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Assessment of Soil Fertility and Nutrient Status in Agricultural Fields

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Abstract

Soil fertility is one of the major factors controlling agricultural productivity, crop quality, and the long-term sustainability of farming systems. Continuous cultivation, imbalanced fertilizer application, removal of crop residues, erosion, and inadequate organic matter management can result in depletion or accumulation of essential plant nutrients. The present study was designed to assess the fertility status and available nutrient levels of agricultural soils using selected physicochemical and chemical parameters. Representative surface soil samples were collected from agricultural fields at a depth of 0–15 cm and analyzed for soil pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (N), phosphorus (P), and potassium (K). The illustrative results showed that soil pH ranged from 6.7 to 7.8, indicating predominantly neutral to slightly alkaline conditions. Electrical conductivity remained within a range generally suitable for agricultural production. Organic carbon varied from 0.42 to 0.71%, indicating low to medium organic matter status. Available nitrogen was comparatively low in several fields, while available phosphorus showed low to medium levels and available potassium ranged from medium to high. The overall nutrient status indicated that nitrogen was the most commonly limiting nutrient, whereas potassium was comparatively better maintained. The results emphasize the importance of regular soil testing, balanced fertilization, organic matter management, crop-residue incorporation, and site-specific nutrient application. Soil testing commonly uses organic carbon, alkaline KMnO_4 -extractable nitrogen, Olsen phosphorus, and neutral ammonium acetate-extractable potassium as important indicators of soil fertility in Indian agricultural soils.

Keyword: Soil Fertility, Soil Health, Organic Carbon, Available Nitrogen, Phosphorus, Potassium, Soil Ph, Nutrient Status, Agricultural Fields, Sustainable Agriculture

Introduction

Soil is a fundamental natural resource supporting agricultural production and terrestrial ecosystems. In addition to providing physical support to plants, soil acts as a reservoir of water and nutrients and provides a habitat for microorganisms that participate in nutrient cycling. Soil fertility refers to the capacity of soil to supply essential nutrients to plants in adequate quantities and appropriate proportions for optimum growth and productivity.

The fertility of agricultural soils is influenced by several interacting factors, including soil texture, organic matter, pH, moisture, climate, parent material, cropping history, fertilizer application, irrigation, erosion, and management practices. Intensive cultivation without adequate nutrient replenishment can gradually reduce soil organic matter and nutrient reserves. Conversely, excessive application of particular fertilizers can cause nutrient imbalance and environmental problems.

Among the chemical properties of agricultural soil, pH is particularly important because it influences nutrient availability, microbial activity, and several chemical reactions in the soil. Soil organic carbon is another important indicator because organic matter contributes to nutrient retention, soil aggregation, water-holding capacity, and biological activity. Soil-health assessments commonly consider pH, electrical conductivity, organic carbon, extractable phosphorus and potassium, and biological indicators as important measures of soil condition ^[3].

Nitrogen, phosphorus, and potassium are the three primary macronutrients required by crops in relatively large quantities. Nitrogen is essential for chlorophyll formation, protein synthesis, vegetative growth, and yield development. Phosphorus plays an important role in energy transfer, root development, flowering, and seed formation, while potassium regulates water relations, enzyme activity, disease resistance, and several physiological processes.

In India, available nitrogen is commonly estimated by the alkaline potassium permanganate method, available phosphorus by an appropriate extraction method such as Olsen's method for neutral to alkaline soils, and available potassium using neutral ammonium acetate extraction [1, 4]. The Government of India soil-testing guidance also uses broad low, medium, and high fertility classes for interpreting available N, P, and K, although such categories should be interpreted in relation to soil type, crop, region, and the specific analytical method used [1].

Soil fertility can also vary considerably within relatively small geographic areas. Farm-level studies have demonstrated substantial spatial variability in organic carbon and available N, P, K and other nutrients, emphasizing the importance of soil sampling and site-specific nutrient management [5].

Therefore, assessment of soil fertility is essential for identifying nutrient deficiencies, preventing unnecessary fertilizer application, maintaining soil productivity, and developing sustainable nutrient-management strategies.

Objectives

The objectives of the present study were:

1. To evaluate selected physicochemical properties of agricultural soils.
2. To determine the available status of major plant nutrients, particularly N, P, and K.
3. To classify the soils according to their nutrient status.
4. To identify major nutrient limitations in the studied agricultural fields.
5. To suggest appropriate soil and nutrient-management practices for maintaining soil fertility.

Materials and Methods

Study Design

The study was designed to assess the fertility status of agricultural fields under conventional crop production. For the purpose of this article, a representative set of agricultural fields was considered. Since actual field observations were not supplied, the numerical observations presented in the Results section are illustrative data intended to demonstrate the structure and interpretation of a soil-fertility study.

For an actual publication, soil samples should be collected from the specified study area and the illustrative values should be replaced by laboratory observations.

Soil Sampling

Surface soil samples were considered from the 0–15 cm soil layer, which represents the principal zone affected by cultivation, fertilizer application, organic-residue incorporation, and root activity.

For each field, several soil cores should be collected in a zig-zag pattern and thoroughly mixed to obtain a representative composite sample. Areas such as fertilizer heaps, manure piles, field borders, waterlogged patches, and unusual spots should be avoided.

The samples should be air-dried under shade, gently crushed, and passed through a 2-mm sieve before chemical analysis. Similar sampling depths and processing procedures have been used in soil fertility investigations [5, 6].

Determination of Soil pH

Soil pH was determined using a soil-to-water suspension, commonly at a 1:2.5 ratio, using a calibrated digital pH meter. Soil pH is an important indicator because it affects

nutrient availability and several biological and chemical processes in soil [6].

Electrical Conductivity

Electrical conductivity was measured in the soil-water extract using a conductivity meter. EC provides an indication of soluble salt concentration and can be used to identify potential salinity-related constraints.

Estimation of Organic Carbon

Organic carbon was estimated using the Walkley and Black wet oxidation procedure. This method is widely used for determining soil organic carbon and is included among recognized soil-testing approaches [2, 7].

Organic carbon was used as an indicator of soil organic matter status and general fertility condition.

Estimation of Available Nitrogen

Available nitrogen was estimated by the alkaline potassium permanganate method of Subbiah and Asija. In this method, readily mineralizable forms of soil nitrogen are released under alkaline oxidation conditions and the evolved ammonia is measured. This method remains a commonly used approach for available-N estimation in Indian soil testing [1, 8].

Estimation of Available Phosphorus

Available phosphorus was determined using an appropriate soil-P extraction procedure. For neutral to alkaline soils, Olsen's method using sodium bicarbonate extractant is widely used. The extracted phosphorus is subsequently determined colorimetrically [1, 9].

The choice of phosphorus extraction method should depend on soil characteristics; Olsen extraction is particularly appropriate for alkaline and calcareous soils, whereas other extractants may be more appropriate for acidic soils [10].

Estimation of Available Potassium

Available potassium was extracted using neutral normal ammonium acetate and estimated using a flame photometer. Neutral ammonium acetate extraction is a standard procedure used for determining exchangeable and available potassium in many agricultural soils [1, 6].

Classification of Nutrient Status

The nutrient values were interpreted using commonly used Indian soil-fertility categories. The Government of India soil-testing manual provides broad low, medium, and high categories for available N, P, and K. For example, available N below 280 kg ha⁻¹ is broadly categorized as low, 280–560 kg ha⁻¹ as medium, and above 560 kg ha⁻¹ as high. For available P using Olsen's method in alkaline soils, values below 10 kg ha⁻¹ are generally considered low, 10–24.6 kg ha⁻¹ medium, and above 24.6 kg ha⁻¹ high. Available K values below 108 kg ha⁻¹, 108–280 kg ha⁻¹, and above 280 kg ha⁻¹ are broadly categorized as low, medium, and high, respectively [1].

These categories are broad interpretative guidelines and should not be treated as universal critical limits for every crop and soil type.

Statistical Analysis

The data were summarized using minimum, maximum, mean, and standard deviation. The coefficient of variation (CV) was calculated as:

$$CV (\%) = (\text{Standard deviation} / \text{Mean}) \times 100$$

The resulting values were used to describe the variability of soil properties among the sampled fields.

Results

Physicochemical Properties of Soil

The illustrative soil data are presented in Table 1.

Table 1: Physicochemical characteristics of agricultural soils

Parameter	Minimum	Maximum	Mean $\pm$ SD
pH	6.7	7.8	7.24 $\pm$ 0.35
EC (dS m ⁻¹)	0.18	0.61	0.37 $\pm$ 0.13
Organic carbon (%)	0.42	0.71	0.56 $\pm$ 0.10

The soil pH ranged from 6.7 to 7.8, with a mean value of 7.24. This indicated that most of the soils were neutral to

Available Macronutrient Status

Table 2: Available N, P and K status of agricultural soils

Nutrient	Minimum	Maximum	Mean $\pm$ SD	General status
Available N (kg ha ⁻¹)	214	386	292 $\pm$ 51	Medium
Available P (kg ha ⁻¹)	7.8	22.6	14.8 $\pm$ 4.3	Medium
Available K (kg ha ⁻¹)	142	326	228 $\pm$ 55	Medium

Available nitrogen ranged from 214 to 386 kg ha⁻¹, with an average of 292 kg ha⁻¹. Based on broad national soil-fertility ratings, the average value falls within the medium category, although several individual fields would be classified as low because their values were below 280 kg ha⁻¹ [1].

Available phosphorus ranged from 7.8 to 22.6 kg ha⁻¹. The average phosphorus level was 14.8 kg ha⁻¹, corresponding broadly to the medium category. Nevertheless, some fields had low phosphorus status.

Available potassium ranged from 142 to 326 kg ha⁻¹, with a mean of 228 kg ha⁻¹. The average potassium status was medium, while some fields showed high potassium availability.

Distribution of Nutrient Classes

Table 3: Illustrative distribution of soil nutrient classes

Nutrient	Low	Medium	High
Organic carbon	2 fields	8 fields	0 fields
Available N	4 fields	6 fields	0 fields
Available P	3 fields	7 fields	0 fields
Available K	0 fields	7 fields	3 fields

The distribution indicated that nitrogen was the most important nutrient requiring management attention. Four of the representative fields were categorized as low in available nitrogen. Phosphorus deficiency was also observed in a smaller proportion of fields.

Potassium was comparatively better supplied, with most fields showing medium status and several fields showing high potassium availability.

4. Discussion

4.1 Soil Reaction and Electrical Conductivity

The mean soil pH of 7.24 indicated a predominantly neutral to slightly alkaline reaction. Soil pH is one of the most important chemical properties affecting nutrient availability, microbial processes, and plant growth. The suitability of a soil for a particular crop, however, depends on the crop's tolerance and on other soil characteristics.

slightly alkaline. Such pH conditions are generally favorable for the availability of many essential plant nutrients, although phosphorus and certain micronutrients can become less available as alkalinity increases.

Electrical conductivity ranged from 0.18 to 0.61 dS m⁻¹, with an average of 0.37 dS m⁻¹. The relatively low EC values indicated that excessive soluble-salt accumulation was not a major limitation in the illustrative dataset.

Organic carbon ranged from 0.42 to 0.71%, with a mean value of 0.56%. According to broad Indian soil-fertility ratings, organic carbon values of 0.5–0.75% are generally regarded as medium, while values below 0.5% are considered low [1].

Thus, although the average organic carbon status was medium, some fields exhibited comparatively low organic carbon.

The relatively low EC values observed in the illustrative dataset suggest that salinity was not a major constraint. Electrical conductivity is useful for identifying soluble-salt accumulation, and soil testing laboratories routinely include EC among the important physicochemical properties of agricultural soil [3, 11].

Continuous irrigation with saline water, inadequate drainage, and excessive evaporation can increase soil salinity over time. Therefore, monitoring EC remains important in intensively irrigated agricultural areas.

Organic Carbon Status

Organic carbon is a critical component of soil fertility. It contributes to nutrient retention, soil aggregation, water storage, microbial activity, and overall soil structure. Soil-health assessment frameworks also recognize soil organic matter and carbon as important indicators associated with nutrient retention and soil productivity [3].

The mean organic carbon content of 0.56% in the illustrative dataset indicates a moderate status, although some fields showed low values. Low organic carbon may be associated with continuous cropping, removal or burning of crop residues, limited use of farmyard manure, erosion, and inadequate organic-matter inputs.

Increasing organic matter through farmyard manure, compost, green manuring, crop-residue incorporation, cover crops, and reduced soil disturbance can contribute to long-term improvement in soil quality.

Available Nitrogen

Nitrogen was identified as the principal nutrient requiring attention in the illustrative assessment. The mean available-N concentration was 292 kg ha⁻¹, but four fields fell below the broad low-N threshold.

Nitrogen deficiency can result in poor vegetative growth, chlorosis of older leaves, reduced leaf area, and decreased yield. Low soil nitrogen is often associated with low organic matter, continuous crop removal, insufficient fertilizer application, and losses through leaching, volatilization, denitrification, and erosion.

Nitrogen management should therefore be based on crop demand, soil-test results, expected yield, and the timing and method of fertilizer application. Split application of nitrogen is generally preferable to applying the entire nitrogen requirement at one time because it can improve synchronization between nutrient supply and crop demand.

Available Phosphorus

The available phosphorus level varied substantially among the representative fields. Three fields were categorized as low and seven as medium.

Phosphorus availability depends strongly on soil reaction and mineral composition. In alkaline and calcareous soils, phosphorus can become associated with calcium compounds, reducing its availability to plants. In acidic soils, phosphorus may become strongly associated with iron and aluminum compounds. Consequently, the selection of an appropriate soil-P test should take soil properties into consideration [10]. Phosphorus fertilizer should not be applied indiscriminately. Excess phosphorus can accumulate in agricultural soils and may contribute to phosphorus movement into water bodies through runoff and erosion [10, 12]. Therefore, soil-test-based phosphorus management is important both agronomically and environmentally.

Available Potassium

Available potassium showed a comparatively favorable status, with most fields falling into the medium category and some fields having high potassium.

Potassium is involved in stomatal regulation, water balance, enzyme activation, photosynthesis, and stress tolerance. Although potassium was not the principal limiting nutrient in the illustrative dataset, its status should continue to be monitored because repeated crop removal can gradually reduce soil potassium reserves.

The application of potassium fertilizer should therefore be based on soil-test results and crop requirement rather than routine application without diagnosis.

Nutrient Balance and Sustainable Fertilization

The results demonstrate that a single fertilizer recommendation for all agricultural fields may not be appropriate. Soil fertility can vary substantially even among neighboring fields. Spatial variability studies have demonstrated that available N, P, K and organic carbon can show considerable heterogeneity at farm scale. [5]

A balanced nutrient-management approach should therefore consider:

- Soil-test-based fertilizer recommendations.
- Appropriate nitrogen, phosphorus, and potassium ratios.
- Regular application of organic amendments.
- Crop-residue incorporation.
- Crop rotation and diversification.
- Legume inclusion where agronomically appropriate.
- Correction of micronutrient deficiencies based on testing.
- Efficient irrigation and drainage management.
- Avoidance of excessive fertilizer application.

Integrated nutrient management, combining mineral fertilizers with organic and biological nutrient sources, can improve nutrient-use efficiency and maintain soil productivity over the long term.

Recommended Soil-Fertility Management Practices

Based on the illustrative results, the following practices are recommended:

Regular Soil Testing

Soil should be tested periodically to monitor changes in pH, EC, organic carbon, N, P, K, secondary nutrients, and micronutrients. A soil-test-based approach can reduce unnecessary fertilizer expenditure and improve nutrient-use efficiency.

Improvement of Organic Matter

Fields with low organic carbon should receive greater attention through:

- Well-decomposed farmyard manure.
- Compost.
- Vermicompost where appropriate.
- Green manure crops.
- Crop-residue incorporation.
- Cover crops.
- Reduced residue burning.

Nitrogen Management

Where soil nitrogen is low, nitrogen should be supplied according to crop requirement and soil-test recommendations. Split fertilizer application and improved timing can help reduce nutrient losses.

Phosphorus Management

Phosphorus should be applied according to soil-test results. Fields with adequate or high phosphorus should not receive unnecessary additional phosphorus.

Potassium Management

Potassium application should be adjusted according to soil-test status and crop removal. High-K fields may require little or no additional potassium fertilizer for certain crops, whereas low-K fields require appropriate supplementation.

Micronutrient Management

Where crop symptoms or soil tests indicate micronutrient deficiency, nutrients such as zinc, iron, manganese, copper, boron, or sulphur should be managed according to appropriate regional recommendations. Soil-fertility programs commonly include both macronutrient and micronutrient assessments [11].

Conclusion

The assessment of soil fertility provides essential information for improving agricultural productivity and maintaining soil quality. The illustrative results of the present study indicated that the agricultural soils were predominantly neutral to slightly alkaline and had relatively low electrical conductivity. Organic carbon was generally in the medium range, although some fields showed comparatively low values.

Available nitrogen represented the most important nutrient-management concern, with several fields showing low nitrogen status. Phosphorus was predominantly low to medium, whereas potassium was comparatively better maintained. These findings demonstrate the importance of soil-test-based nutrient management rather than uniform fertilizer application across all agricultural fields.

Improvement of soil organic carbon through organic amendments, crop-residue management, crop diversification, and green manuring, combined with balanced application of mineral fertilizers, can contribute to sustainable soil fertility. Regular soil testing and field-specific fertilizer

recommendations should be promoted to improve nutrient-use efficiency, reduce unnecessary fertilizer inputs, and maintain long-term agricultural productivity.

For a publishable field study, the illustrative results presented here should be replaced with actual laboratory measurements, sampling coordinates/location, number of fields and samples, crop history, statistical analysis, and photographs or maps of the study area.

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Conflict of Interest

The authors declare that there is no conflict of interest associated with this study.

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Data Availability

The data presented in the Results section are illustrative because the present manuscript was prepared without an original field dataset. For an experimental submission, the authors should provide the actual laboratory observations and corresponding dataset.

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