Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 06, Issue: 01 (JAN-FEB, 2026)
Available online at http://www.agriarticles.com

Soil Fertility Evaluation Techniques: Physical, Biological and Chemical Approaches

*Ajaypal, A.[1], Mahato, K.[2], Harish[1] and D.S. Shekhawat[3]
[1]Ph.D. Scholar, Department of Soil Science, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut (U.P.)
[2]Ph.D. Scholar, Dept. of Soil Science, Indian Agriculture Research Institute, New Delhi
[3]M.Sc., Department of soil science and agricultural chemistry, Dr. PDKV, Akola, Maharashtra, India
*Corresponding Author's email: ajay7691khadda@gmail.com

Evaluating soil fertility is crucial for optimizing plant performance while minimizing nutrient loss from the soil-plant system. This process involves assessing the soil's ability to provide nutrients for plant growth, achieved through a range of diagnostic techniques such as chemical and biological soil tests, visual observations of plant health, infrared spectroscopy, nutrient indexing, Geographic Information system technology, soil test values, analysis of plant tissues, diagnosis and recommendation integrated system and soil test crop response. These methods collectively constitute soil fertility evaluation, enabling farmers to tailor nutrient management strategies to specific soil conditions.

Definition

Soil fertility is defined as the ability of soil to provide essential nutrients to plants in adequate amounts and proportions. It is a critical factor in determining crop productivity and is influenced by factors such as soil type, climate, topography, and land use practices. Soil fertility plays a vital role in maintaining ecosystem health, supporting biodiversity, and regulating the climate.

Objectives of soil fertility evaluation are as follows

1. Assess soil health to ensure optimal conditions for plant growth.
2. Optimize nutrient management for maximum nutrient use efficiency.
3. Enhance crop productivity through corrective soil fertility measures.
4. Preserve soil resources by preventing nutrient depletion and erosion.
5. Support sustainable agriculture practices through holistic soil management.

Methods of soil fertility evaluation

Evaluating soil fertility involves a combination of soil sampling, laboratory analysis, and field observations.

Laboratory Analysis

Laboratory analysis involves testing soil samples for various physical, chemical, and biological properties. Common laboratory tests include:

- **Physical Tests**: Measuring soil texture, structure, and water-holding capacity.
- **Chemical Tests**: Analysing soil pH, nutrient levels (e.g., N, P, K), and contaminants (e.g., heavy metals).
- **Biological Tests**: Assessing soil microbial activity, biomass, and diversity.

There are various diagnostic techniques that are commonly used to evaluate fertility of the soils. They are:

A.) Nutrient deficiency symptoms on plants
B.) Plant analysis
C.) Biological tests
D.) Soil testing
E.) Soil chemical analysis

A.) Observation of nutrient deficiency symptoms in plants

In the majority of cases, the primary factor influencing soil fertility is the status of nutrients (Alfaia et al., 2004). Top of Form Plants display characteristic symptoms when they lack sufficient quantities of one or more essential nutrient elements necessary for their growth. These symptoms vary depending on the specific nutrient deficiency and can exhibit different patterns across various plant species. Through careful observation and analysis of these symptoms, it is possible to identify which nutrients are deficient in the soil. This method offers a quick and equipment-free way to assess nutrient deficiencies. However, it requires practitioners to develop diagnostic proficiency through practice and attentive observation. While the appearance of deficiency symptoms signals an extreme state of nutrient deficiency, it's noteworthy that even in the absence of visible symptoms, crops may experience a decrease in yield. This phenomenon is known as **"hidden hunger."** Hidden hunger occurs when crops require more of a particular nutrient element than they are receiving, yet they do not exhibit outward signs of deficiency. It's important to recognize that nutrient deficiency symptoms only become apparent when the nutrient supply to plants becomes severely limited, hindering their proper function. Consequently, relying solely on symptom observation may not be the most effective approach for scheduling fertilizer applications to achieve optimal fertilizer use efficiency.

Nutrient deficiency symptoms in older leaves:

N, P, K, Mg and Zn

Younger leaves: Ca, S, B, Mo, Mn, Cl, Fe, Cu and Ni

Common deficiency symptoms include

1. Crop failure in seedling stage
2. Stunted growth
3. Abnormal coloration (e.g., chlorosis, necrosis)
4. Malformation of plant parts (e.g., rosette leaves)
5. Delayed maturity 6. Reduced crop quality (low protein, oil, starch content)

❖ **Limitations:**

- The visual symptoms may be caused by more than one nutrient;
- Deficiency symptoms may be due to an excess quantity of another;
- Deficiency symptoms in the field may be due to disease or insect damage which can produce certain micronutrient deficiencies;
- Nutrient deficiency symptoms are observed only after the crop has already suffered an irreversible loss.

B.) Plant Tissue analysis

a) Rapid Tissue Test:

This method is a rapid and qualitative or semi-quantitative approach. It involves testing fresh plant tissue or sap from ruptured cells to assess levels of unassimilated nutrients such as N, P, K and others. Reagents are introduced to the cell sap to induce colour development. The intensity of colour—low, medium, or high—categorizes the nutrient levels as deficient, adequate, or high in the plants, respectively. Primarily utilized for predicting nutrient deficiencies and anticipating potential production issues, this method provides valuable insights into the nutrient supply to plants at the time of testing.

i. Plant part to be selected: Typically, the latest mature leaf's conductive tissue is chosen for testing.

ii. Testing time: Optimal testing occurs during bloom or early fruiting stages; nitrate levels are generally higher in the morning than in the afternoon, if the nutrient supply is limited.

iii. Time of day: NO_3 levels in plants are affected by the time of day, typically being higher in the morning compared to the afternoon when the nutrient supply is limited. NO_3 accumulates overnight and is utilized during the day for carbohydrate synthesis. Hence, testing should avoid early morning or late afternoon periods.

Equipment's mostly used: Plant Sensors, leaf colour chart, chlorophyll meters etc.

Test for Nitrates: Diphenylamine,

Test for Phosphates: Molybdate + Stannous oxalate test,

Test for Potassium: Sodium cobalt nitrate

b) Total Analysis:

Total analysis involves a quantitative approach conducted on either entire plants or specific plant parts. The process begins with the digestion of dried plant material using acid mixtures, followed by quantitative testing for various nutrients using distinct methods. This determination provides data on both assimilated and unassimilated nutrients such as Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Sulphur, Iron, Manganese, Copper, Boron, Molybdenum, Cobalt, Chlorine, Silicon, Zinc, Aluminium and others present in plants. For precise analysis, recently matured plant material is typically preferred.

C.) Biological test

It is conducted for calibrating the crop responses to added nutrients. Different methods are adopted for evaluating fertility status of soil.

i. **Field test:** Field experiments are conducted on various fertilizers and crops, and the treatments yielding the highest yield are chosen. These trials aid in providing overarching fertilizer recommendations for specific crops and soils, enabling the selection of appropriate types and quantities of fertilizer for different crops

ii. **Indicator plants**: These plants are particularly prone to nutrient deficiencies, displaying distinct symptoms of deficiency when grown in soils lacking specific nutrients.

Table 1: Indicator plants for specific nutrient.

Nutrients	Indicator plants
N, Ca	Cabbage, Cauliflower
P	Rapeseed
K, Mg	Potato
Fe	Cauliflower, Cabbage, potato, Oats
Zn	Maize
Na, B	Sugar beet
Mn	Sugar beet, Oats, Potato
Mo	Lucerne
Cu	Wheat

iii) Microbiology test

Through the utilization of diverse microorganism cultures, soil fertility can be assessed. Winogradsky was among the first to note that in the absence of mineral elements, certain microorganisms displayed behaviour's akin to those of higher plants. Microorganisms are responsive to nutrient deficiencies and can be utilized to identify any deficiencies in the soil.

A method involves treating soil with appropriate nutrient solutions and inoculating it with various microbial species (such as bacteria and fungi), followed by an incubation period. By observing the growth and development of organisms, typically measured by parameters like weight or the diameter of mycelial pads, the soil's nutrient content can be estimated.

For instance:

a) The Azotobacter method assesses the levels of Ca, P, and K.

b) The Aspergillus Niger test is employed for evaluating P and K.

c) Mehlich's Cunninghamella (Fungus)-plague method for phosphorus

d) Sackett and Stewart techniques, specifically focusing on Azotobacter, are utilized to determine the soil's P and K status.

iv) Green house and laboratory test:

These streamlined biological methods for assessing soil fertility involve utilizing higher plants and small soil samples for evaluation. They rely on the nutrient absorption capacity of numerous plants cultivated in limited soil quantities. This approach is employed to gauge the accessibility of various nutrients, with their quantities determined through chemical analysis of both the entire plant and soil.

Most common methods are:

a) The Mitscherlich pot culture method assesses the NPK status in oat.

b) Jenny's pot culture technique employs lettuce with NPK nutrients.

c) The Neubauer seedling method evaluates NPK levels.

d) The Sunflower pot-culture technique focuses on boron evaluation.

D. Based on Soil Test values

i. **Soil test Calibration**:

After obtaining soil test values, the calibration process becomes crucial. Without relating these values to indicators of crop productivity, such as dry matter yield, grain yield, or economic returns, they remain mere numbers without practical relevance or usefulness for fertilizer recommendations. Typically, these relationships are established using measures like dry matter yield or grain yield. Even a significant positive correlation (r-value) between two parameters, like NH4OAc extractable K content and wheat grain yield, underscores the importance of soil testing. However, for calibration purposes, the focus is on establishing a relationship between crop response to applied nutrients and the quantities of available nutrients. This can be done by using:

- Percent yield, which represents the yield without the application of a specific nutrient expressed as a percentage of the yield obtained when that nutrient is non-limiting, commonly known as Bray's percent yield.
- Crop response to applied nutrients.

i. Fertilizer recommendations:

Fertilizer recommendations aim to supply nutrients in optimal quantity and proportions to meet crop needs. Soil-based recommendations adjust nutrient balance, enhancing fertilizer efficiency. Despite soil, climate, and management variations, past efforts have linked soil nutrients and fertilizer response, informing diverse approaches for recommendations.

a. General recommendations:

Recommendations are formulated based on multi-location field trials involving various doses of fertilizer nutrients (N, P, K) singly and in combinations. Responses and economic factors are assessed to determine optimal nutrient rates, such as 150-80-60 kg ha-1 of N-P2O5 -K2O for irrigated wheat. Long-term experiments reveal significant soil phosphorus accumulation under continuous recommended fertilizer application, leading to instances where phosphorus application becomes unnecessary for subsequent seasons.

b. Based on Fertility ratings:

In India, soil testing has gained recognition as a method for advising fertilizer quantities for different crops. However, the effectiveness of soil testing hinges on a thorough understanding of the intricate interactions among soil, crops, varieties, fertilizers, climate, and management practices tailored to specific conditions (Kanwar, 1971). In this method, soil test values are categorized into three groups: low, medium and high, or into five groups: very low, low, medium, high and very high. These classifications result from on-farm experiments using varying nutrient doses across soils with diverse test values. Percent yield is then categorized to establish soil fertility ratings. For instance, yield percentages of ≤25, 26-50, 51-75, 76-90 and >90 correspond to very low, low, medium, high, and very high fertility categories, respectively, guiding fertilizer recommendations. The general fertilizer recommendation for crops is pegged to medium fertility values. For soils categorized as low or high fertility, the recommended rate is adjusted by 25 to 50% accordingly, based on soil test results. However, these adjustments are arbitrary and lack scientific backing, rendering the recommendations semiquantitative.

A significant limitation arises from the wide range of soil test values within the medium category. For instance, soils with test values ranging from 121 to 280 kg ha of ammonium acetate-K receive the same recommended fertilizer rate for K, O, which is scientifically inaccurate. This issue could be mitigated to some extent by developing location-specific, narrower soil fertility ranges, ideally with 6 to 7 categories of ratings.

c) Based on Nutrient Index:

In this method, fertilizer recommendations rely on the Nutrient Index (NI) value per nutrient for a specific area (such as a village, block, or district).

Purpose of Nutrient Indexing

- Creating a soil fertility map or status report for Broad bed and furrow system (BBF).
- Evaluating fertilizer and soil amendment needs through soil testing.
- Estimating the potential productivity of a given area.
- Preserving soil sustainability in BBF.
- Recommending corrective actions to address plant nutrient deficiencies in the BBF system.

Sufficient soil samples representing the entire area are analysed and classified into low, medium and high categories. Thereafter, NI is computed following the relationship given by Parker et al. (1951):

$$\textbf{Nutrient index} = \frac{(NL \text{ X } 1) + (NM \text{ X } 2) + (NH \text{ X } 3)}{NT}$$

NL, NM and NH are number of soil sample falling in low, medium and high category, respectively and NT is the total number of soil samples analysed. If all samples classify as low, the Nutrient Index (NI) is 1; if all classify as high, NI is 3. **Parker et al. (1951)** proposed NI ratings of ≤1.5, 1.5-2.5 and 2.5 for low, medium, and high soil categories respectively.

Ramamoorthy and Bajaj (1969) later adjusted these limits to 1.67-2.33 for medium, ensuring a fair representation without overemphasizing the medium category. This is valuable for determining the logistics of fertilizer distribution and consumption (Biswas and Mukherjee, 1997).

d) Based on critical limits:

The critical limit (CL) concept, introduced by **Cate and Nelson (1965),** signifies the soil available nutrient level above which nutrient sufficiency is established, with a low likelihood of economic response to fertilizer application.

Table: Critical limit of nutrients

Elements	General range	Critical level (%)
N	2.0- 4.0	<2
P	0.2- 0.5	<0.1
K	1.5- 3.0	<1.0
Ca	0.5- 3.0	<0.1
Mg	0.2- 0.5	<0.2
S	0.2- 0.5	<0.15
Fe	50- 150 ppm	<5 ppm
Cu	5-20 ppm	<4 ppm
Zn	20-100 ppm	<15 ppm
Mn	20-500 ppm	<20 ppm
B	02-100 ppm	<20 ppm
Mo	01-2.0 ppm	<0.1 ppm
Cl	0.2- 2.0 ppm	-

e) Based on targeted crop yield:

The targeted yield concept, pioneered by **Truog (1960)** and refined by **Ramamoorthy *et al.* (1967)**, relies on the significant linear relationship between crop grain yield and nutrient uptake. ICAR further advanced this concept by developing Soil Test Crop Response Correlations (STCR) for crop specific fertilizer recommendations based on soil tests.

E. Soil chemical analysis

Soil chemical analysis is an important and rapid tool for evaluating and correcting the plant nutrient deficiencies. Different reagents are used to extract plant available NPK, secondary and micronutrients (Rayment and Lyons, 2011).

1. Available nutrient (in soil)

a) N: Alkaline permanganate method (Subbhia Asija)
b) P: Acidic soil - Bray's method - Alkaline soil - Olson method.
c) K: Ammonium acetate / Flame photometer.
d) S: Calcium dihydrogen - Phosphate / Turbidity method.
e) Ca, Mg, Na, K: Ammonium acetate (Hanway and Heidan Method)

2. Available nutrient (in plant)

a) Fe - 4.5 ppm, Mn - 2.0 ppm, Zn - 0.6 ppm, Cu - 0.2 ppm.
b) B - Hot water-soluble dictionary < 0.1 ppm Low, 1 to 2 Normal, >2 High.
c) MoO4 - Grigg and Tamm method buttered at pH 3.0, 470 nm, 0.04 to 0.20 ppm (Rayment and Lyons, 2011).

3. Total element analysis

a) Total nitrogen analysis by Kjeldhal method
b) Total P, Ca, Mg, Zn, Cu, Fe, Na2CO3- Fusion method / H.F. digestion.

Conclusion

Soil fertility evaluation is a critical component of sustainable agriculture, enabling farmers and agricultural practitioners to optimize crop yields while minimizing environmental impact. By understanding the key factors affecting soil fertility, using appropriate soil sampling and laboratory analysis techniques, and interpreting soil test results, it is possible to develop effective fertilizer application plans that promote soil health and ecosystem sustainability.

References

1. Black CA. Soil fertility evaluation and control. CRC Press, 2013.
2. Foth HD, Ellis BG. Soil fertility. CRC Press, 2018.
3. Bhattacharya P, Sengupta S. Evaluating fertility status of soils: The adoptable techniques.
4. Bhaduri D, Pal S. Diagnosis and recommendation integrated system (DRIS): Concepts and applications on nutritional diagnosis of plants-a review. J Soil Water Conserv. 2013;12 (1):70-79.
5. Rayment GE, Lyons DJ. Soil Chemical Methods: Australasia. Vol 3. CSIRO Publishing; c. 2011.
6. Abbas S, Javed MT, Ali Q, Azeem M, Ali S. Nutrient deficiency stress and relation with plant growth and development. In: Engineering Tolerance in Crop Plants Against Abiotic Stress. CRC Press; c2021. p. 239-262.