International Journal of Plant & Soil Science

Volume 38, Issue 3, Page 108-119, 2026; Article no.IJPSS.154884
ISSN: 2320-7035

Assessment of Soil Nitrogen Content in Agricultural Fields Using the Alkaline Permanganate Implications for Sustainable Soil Fertility Management

Suraj Kabugade [a*], Shreyash Shinde [b], Ashok R. Athalye [a] and Vishal Kamble [b]

[a] Department of Fibres & Textile Processing Technology, Institute of Chemical Technology, Mumbai 400 019, India.
[b] Department of Chemistry, Changu Kana Thakur Arts, Commerce and Science College, New Panvel (Autonomous), Mumbai, 410206, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author SK designed the study, performed the experimental work, carried out the nitrogen analysis using the Kjeldahl method, and wrote the first draft of the manuscript. Author SS assisted in soil sample collection and laboratory analysis. Author ARA supervised the research work and provided academic guidance. Author VK contributed to data interpretation and manuscript revision. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i36004

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:
https://pr.sdiarticle5.com/review-history/154884

Original Research Article

Received: 13/01/2026
Published: 18/03/2026

Abstract

A comprehensive assessment of soil nitrogen content was carried out across seven villages in the Raigad district using the classical Alkaline Permanganate Method. This study aimed to determine nitrogen content in soils from selected agricultural fields, providing insights into soil fertility and sustainable nutrient

**Corresponding author: E-mail: surajkabugade16@gmail.com;*

Cite as: *Kabugade, S., Shinde, S., Athalye, A. R., & Kamble, V. (2026). Assessment of Soil Nitrogen Content in Agricultural Fields Using the Alkaline Permanganate Implications for Sustainable Soil Fertility Management. International Journal of Plant & Soil Science, 38(3), 108–119. https://doi.org/10.9734/ijpss/2026/v38i36004*

management practices. Soil samples were collected from surface horizons and analyzed for total nitrogen, with results expressed both as percentages and in kilograms per hectare to ensure agronomic relevance. Significant variability was observed among villages: Sarde, Nagoan, and Mahaivali exhibited high nitrogen levels, indicating fertile soils likely enriched by organic amendments and crop rotation practices. Conversely, Avare and Vindhane recorded low nitrogen content, reflecting potential nutrient depletion or continuous cropping without replenishment. Villages such as Koproli, Jui, and Kegaon displayed intermediate nitrogen levels, suggesting moderate fertility with opportunities for improvement through targeted nutrient management. The study underscores the utility of the Alkaline Permanganate Method for reliable nitrogen quantification and highlights the importance of regular soil testing to guide precise, site-specific fertilization strategies. These findings contribute to both scientific research and practical agricultural management aimed at improving crop productivity and promoting sustainable soil use.

Keywords: Alkaline permanganate method; nutrient management; Raigad; soil fertility; soil nitrogen; sustainable agriculture.

1. Introduction

Soil is a complex and dynamic natural resource that underpins terrestrial ecosystems and agricultural production. Understanding its physical, chemical, and biological properties is essential for evaluating soil health and fertility, which directly impact crop growth, yield, and quality (Țopa et al., 2025). Soil analysis involves a systematic examination of soil components to assess nutrient availability, pH balance, organic matter content, texture, and potential contaminants. This information enables farmers, agronomists, and environmental scientists to make informed decisions regarding land management, crop selection, fertilization strategies, and sustainable agricultural practices (Kalfas et al., 2024).

As the global population grows, enhancing food production while maintaining soil quality has become increasingly important (Busari et al., 2015). Proper soil management relies heavily on accurate nutrient assessment, as nutrient imbalances can lead to decreased productivity and degradation of soil resources (Derpsch et al., 2024). Among essential nutrients, nitrogen is arguably the most critical for plant growth. It is a fundamental constituent of amino acids, proteins, nucleic acids, and chlorophyll molecules, thereby influencing photosynthesis, enzyme activity, and overall metabolism in plants (Zayed et al., 2023). Nitrogen availability in soil affects various physiological processes, and its deficiency manifests as poor vegetative growth, chlorosis (yellowing of leaves), and reduced crop quality (Bhat et al., 2024). Conversely, excess nitrogen can disrupt nutrient uptake, promote excessive vegetative growth at the expense of reproductive development, and cause environmental issues such as nitrate leaching, eutrophication of water bodies, and greenhouse gas emissions (Anas et al., 2020).

Accurately quantifying soil nitrogen is essential for optimizing fertilizer use, improving crop yields, and supporting sustainable agriculture. Nitrogen exists in the soil in both organic and inorganic forms, and its availability depends on numerous factors such as microbial activity, moisture content, temperature, and soil texture (Bingham & Cotrufo, 2016). To measure the total nitrogen effectively, reliable analytical techniques are required. Among various methods available, the Alkaline Permanganate Method method remains a widely accepted and standardized procedure for determining total nitrogen content in diverse samples (Sáez-Plaza et al., 2013).

Accurate determination of soil nitrogen is critical for sustainable agriculture, as it informs precise fertilizer management and helps maintain soil fertility (Vullaganti et al., 2025). The Alkaline Permanganate Method method, being a widely validated analytical procedure, ensures reliable quantification of both organic and inorganic nitrogen, providing data essential for optimizing crop productivity (Soulaimani et al., 2025). This study generates baseline nitrogen data that can support both scientific research and practical agricultural management strategies. Such information is vital for implementing site-specific fertilization, improving nutrient-use efficiency, and preventing environmental issues like nitrate leaching and greenhouse gas emissions.

Since its development by Johan Alkaline Permanganate Method in 1883, this method has undergone extensive refinement. It involves three main steps: digestion, distillation, and titration. In the digestion phase, organic nitrogen compounds are converted into ammonium sulfate using concentrated sulfuric acid and a catalyst, often selenium or copper (Aguirre, 2023). This is followed by steam distillation, where ammonia is released from the alkaline-digested sample and trapped in a boric acid solution. Finally, the trapped ammonia is quantified through titration with a standardized acid solution, typically hydrochloric or sulfuric acid (Utomo et al., 2023). The amount of acid used corresponds directly to the nitrogen content in the sample. The simplicity, cost-effectiveness, and ability to determine total organic nitrogen make this method a gold standard, especially in agricultural research (Hicks et al., 2022). In recent years, technological improvements have led to the development of semi-automated and fully automated Alkaline Permanganate Method systems, enhancing safety, reproducibility, and processing speed. These modern instruments integrate temperature controls, distillation units, and automated titrators, which collectively reduce human error and ensure consistent results across multiple samples. This makes the method suitable not only for soil but also for analyzing plant tissues, food products, wastewater, and fertilizers (Asadu et al., 2024).

In the context of agriculture, accurate nitrogen data obtained through this method enables better nutrient budgeting, helping to avoid both under- and over-fertilization. Such precision is crucial for promoting plant health, improving yield quality, and conserving soil fertility in the long term. Moreover, the correct application of nitrogen fertilizers based on analytical data helps to prevent nitrogen runoff and gaseous emissions, which are significant contributors to water and air pollution. Thus, this method supports both agronomic efficiency and environmental stewardship (Ferland et al., 2024).

The results of the analysis were intended to inform more effective, site-specific fertilizer recommendations tailored to the actual nitrogen needs of crops in those regions. This could help reduce unnecessary fertilizer use and enhance nutrient-use efficiency. Additionally, the findings contribute to the broader goal of sustainable land management by supporting practices that maintain or improve soil fertility without compromising environmental health (Vasile Scăețeanu & Madjar, 2025).

2. Materials and Methods

2.1 Materials

The chemicals used for nitrogen analysis in soil samples included potassium permanganate ($KMnO_4$), sodium hydroxide (NaOH), bromocresol green, methyl red, boric acid, and sulfuric acid (H_2SO_4). All reagents used were of analytical grade to ensure accurate and reliable results. Potassium permanganate and sodium hydroxide were used as key reagents for oxidation and alkaline digestion. Bromocresol green and methyl red served as indicators to detect pH changes during titration. Boric acid was used as a buffer to capture ammonia gas during the distillation process, while sulfuric acid was applied in the titration step to quantify nitrogen content. These chemicals were sourced from certified and trusted laboratory suppliers, ensuring their purity and suitability for soil analysis.

In this study, soil samples from various agricultural fields were collected and analyzed for nitrogen content using the Alkaline Permanganate Method method. The selection of this method ensured the reliable detection of total nitrogen, including organically bound forms not measurable through other rapid test kits (Dimkpa et al., 2017). The digestion process was followed by steam distillation and acid-base titration, which provided precise and reproducible measurements of nitrogen levels in each sample. The objective of this work was to gain comprehensive insights into the spatial variation of soil nitrogen across different sites and soil types (Clarke et al., 2024).

Soil samples were collected from agricultural fields across several villages, Babhulgaon, Bhivpur, Darodi, Kolwadi, Padali, Sugaon, and Umbraj representing diverse soil conditions within the study area. By combining systematic sample collection with high-quality reagents, the Alkaline Permanganate Method method provided consistent and accurate nitrogen measurements (Robert Okalebo et al., 2002).

2.2 Methods

To begin the Alkaline Permanganate Method analysis, prepare the required reagents as follows: dissolve 3.2 g of $KMnO_4$ in distilled water to make 1000 mL of 0.32% solution; dissolve 25 g of NaOH in distilled water to make 1000 mL solution; prepare the mixed indicator by combining 13 mL of bromocresol green with 0.6 g of methyl red in 100 mL of ethanol; prepare boric acid solution by dissolving 20 g of boric acid in 1000 mL of distilled water; and dilute 0.56 mL of H_2SO_4 to 1000 mL with distilled water for titration. Weigh 5 g of soil into an Alkaline Permanganate Method digestion tube and add 25 mL each of the $KMnO_4$ and NaOH solutions. In a conical flask, place 20 mL of boric acid solution. Ensure the steam distillation unit has sufficient water and is functioning properly. Start distillation. The released ammonia is absorbed in boric acid, changing the solution color from red to yellow. Titrate with H_2SO_4 until the color changes to reddish.

2.3 Machine of Soil Nitrogen Analyzer

Fig. 1. Machine nitrogen analyzer

The instrument shown in the image is a steam distillation-based nitrogen analyzer, commonly used for determining the nitrogen content in soil and other organic samples. The device automates parts of the Alkaline Permanganate Method by providing preset operational options on a digital control screen. The process starts by preparing standard reagents such as 0.32% $KMnO_4$, NaOH, boric acid, mixed indicator (bromocresol green and methyl red in ethanol), and 0.01N H_2SO_4. First, weigh 5 g of dried, sieved soil sample into an Alkaline Permanganate Method digestion tube. Then, add 25 mL each of the $KMnO_4$ and NaOH solutions. In a separate conical flask, place 20 mL of boric acid solution containing the mixed indicator. Before starting, ensure the boiler level is adequate. This can be manually adjusted using the "Add Manually" option on the analyzer's screen. After confirming the boiler level and water supply, press "Start" to initiate steam distillation. During distillation, ammonia gas released from the alkaline digestion reacts with the boric acid in the receiving flask, changing its color from red to yellow. Once distillation is complete, titrate the boric acid solution with 0.01N H_2SO_4 until the color changes from yellow to a reddish endpoint. The volume of acid used indicates the amount of ammonia, and thereby nitrogen, present in the soil.

Compared to the traditional Alkaline Permanganate Method, which involves manual digestion, distillation, and titration steps, this nitrogen analyzer offers more automation, safety, and time-efficiency. The manual process is labor-intensive and requires close monitoring, whereas the analyzer ensures consistent and reproducible results by minimizing human error. This makes the analyzer highly suitable for routine soil nitrogen testing in research and agricultural laboratories (Nie et al., 2017).

3. Results and Discussion

3.1 Nitrogen Analysis in Soil – Explanation of the Formula

The nitrogen content in soil samples was determined using the Alkaline Permanganate Method method, a well-established analytical technique commonly used for the estimation of total organic nitrogen. The procedure involves three main stages: digestion of the soil sample, distillation of the released ammonia, and final quantification by acid–base titration. After completion of the titration step, the nitrogen content of the sample was calculated using the following equation (Fao, n.d.):

$$Nitrogen(\%) = \frac{(T - B) \times N \times 0.014 \times 100}{W}$$

T : Volume of standard sulfuric acid (H_2SO_4) in milliliters used for titration of the distilled soil sample.
B : Volume of sulfuric acid (H_2SO_4) in milliliters required for the blank titration, carried out without soil to correct for reagent impurities.
N : Normality of the sulfuric acid solution used in titration (0.02 N in this study).
0.014 : Milliequivalent weight of nitrogen expressed in grams. This constant is obtained from the atomic weight of nitrogen (14.01 g/mol) divided by 1000 to convert it into grams per milliequivalent.
100 : Conversion factor used to express nitrogen content in percentage.
W : Weight of the soil sample taken for analysis, expressed in grams. In this study, a constant sample weight of 5 g was used.

This equation provides the percentage of nitrogen present in the soil sample based on its dry weight. The blank correction ensures that any acidity originating from reagents or experimental conditions is excluded from the final nitrogen value, thereby improving the accuracy of the measurement.

3.2 Example Calculation

As an illustration, consider a soil sample where the titration volume (T) was **12.3 mL** and the blank titration value (B) was **0.5 mL**. The nitrogen percentage can be calculated as follows:

$$Nitrogen(\%) = \frac{(12.3 - 0.5) \times 0.02 \times 0.014 \times 100}{5}$$

$$Nitrogen(\%) = 0.06608\%$$

Conversion to Kilograms per Hectare:

For practical agricultural interpretation, the nitrogen percentage obtained from laboratory analysis was converted into kilograms per hectare (kg/ha). This conversion allows the nitrogen content to be expressed in field-relevant units that are useful for fertilizer recommendation and soil fertility evaluation.

The conversion was performed using the following relationship:

- %N = 0.06608
- Soil depth = 15 cm (topsoil layer considered)
- Bulk density = 1.3 g/cm³ (typical value for agricultural soils)
- 10 = conversion factor to get kg/ha

Substitute the values:

$$\text{Nitrogen (kg/ha)} = 0.06608 \times 15 \times 1.3 \times 10$$
$$0.06608 \times 15 = 0.9912$$
$$0.9912 \times 1.3 = 1.28856$$
$$1.28856 \times 10 = 12.8856$$
$$\text{Nitrogen (kg/ha)} \approx 12.89 \text{ kg/ha}$$

This value estimates soil nitrogen availability and offers guidance for planning nutrient management strategies to enhance soil fertility and crop yields. Such low fertility conditions could negatively affect crop yields unless effective nutrient management is adopted.

3.3 Variation in Nitrogen Content Across Soil Samples

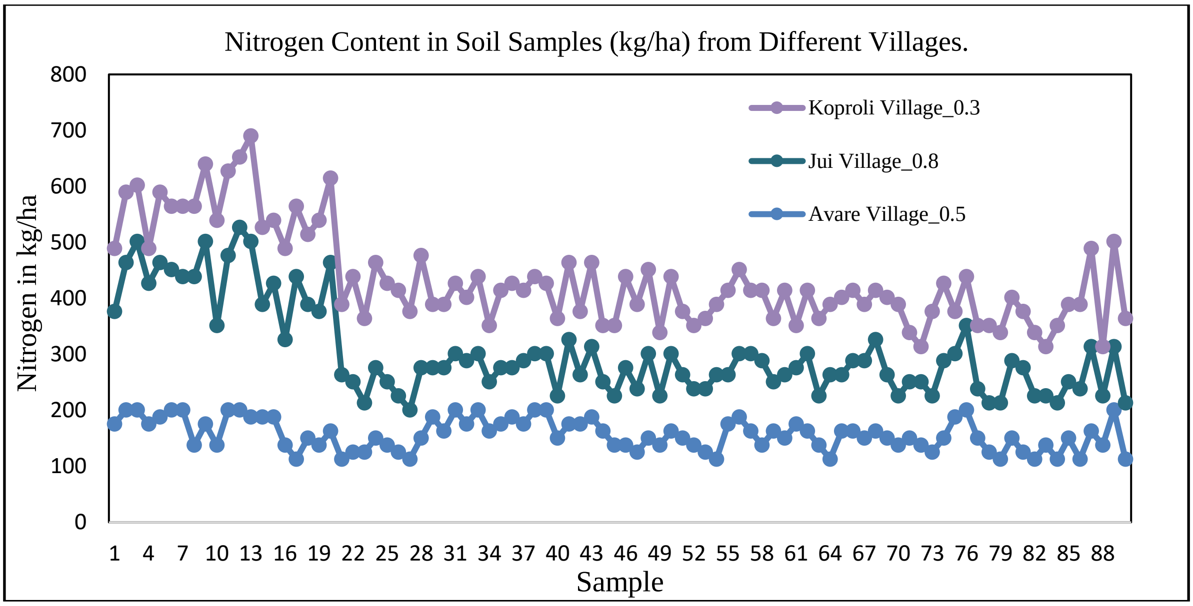

Fig. 2. Nitrogen content (kg/ha) in soil samples from Koproli, Jui, and Avare

This section presents a comparative evaluation of nitrogen concentrations in soil samples obtained from the villages of Koproli, Jui, and Avare. The x-axis of the corresponding graph indicates the individual sample numbers, while the y-axis represents the nitrogen content measured in kilograms per hectare (kg/ha). The numerical values listed beside each village name (0.3, 0.8, 0.5) appear to serve as internal classification codes and are not associated with nitrogen levels.

Among the three villages, Koproli exhibits the highest nitrogen content across its soil samples. The concentrations range from approximately 400 to over 700 kg/ha, with notable peaks observed at several sampling points. This suggests spatial variation in soil fertility within the village. The elevated nitrogen values may be the result of better soil management practices, including the application of nitrogen-rich fertilizers, higher organic matter presence, or effective crop rotation techniques that help sustain nutrient levels.

Jui village shows moderate nitrogen content, with most values falling between 300 and 500 kg/ha. The graph indicates a relatively steady trend with smaller fluctuations compared to Koproli. This consistency may reflect balanced and sustained nutrient availability, supported by moderately intensive agricultural practices. Such stability suggests that the soil in Jui is adequately fertile to support crop production under normal farming conditions.

In contrast, Avare village records the lowest nitrogen levels, with most samples ranging between 150 and 250 kg/ha. The minimal variation across samples indicates consistently low nutrient availability. This condition may be attributed to inadequate fertilization, prolonged cultivation without replenishment, or limited incorporation of organic matter. A nitrogen deficiency could limit crop productivity if corrective measures are not taken.

Table 1. Average nitrogen content (% and kg/ha) in soil samples from selected villages of Raigad district

Village	Blank Section	Mean N (kg/ha)	Approx. N (%)
Koproli	0.3	519	2.32
Jui	0.8	359	1.60
Avare	0.5	155	0.69

The nitrogen content in soils varied notably across the surveyed villages (Table 1). Koproli Village exhibited the highest average nitrogen content, approximately 519 kg/ha, corresponding to 2.32 % N, indicating relatively fertile soils. Jui Village showed moderate nitrogen levels, with an average of 416 kg/ha (1.86 % N), while Avare Village recorded the lowest average nitrogen content of 150 kg/ha (0.67 % N), reflecting poor nutrient availability. These averages highlight distinct differences in soil fertility among the villages, likely influenced by variations in organic matter application, fertilizer practices, and crop rotation strategies. The summarized data provide a clear picture of regional nitrogen distribution and support the need for site-specific nutrient management to enhance crop productivity and maintain soil health.

The overall pattern in nitrogen concentration across the three villages follows the trend: Koproli > Jui > Avare. This gradient highlights distinct differences in soil fertility status among the locations and underlines the importance of tailored soil management strategies. Regular monitoring of soil nutrients and the implementation of appropriate fertilization practices are essential for enhancing soil quality and promoting sustainable agricultural outcomes in these regions (Rotich et al., 2025).

3.4 Variation in Nitrogen Content Across Soil Samples

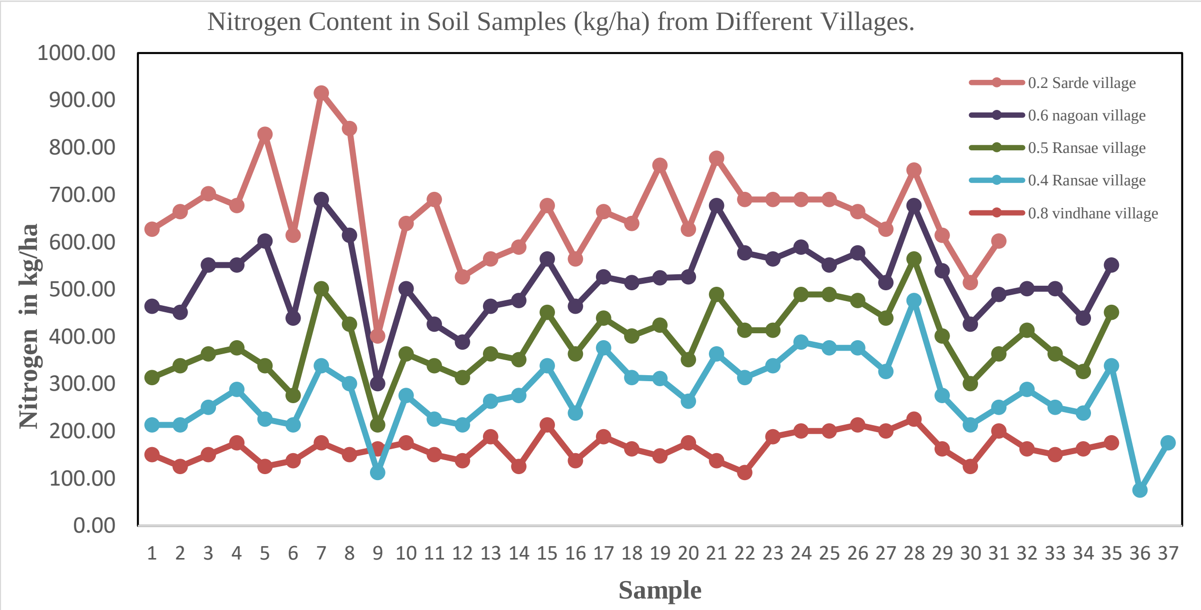

Fig. 3. Nitrogen content (kg/ha) in soil samples from Sarde, Nagoan, Ransae, and Vindhane)

The graph titled *"Nitrogen Content in Soil Samples (kg/ha) from Different Villages"* presents a comparative analysis of nitrogen concentrations across soil samples collected from five locations: Sarde, Nagoan, Ransae (represented through two distinct data series), and Vindhane. The x-axis displays sample numbers ranging from 1 to 37, while the y-axis represents nitrogen levels measured in kilograms per hectare (kg/ha). The numerical values shown next to the village names (e.g., 0.2, 0.6, etc.) are interpreted as internal codes or identifiers and do not influence the actual nitrogen measurements.

Among the five villages, Sarde consistently shows the highest nitrogen concentrations across the sample range. The values frequently exceed 700 kg/ha, with several samples even surpassing 900 kg/ha. While the data show some dips at certain points, the overall trend remains significantly high. This pattern suggests the presence of nutrient-rich soils in Sarde, potentially due to the use of organic matter, regular application of nitrogenous fertilizers, or favorable natural soil properties that retain and recycle nutrients effectively.

Nagoan also exhibits elevated nitrogen values, although generally lower than those observed in Sarde. Most nitrogen concentrations from this village range between 500 and 700 kg/ha, with at least one sample peaking slightly above 700 kg/ha. The trend suggests consistent soil fertility, possibly maintained through well-managed agricultural practices and adequate fertilization. This relatively narrow range also reflects a more uniform distribution of nitrogen content across different sampling sites within the village.

Ransae Village appears twice in the graph, represented by two different data series. This likely corresponds to different sampling zones, layers, or collection periods within the same village. The first data series shows nitrogen levels mostly between 300 and 500 kg/ha, indicating moderate soil fertility. The second series, however, reveals a considerably lower nitrogen range, generally between 200 and 350 kg/ha. The noticeable difference between the two sets of data within the same village highlights possible spatial variability in soil nutrient levels or changes over time due to seasonal practices or variable input strategies.

Table 2. Comparative Analysis of Soil Nitrogen Content Across Specific Village Zones

Village	Blank Section	Samples	Mean N (kg/ha)	Approx. N (%)
Sarde	**0.2**	**1 – 35**	**163.65**	**0.73%**
Nagoan	**0.6**	**22 – 58**	**128.48**	**0.57%**
Ransae	**0.5**	**23 – 57**	**102.50**	**0.46%**
	0.4	**58 – 92**	**128.84**	**0.58%**
Vindhane	**0.8**	**46 – 76**	**134.09**	**0.60%**

The recorded nitrogen fluctuations across these specific village sections highlight the dynamic nature of soil nutrient levels, likely influenced by seasonal agricultural cycles and variable input strategies. Sarde (Section 0.2) demonstrates the highest relative concentration in this group at 0.73%, suggesting a more robust nutrient baseline or more effective recent fertilization compared to Ransae (Section 0.5), which recorded the lowest mean at 0.46%. The variance observed between sections—such as the recovery seen in Ransae from 0.46% to 0.58%—points toward the impact of localized management practices and the timing of soil sampling. Overall, these results indicate that nitrogen availability is not uniform and requires adaptive management to address specific depletion zones across the different village landscapes.

Vindhane Village consistently shows the lowest nitrogen levels among all five locations analyzed. Most values fall between 100 and 200 kg/ha, with only minor fluctuations across the sample set. The persistently low nitrogen content may indicate long-term nutrient depletion, insufficient fertilizer application, or continuous cultivation without proper soil restoration practices. Low fertility conditions may reduce crop yields if appropriate nutrient management practices are not implemented.

The nitrogen concentration trend across the villages can be ranked as follows: Sarde > Nagoan > Ransae (Series 1) > Ransae (Series 2) > Vindhane. These findings underscore the regional disparities in soil fertility and the need for tailored soil improvement strategies, such as precision fertilization and organic matter incorporation, to enhance agricultural productivity.

3.5 Variation in Nitrogen Content Across Soil Samples

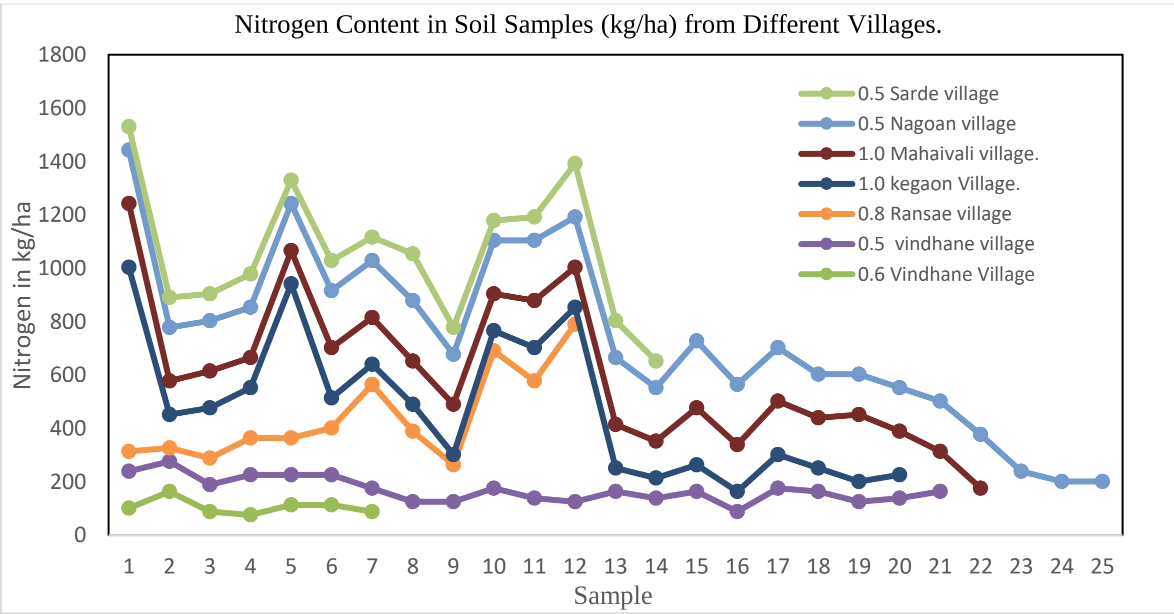

Fig. 4. Nitrogen content (kg/ha) in soil samples from Sarde, Nagoan, Mahaivali, Kegaon, Ransae, Vindhane

The graph represents nitrogen content (kg/ha) in soil samples collected from seven different villages: Sarde, Nagoan, Mahaivali, Kegaon, Ransae, and Vindhane. The x-axis shows the sample number from 1 to 24, and the y-axis indicates the nitrogen concentration in kg/ha. Each village is denoted by a differently styled line, allowing easy visual comparison of nitrogen variability across the locations. The values such as 0.5, 1.0, etc., mentioned in the legend are sample identifiers and do not directly influence the nitrogen values.

Sarde Village displays the highest nitrogen content among all the villages. Its nitrogen levels are significantly elevated, especially at the beginning, with peaks exceeding 1500 kg/ha and consistently remaining above 1000 kg/ha for several samples. This trend indicates that Sarde has nutrient-rich soils, likely due to effective agricultural management, appropriate use of organic fertilizers, or inherent natural fertility. The consistently high values also suggest that Sarde may benefit from good irrigation and high biomass turnover, which contribute to enhanced nitrogen retention. Such fertility conditions are highly favorable for growing nitrogen-demanding crops such as paddy, wheat, and maize, supporting both crop health and yield potential.

Nagoan Village also demonstrates relatively high nitrogen content, with values ranging between 750 and 1400 kg/ha in the initial samples. There is a gradual decrease after sample 12, but the nitrogen levels remain above 400 kg/ha, indicating adequate fertility. This pattern could reflect seasonal nutrient depletion or the effects of repeated cultivation without adequate nutrient replenishment. Nevertheless, the high initial values suggest that nitrogen is sufficient for short-term productivity. However, the declining trend emphasizes the importance of adopting sustainable soil management practices like compost incorporation, crop rotation, or cover cropping to maintain soil health over time.

Mahaivali Village shows moderate to high nitrogen content across its samples. The nitrogen concentration generally ranges from 600 to 1100 kg/ha, with several observable peaks and dips. These results suggest the soil in Mahaivali is fertile and suitable for cultivating various crops. The fluctuations may be due to differences in land use or inconsistent application of fertilizers across the sampled areas. Despite the variation, the overall fertility level is satisfactory, and integrating balanced nutrient strategies, including timely fertilizer application and organic amendments, may further improve crop yields and soil quality.

Kegaon Village presents nitrogen values that mostly range between 450 and 950 kg/ha. The data pattern reveals several peaks, particularly around samples 5 and 12, suggesting localized areas of higher fertility. However, nitrogen levels drop considerably after sample 13, falling to approximately 250–400 kg/ha. This indicates intra-village variability in soil fertility. The findings emphasize the importance of conducting field-specific soil tests and implementing site-based fertilization practices to ensure uniform productivity and reduce nutrient wastage.

Ransae Village exhibits moderate nitrogen concentrations, predominantly between 300 and 600 kg/ha. Although not as high as Sarde or Nagoan, these values remain suitable for general agricultural purposes. The data shows steady fluctuations without sharp drops, indicating stable soil conditions. Such stability might result from consistent farming techniques, moderate fertilizer application, or a natural nitrogen cycle balance. To boost yields, farmers might consider increasing organic inputs or incorporating nitrogen-fixing crops such as legumes to enhance soil fertility naturally.

Vindhane Village appears twice in the dataset. The first dataset reveals very low nitrogen values, mainly between 100 and 250 kg/ha. This persistent deficiency suggests poor nitrogen fertility, which could adversely affect crop productivity. Potential causes include overuse of land, insufficient fertilizer application, or soil with low nutrient-holding capacity such as sandy textures. Immediate interventions such as adding compost, practicing legume cultivation, and adopting conservation tillage could aid in restoring soil nitrogen levels and improving long-term soil health in this region.

Table 3. Comparative analysis of soil nitrogen content across specific village zones

Village	Blank Section	Sample Range	Mean N (kg/ha)	Approx. N (%)
Sarde	0.5	1 – 25	798.20	3.56%
Nagoan	0.5	1 – 25	733.40	3.27%
Mahai-vali	1.0	1 – 22	610.00	2.72%
Kegaon	1.0	1 – 20	452.25	2.02%
Ransae	0.8	1 – 12	447.27	2.00%
Vindhane	0.5	1 – 21	171.43	0.77%
Vindhane	0.6	1 – 7	107.14	0.48%

The data indicates a distinct stratification of nitrogen levels across the sampled regions, with Sarde (0.5) and Nagoan (0.5) showing significantly higher concentrations, both exceeding the 3% threshold. In contrast, the Vindhane sections represent the lower end of the spectrum, with values dropping below 1%. This wide range, from 0.48% to 3.56%, suggests that while some areas benefit from high nutrient retention or intensive input strategies, others remain critically depleted. These findings are essential for developing site-specific fertilization plans to balance regional soil health.

4. Conclusion

This study evaluated soil nitrogen content across multiple villages using the Alkaline Permanganate Method method, a reliable technique for determining total organic nitrogen. Nitrogen levels varied significantly among locations, reflecting differences in soil fertility and agricultural practices. Villages such as Sarde, Nagoan, and Mahaivali showed high nitrogen content, indicating fertile soils supported by effective practices, including organic fertilization and crop rotation. In contrast, Avare and Vindhane had low nitrogen levels, suggesting nutrient depletion due to continuous cropping and inadequate soil conservation. Koproli, Jui, and Kegaon exhibited moderate nitrogen levels, highlighting areas that could benefit from improved nutrient management.

Translating nitrogen percentages into kilograms per hectare provided practical insights for fertilizer application and agricultural planning. The observed spatial variability emphasizes the need for site-specific soil fertility management. Regular soil testing and customized fertilization, including organic amendments and nitrogen-fixing crops, are crucial for maintaining soil health. Addressing nitrogen deficiencies can improve crop performance while promoting long-term soil conservation and sustainable agriculture in the region.

5. Summary

Across all three graphs, the villages of Sarde, Nagoan, and Mahaivali consistently exhibit the highest soil nitrogen content, indicating superior soil fertility. In contrast, Koproli, Jui, and Kegaon display moderate nitrogen levels, while Avare and Vindhane consistently show the lowest nitrogen content, suggesting relatively poorer soil fertility.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Acknowledgements

The authors would like to express their sincere gratitude to the Department of Fibres and Textile Processing Technology, Institute of Chemical Technology (ICT), Mumbai, for providing guidance and academic support during this research work. The authors also acknowledge the support and cooperation of CKT College, Panvel, for assistance in soil sample collection and laboratory work. The authors are especially thankful to Prof. Dr. Ashok R. Athalye for his valuable guidance and encouragement throughout the study.

Competing Interests

Authors have declared that no competing interests exist.

References

Aguirre, J. (2023). The Alkaline Permanganate Method Method. In *The Alkaline Permanganate Method Method: 140 Years* (pp. 53–78). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-31458-2_4

Anas, M., Liao, F., Verma, K. K., Sarwar, M. A., Mahmood, A., Chen, Z. L., Li, Q., Zeng, X. P., Liu, Y., & Li, Y. R. (2020). Fate of nitrogen in agriculture and environment: Agronomic, eco-physiological and molecular approaches to improve nitrogen use efficiency. In *Biological Research* (Vol. 53, Number 1). BioMed Central Ltd. https://doi.org/10.1186/s40659-020-00312-4

Asadu, C. O., Ezema, C. A., Ekwueme, B. N., Onu, C. E., Onoh, I. M., Adejoh, T., Ezeorba, T. P. C., Ogbonna, C. C., Otuh, P. I., Okoye, J. O., & Emmanuel, U. O. (2024). Enhanced efficiency fertilizers: Overview of production methods, materials used, nutrients release mechanisms, benefits and considerations. *Environmental Pollution and Management, 1*, 32–48. https://doi.org/10.1016/j.epm.2024.07.002

Bhat, M. A., Mishra, A. K., Shah, S. N., Bhat, M. A., Jan, S., Rahman, S., Baek, K. H., & Jan, A. T. (2024). Soil and mineral nutrients in plant health: A prospective study of iron and phosphorus in the growth and development of plants. In *Current Issues in Molecular Biology* (Vol. 46, Number 6, pp. 5194–5222). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/cimb46060312

Bingham, A. H., & Cotrufo, M. F. (2016). Organic nitrogen storage in mineral soil: Implications for policy and management. In *Science of the Total Environment* (Vols. 551–552, pp. 116–126). Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2016.02.020

Busari, M. A., Kukal, S. S., Kaur, A., Bhatt, R., & Dulazi, A. A. (2015). Conservation tillage impacts on soil, crop and the environment. In *International Soil and Water Conservation Research* (Vol. 3, Number 2, pp. 119–129). International Research and Training Center on Erosion and Sedimentation and China Water and Power Press. https://doi.org/10.1016/j.iswcr.2015.05.002

Clarke, D. E., Stockdale, E. A., Hannam, J. A., Marchant, B. P., & Hallett, S. H. (2024). Spatial-temporal variability in nitrogen use efficiency: Insights from a long-term experiment and crop simulation modeling to support site specific nitrogen management. *European Journal of Agronomy, 158*. https://doi.org/10.1016/j.eja.2024.127224

Derpsch, R., Kassam, A., Reicosky, D., Friedrich, T., Calegari, A., Basch, G., Gonzalez-Sanchez, E., & dos Santos, D. R. (2024). Nature's laws of declining soil productivity and conservation agriculture. *Soil Security, 14*. https://doi.org/10.1016/j.soisec.2024.100127

Dimkpa, C., Bindraban, P., McLean, J. E., Gatere, L., Singh, U., & Hellums, D. (2017). Methods for rapid testing of plant and soil nutrients (pp. 1–43). https://doi.org/10.1007/978-3-319-58679-3_1

FAO. (n.d.). Standard operating procedure for soil nitrogen Alkaline Permanganate Method method.

Ferland, D., Wagner-Riddle, C., Brown, S. E., Bourgault, M., Helgason, W., Farrell, R. E., & Congreves, K. A. (2024). Improved nitrogen fertilizer management reduces nitrous oxide emissions in a northern Prairie cropland. *Science of the Total Environment, 956*. https://doi.org/10.1016/j.scitotenv.2024.177211

Hicks, T. D., Kuns, C. M., Raman, C., Bates, Z. T., & Nagarajan, S. (2022). Simplified method for the determination of total Alkaline Permanganate Method nitrogen in wastewater. *Environments - MDPI, 9*(5). https://doi.org/10.3390/environments9050055

Kalfas, D., Kalogiannidis, S., Papaevangelou, O., Melfou, K., & Chatzitheodoridis, F. (2024). Integration of technology in agricultural practices towards agricultural sustainability: A case study of Greece. *Sustainability (Switzerland), 16*(7). https://doi.org/10.3390/su16072664

Nie, P. C., Dong, T., He, Y., & Qu, F. (2017). Detection of soil nitrogen using near infrared sensors based on soil pretreatment and algorithms. *Sensors (Switzerland), 17*(5). https://doi.org/10.3390/s17051102

Robert Okalebo, J., Gathua, K. W., & Woomer, P. L. (2002). *Laboratory methods of soil and plant analysis: A working manual* (2nd ed.). The Sustainable Agriculture Centre for Research Extension and Development in Africa.

Rotich, B., Szegi, T., Gelsleichter, Y. A., Fuchs, M., Ocansey, C. M., Phenson, J. N., Abdulkadir, M., Kipkulei, H., Wawire, A., Mutuma, E., Mesele, S. A., Michéli, E., & Csorba, Á. (2025). Variation in soil organic carbon and total nitrogen stocks across elevation gradients and soil depths in the Mount Kenya East Forest. *Land, 14*(6), 1217. https://doi.org/10.3390/land14061217

Sáez-Plaza, P., Michałowski, T., Navas, M. J., Asuero, A. G., & Wybraniec, S. (2013). An overview of the Alkaline Permanganate Method method of nitrogen determination. Part I. Early history, chemistry of the procedure, and titrimetric finish. *Critical Reviews in Analytical Chemistry, 43*(4), 178–223. https://doi.org/10.1080/10408347.2012.751786

Soulaimani, A., Gharous, M. El, Mejahed, K. El, Oulfakir, R., Fathallah, S., & Gmouh, S. (2025). Validation of continuous flow analysis for determining total nitrogen in plants compared to the Alkaline Permanganate Method method. *Discover Plants, 2*(1). https://doi.org/10.1007/s44372-025-00434-7

Țopa, D. C., Căpșună, S., Calistru, A. E., & Ailincăi, C. (2025). Sustainable practices for enhancing soil health and crop quality in modern agriculture: A review. In *Agriculture (Switzerland)* (Vol. 15, Number 9). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/agriculture15090998

Utomo, W. P., Wu, H., & Ng, Y. H. (2023). Quantification methodology of ammonia produced from electrocatalytic and photocatalytic nitrogen/nitrate reduction. In *Energies* (Vol. 16, Number 1). MDPI. https://doi.org/10.3390/en16010027

Vasile Scăețeanu, G., & Madjar, R. M. (2025). The control of nitrogen in farmlands for sustainability in agriculture. In *Sustainability (Switzerland)* (Vol. 17, Number 12). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/su17125619

Vullaganti, N., Ram, B. G., & Sun, X. (2025). Precision agriculture technologies for soil site-specific nutrient management: A comprehensive review. In *Artificial Intelligence in Agriculture* (Vol. 15, Number 2, pp. 147–161). KeAi Communications Co. https://doi.org/10.1016/j.aiia.2025.02.001

Zayed, O., Hewedy, O. A., Abdelmoteleb, A., Ali, M., Youssef, M. S., Roumia, A. F., Seymour, D., & Yuan, Z. C. (2023). Nitrogen journey in plants: From uptake to metabolism, stress response, and microbe interaction. In *Biomolecules* (Vol. 13, Number 10). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/biom13101443

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2026): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/154884