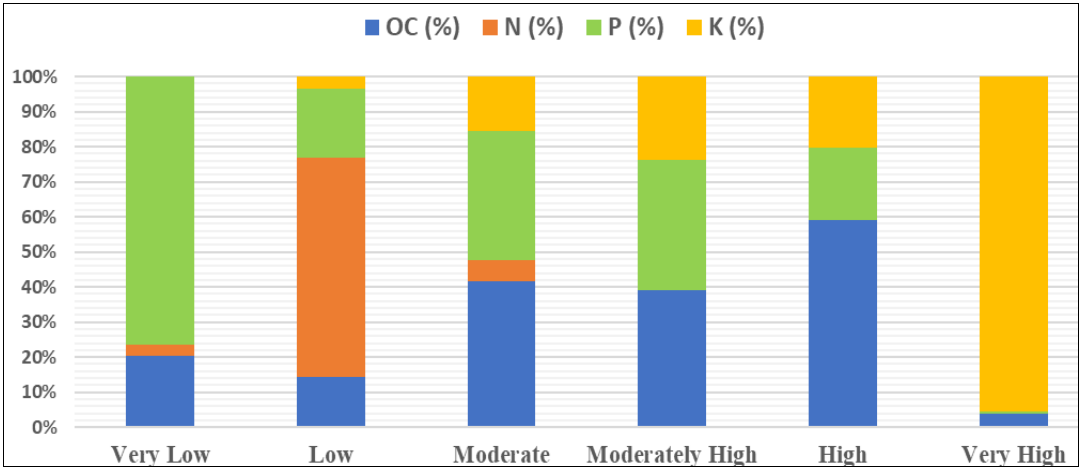


Fig 1: Comparative distribution of OC, N, P, and K fertility classes in Sangli district soils

3.2.4 Available Nitrogen (N)

Available nitrogen status was predominantly low, with 95.60% of soil samples falling under the low category (Table 4 and Figure 1). Only 3.52% of the samples were classified as

moderate and 0.88% as very low, while no samples were recorded in the moderately high, high, or very high categories. The widespread nitrogen deficiency may be due to low organic matter mineralization and continuous nutrient removal by crops

without adequate nitrogen replenishment (Behera *et al.*, 2025)^[3]. Similar low nitrogen status was reported by Patil *et al.* (2017)^[18] in Kadegaon tehsil of Sangli district, where continuous cultivation and low organic matter content contributed to nitrogen deficiency in soils. Also, Ghodke *et al.* (2016)^[6] reported that nearly 70 per cent of soils from western Maharashtra were low in available nitrogen.

3.2.5 Available Phosphorus (P)

The distribution of available phosphorus showed that 30.21% of the samples were in the low category, followed by moderate (21.41%), very low (19.94%), and moderately high (19.35%) classes (Table 4 and Figure 1). High and very high phosphorus levels were observed in only 8.80% and 0.29% of the samples, respectively. These results indicate that phosphorus availability is generally low to moderate in the soils of Sangli district, which may limit crop productivity in some areas. The low to moderate phosphorus status may be related to fixation of phosphorus in alkaline and calcareous soils, which reduces its availability to plants (Omar *et al.*, 2024)^[16]. Similar findings were reported by Patil *et al.* (2017)^[18] in Sangli district, where available phosphorus was predominantly low to medium. Likewise, Hadole *et al.* (2024)^[9] observed low to medium phosphorus status and attributed it to alkaline soil conditions and phosphorus fixation. Ghodke *et al.* (2016)^[6] also reported that soil pH and calcium carbonate content influenced phosphorus availability, resulting in low to moderate phosphorus levels in the soils of western Maharashtra.

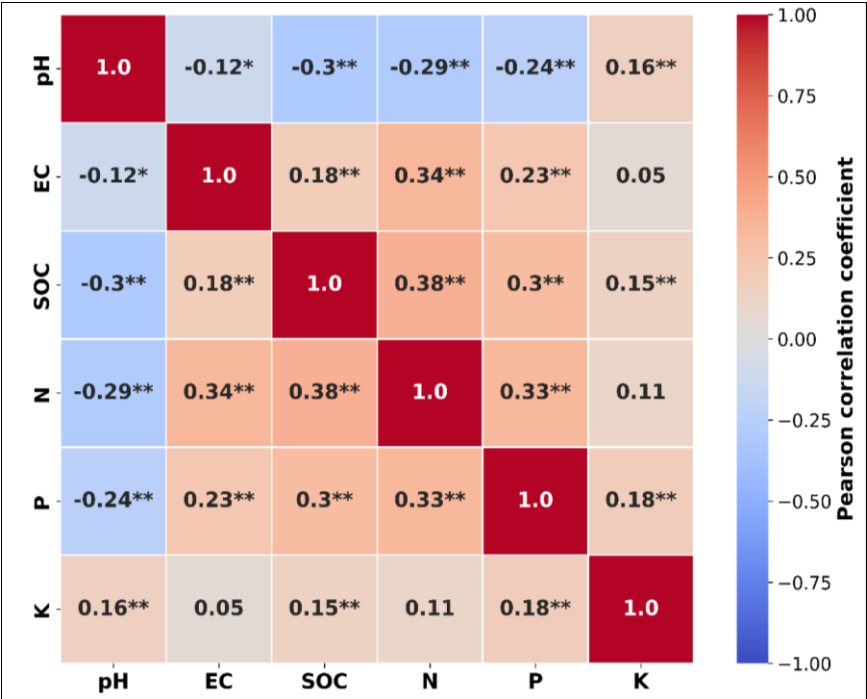
3.2.6 Available Potassium (K)

Available potassium content was generally high across the district (Table 4 and Figure 1). The majority of the soil samples (64.52%) were classified in the very high category, followed by moderately high (12.32%), moderate (9.09%), and high (8.80%) classes. Only 5.28% of the samples were in the low category, and no samples were classified as very low. The high potassium status may be attributed to the presence of potassium-rich parent

materials and the release of potassium through weathering of soil minerals (Gurav *et al.*, 2018)^[7]. The high potassium status recorded in the present study is consistent with earlier findings from Sangli district and other parts of Maharashtra. Similar moderate to high available potassium levels were reported in the soils of Kadegaon tehsil, Sangli district (Patil *et al.*, 2017)^[18]. Comparable observations were also reported from different regions of Maharashtra (Chaudhari *et al.*, 2019; Jagtap *et al.*, 2019; Kumar *et al.*, 2020)^[12, 14].

3.3. Correlation among soil properties

The Pearson correlation matrix among soil properties is presented in Figure 2. Soil pH exhibited significant negative correlations with EC ($r = -0.12$), SOC ($r = -0.30$), available N ($r = -0.29$), and available P ($r = -0.24$). These relationships indicate that increasing soil alkalinity may reduce the availability and accumulation of certain nutrients. However, pH showed a weak positive correlation with available K ($r = 0.16$), suggesting that potassium availability was less affected by soil reaction. Soil organic carbon (SOC) was positively correlated with available N ($r = 0.38$), P ($r = 0.30$), and K ($r = 0.15$). The strongest correlation was observed between SOC and N, highlighting the role of soil organic matter as a major source of nitrogen through mineralization processes. The positive association between SOC and phosphorus further suggests the contribution of organic matter to nutrient retention and availability. Available nitrogen showed significant positive correlations with EC ($r = 0.34$) and P ($r = 0.33$), indicating that soils with higher nutrient status tended to contain greater amounts of both nitrogen and phosphorus. Similarly, available phosphorus was positively correlated with EC ($r = 0.23$) and K ($r = 0.18$). Available potassium exhibited weak positive correlations with most soil properties, reflecting its generally high abundance in the study area.



Note: *Asterisks indicate the level of statistical significance of the correlation coefficients: * $p < 0.05$ and ** $p < 0.01$.

Fig 2: Correlation matrix of soil properties in Sangli district

Similar findings have been reported in earlier studies. Kumar *et al.* (2020) ^[14] observed a positive relationship between soil organic carbon and available nitrogen, indicating the role of organic matter in nutrient mineralization. Pandey *et al.* (2021) ^[17] reported significant negative correlations of soil pH with nutrient availability and positive associations between organic carbon and major nutrients. Likewise, Gurumurthy *et al.* (2022) ^[8] found that available phosphorus was negatively correlated with soil pH, while soil organic carbon showed positive relationships with available nutrients.

4. Conclusion

The soils of Sangli district were predominantly moderately alkaline and non-saline, indicating generally favourable conditions for agricultural production. However, a small proportion of soils exhibited elevated electrical conductivity, suggesting localized salinity issues that may affect crop growth in certain areas. Soil organic carbon status was mostly moderate to high, reflecting a relatively good organic matter reserve. Available nitrogen was predominantly low, identifying nitrogen deficiency as the major soil fertility constraint in the district. Available phosphorus was largely in the low to moderate range, whereas available potassium was sufficient to very high in most soils.

Correlation analysis revealed positive relationships between soil organic carbon and nutrient availability, highlighting the importance of organic matter in maintaining soil fertility. In contrast, higher soil pH was associated with reduced availability of nitrogen and phosphorus. The results indicate that improving nitrogen nutrition, maintaining soil organic matter, managing phosphorus efficiently, and addressing localized salinity where present are important for sustaining soil fertility and enhancing crop productivity in Sangli district.

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