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COMPREHENSIVE ASSESSMENT OF VARIOUS SOIL FERTILITY EVALUATION TECHNIQUES FOR ESTIMATING NUTRIENT STATUS OF SOIL: A REVIEW

Hridesh Harsha Sarma[1]*, Aditya Bezbaruah[2], Nilabh Talukdar[1], Kishore Kumar Kurmi[3] and Bipasha Borkotoky[4]

[1]Department of Agronomy, Assam Agricultural University, Jorhat - 785 013, Assam, India.
[2]Department of Agriculture, District Agriculture Office, Karimganj, Assam, India.
[3]Department of Seed Science and Technology, Assam Agricultural University, Jorhat - 785 013, Assam, India.
[4]Department of Soil Science, Assam Agricultural University, Jorhat - 785 013, Assam, India.
Corresponding author E-mail : hrideshsarma.official@gmail.com

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ABSTRACT

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. By employing appropriate calibration methods, farmers can effectively calibrate nutrient management approaches based on localized soil characteristics, ensuring optimal agricultural outcomes.

Key words : Biological tests, Infrared spectroscopy, Nutrient index, Plant health, Soil fertility.

Introduction

Soil fertility, a cornerstone of agricultural productivity and environmental sustainability, encompasses the complex interplay of various factors that influence the soil's ability to support plant growth and development. The concept of soil fertility is frequently employed in soil science, encompassing soil properties such as nutrients, moisture, minerals and organic matter, among others (Desbiez *et al*., 2004). From initial views of soil as the organic-rich upper layer to contemporary pedological classifications of soil profiles, there exists a diverse history of beliefs and comprehension regarding this crucial resource that sustains life (Richard, 2006). In the realm of agricultural sciences, understanding soil fertility is paramount as it directly impacts food security, economic prosperity and environmental health. A mere gram of soil typically harbors tens to billions of fungi and bacteria, alongside thousands of distinct plant and animal species. Soil serves as both a self-contained ecosystem and an indispensable component of the broader terrestrial ecosystem (Uphoff *et al*., 2006). At its core, soil fertility revolves around the availability of essential nutrients to plants. However, interpreting soil test results to determine fertilizer needs is not straightforward due to the heterogeneous nature of soils. Soil variability poses challenges, as the total nutrient content often does not accurately reflect the nutrients accessible to plant roots. Despite numerous extraction methods developed to remove nutrient elements from the soil, none perfectly mimic the uptake process by plants. Consequently, to bridge this gap between soil tests and actual plant response, it is imperative to correlate soil test data with results obtained from field experiments where fertilizers are applied, providing insights into nutrient availability and plant performance. The significance of soil fertility extends far beyond mere agricultural production. Fertile soils are vital components of stable societies, sustaining the growth of crops necessary for food, fibre, animal feed, medicines, industrial products and energy. Moreover, they contribute to the creation of aesthetically pleasing environments, enhancing overall well-being. Thus, soil fertility management emerges as a critical scientific discipline that integrates principles from soil biology, chemistry and physics to develop practices aimed at managing nutrients in a profitable and environmentally sound manner.

Soil fertility is among the most significant factors influencing farmers' decisions regarding agricultural production, fertilizer application and the implementation of soil and water conservation measures (Mulder, 2000). Defining soil fertility involves considering various chemical, physical, and biological attributes of the soil. Soil fertility refers to the soil's capacity to supply sufficient quantities and proportions of essential plant nutrients required for optimal growth.Soil comprises minerals, organic material, an abundance of organisms and fluctuating levels of air and water, all vital for sustaining life (Wilding and Lin, 2006). It is governed by factors such as soil texture, depth, mineralogy, organic matter content, nutrient- and water-holding capacity, and soil structure. While some of these factors, like texture and depth, are inherent and cannot be manipulated in crop production, others, such as organic matter content and nutrient capacity, are dynamic and can be managed to improve soil fertility. Effective soil fertility management requires a holistic approach that balances agricultural productivity with environmental protection. As the optimization of soil nutrient status for crop production must coexist with efforts to prevent soil, air and water pollution, modern soil fertility practices integrate environmental sustainability principles. The limiting factors affecting soil fertility vary depending on the region. For instance, in tropical areas, significant factors include moisture stress, high phosphorus fixation, and elevated acidity levels (Cardoso and Kuyper, 2006). Hence, soil fertility is a complex concept that cannot be directly measured but can be assessed through other soil properties (Bautista-Cruz *et al.*, 2007). By adopting practices that minimize chemical inputs, reduce soil erosion, and enhance soil health, farmers can promote both productivity and ecological resilience. Productive soils exhibit a range of attributes that support optimal plant growth throughout the crop lifecycle.

Shaped by the activities of farmers both past and present, the assessment of soil fertility serves as a cornerstone in precision agriculture for land management. It not only aids in gauging land productivity levels, but also directs the judicious development and utilization of resources (Liu, 2010.) Adequate soil volume provides space for root development, allowing plants to access water and nutrients essential for growth. Moreover, soil structure and composition play crucial roles in anchoring plants and facilitating root penetration. Dynamic soil quality indicators, such as organic matter content and nutrient-holding capacity, contribute significantly to soil fertility. Organic matter serves as a reservoir of nutrients and enhances soil structure, water retention and microbial activity, thereby improving overall soil health and fertility. In the context of sustainable agriculture, encompassing both economic and environmental considerations, soil fertility can be described as the capacity of soil to provide a conducive substrate for the sustainable growth and development of plants (Izac, 2003; Adjei-Nsiah *et al.*, 2007).

Furthermore, advancements in soil fertility management leverage innovative technologies to enhance precision and efficiency. Techniques like remote sensing, geographic information systems (GIS) and precision agriculture enable farmers to assess soil fertility at a landscape scale and tailor nutrient management strategies to specific soil conditions. By incorporating real-time data and spatial variability analysis, farmers can optimize fertilizer application, reduce environmental impact and maximize crop yields.

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.

Techniques of soil fertility evaluation

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

A. Plant tissue analysis
B. Biological tests
C. Infrared spectroscopy
D. Soil Observation of nutrient deficiency symptoms in plants
E. test values

F. Geographic Information System (GIS) Technology

G. Modern approaches of soil fertility evaluation

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 FormPlants 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)

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 color development. The intensity of color—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.

Equipments mostly used : Plant Sensors, leaf color chart, chlorophyll meters etc.

Test for Nitrates: Diphenylamine, Test for Phosphates: Molybdate + Stannous oxalate test, Test for Potassium: Sodium cobaltnitrate

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.

S. no.	Nutrients	Indicator plants
1	N, Ca	Cabbage, cauliflower
2	P	Rape
3	K, Mg	Potato
4	Fe	Cauliflower, cabbage, potato, oats
5	Zn	Maize
6	Na, B	Sugar beet
7	Mn	Sugar beet, oats, potato
8	Mo	Lucerne
9	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 behaviors 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. Infrared Spectroscopy for soil fertility determination

Infrared reflectance spectroscopy offers several advantages over conventional soil analysis techniques. It is rapid, cost-effective, and efficient, making it ideal for analyzing a large number of samples. Additionally, spectroscopic methods eliminate the need for time-consuming sample preprocessing and the use of environmentally harmful chemical extractants. In some cases, infrared spectroscopy can be more straightforward and accurate than traditional soil analysis methods. For instance, it has been suggested to be more accurate than dichromate digestions for soil organic carbon analysis and to offer higher precision in predicting soil pH and lime requirement. Another advantage is the potential for these techniques to be adapted for in situ field use, which is particularly beneficial given the increasing global demand for large quantities of inexpensive and high-quality spatial soil data for environmental monitoring and precision agriculture.

Infrared spectroscopic methods exhibit high sensitivity to both organic and inorganic components of soil, rendering them valuable tools in agricultural and environmental research. Within the mid-infrared (MIR) spectrum, ranging from 2,500 to 25,000 nm, fundamental molecular frequencies relevant to soil constituents are particularly pronounced. This technique relies on the vibrational motions of atoms within molecules. A typical infrared spectrum is generated by transmitting infrared radiation through a soil sample and assessing the extent of absorption at specific energy levels. The frequency of vibration of a portion of a sample molecule determines the energy level at which any peak appears in an absorption spectrum, thus making infrared spectroscopy a viable alternative for soil evaluation (Dematte *et al.*, 2004).

Spectral analysis plays a crucial role in assessing soil fertility using infrared spectroscopy. Given the presence of multiple components in soil, a multivariate calibration approach is necessary to extract relevant soil fertility information from the spectra. Partial Least Squares (PLS) and Artificial Neural Networks (ANN) are two key statistical methods employed for this purpose. Adequate numbers of soil samples and a diverse range of soil variance are essential for effective multivariate calibration. Establishing a comprehensive library of soil infrared spectra, comprising thousands of soil samples, is imperative as it serves as a valuable information resource for evaluating soil fertility (Du and Zhou, 2009).

Types of Infrared Spectroscopy

i. Infrared transmission spectroscopy
ii. Infrared attenuated total reflectance spectroscopy
iii. Infrared photoacoustic spectroscopy

E. 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 NH_4OAc 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

ii) 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-P_2O_5-K_2O 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 semi-quantitative. 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

Table 2 : Soil fertility rating proposed by Muhr *et al.* (1965).

Nutrient	**Fertilizer Rating**		
	Low	**Medium**	**High**
Organic Carbon (%)	≤0.50	0.51-0.75	>0.75
Alkaline $KMnO_4$-N(Kg ha^{-1})	≤280	281-560	>560
Olsen-P (Kg ha^{-1})	≤10	11-25	>25
Ammonium acetate-K (kg ha^{-1})	≤120	121-280	>280

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 analyzed and classified into low, medium and high categories.

Thereafter, NI is computed following the relationship given by Parker *et al.* (1951):

$$\text{Nutrient Index} = \frac{(NL \times 1) + (NM \times 2) + (NH \times 3)}{NT}$$

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 analyzed. 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. Conversely, soils below the CL are likely to respond economically to nutrient application. To determine the CL for a specific nutrient, field or pot experiments are conducted on soils with varying test values, applying graded nutrient rates while keeping other nutrients non-limiting. Post-harvest, percent dry matter yield is plotted against soil test values, and a horizontal line at 85% yield is drawn. A perpendicular line is then drawn to the Y-axis, maximizing data distribution in lower left and upper right quadrants. The CL is identified where the perpendicular intersects the X-axis, distinguishing nutrient-responsive from non-responsive soils. This method, often utilized for micronutrient recommendations in soils below CLs, can be refined using statistical procedure given by Cate and Nelson's (1971).

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.

Key parameters for the targeted yield concept include:

- Nutrient requirement per ton of grain production (NR)
- Percentage contribution of soil-available nutrients (Cs)
- Percentage contribution of fertilizer nutrients (CF)

These soil test-based recommendations are tailored to various yield goals rather than a single optimum yield level. A diverse range of fertilizer prescriptions is derived by inputting soil test values into mathematical equations to determine the required nutrient amounts for a specific yield target.

Table 3 : Interpretation of soil test.

Nutrient Index	**Meaning of Index level for the crops**
Very Low	Probability of application of nutrient to be beneficial will be 80%
Low	Probability of application of nutrient to be beneficial will be 65%
Optimum	Probability of application of nutrient to be beneficial will be 50%
High	Probability of application of nutrient to be beneficial will be less than 1%

F. Geographic Information System (GIS) Technology

Measuring soil fertility using Geographic Information System (GIS) involves integrating various data sources and analytical techniques to create spatial models and maps that represent the spatial variability of soil properties related to fertility. Following steps are involved in this process

- **Soil sampling:** The first step is to collect soil samples from different locations within the area of interest. The sampling locations are carefully selected based on factors such as land use, topography and existing soil maps. GPS coordinates are recorded for each sample location.
- **Laboratory analysis :** The soil samples are analyzed in a laboratory to determine various fertility parameters, such as pH, organic matter content, nutrient levels (nitrogen, phosphorus, potassium, etc.), cation exchange capacity, and other relevant properties.
- **Spatial data collection :** In addition to soil data, other spatial data layers are collected or generated, including topography (digital elevation models), land use/land cover maps, remote sensing imagery (*e.g.*, satellite or aerial imagery), and climate data (precipitation, temperature).
- **Data integration and preprocessing :** All the collected data (soil sample data, spatial data layers) are integrated into a GIS environment. Data preprocessing steps, such as data formatting, georeferencing and projection transformations are performed to ensure compatibility and accurate spatial alignment.
- **Geostatistical analysis :** Geostatistical techniques, such as kriging or inverse distance weighting are used to interpolate the soil fertility parameters from the sample points to create continuous surface maps. These techniques consider the spatial autocorrelation and account for the spatial dependence of soil properties.
- **Overlay analysis and modelling :** The interpolated soil fertility maps are combined with other spatial data layers (*e.g.*, topography, land use, climate) through overlay analysis and spatial modelling techniques. This allows for the identification of relationships and patterns between soil fertility and environmental factors.
- **Fertility mapping and zoning :** Based on the integrated analysis, soil fertility maps and zones are created, classifying the study area into different fertility levels or classes. These maps can be used for site-specific nutrient management, precision agriculture and land use planning.
- **Validation and updating :** The soil fertility maps and models are validated using additional field data or expert knowledge. Regular updates are conducted by incorporating new soil sample data or changes in environmental conditions to maintain the accuracy and relevance of the fertility maps.

GIS plays a crucial role in measuring soil fertility by enabling the integration of diverse data sources, spatial analysis, and modelling techniques. The resulting soil fertility maps and zones provide valuable information for sustainable agricultural practices, environmental monitoring and land management decisions.

G. Modern approaches of soil fertility evaluation

i. Soil test crop response (STCR) : With the introduction of high-yielding varieties and hybrids, the importance of systematic Soil Test Crop Response (STCR) research across various soil and agro-climatic regions became apparent. ICAR initiated the AICRP on STCR, with the concept developed by Ramamoorthy *et al*. (1987). STCR establishes the connection between soil test values and crop yield, necessitating correlation between soil test values and actual crop responses observed under field conditions.

This method strives to establish a reliable framework for adjusting fertilizer doses precisely, considering diverse soil test values and farmers' response conditions, with the goal of attaining specific targeted yield levels. Fertilizer recommendations are guided by two key criteria:

- Regression analysis to refine fertilizer dose adjustments
- Providing recommendations based on a percentage of maximum yield.

To formulate fertilizer prescription equations for achieving targeted yields, essential data must be generated using standard STCR field experimentation methods. This includes:

a. Determining the nutrient requirement (NR) in kilograms per quintal of the produce.

b. Establishing the percentage contribution from soil-available nutrients (Cs).

c. Determining the percentage contribution from added fertilizers (Cf) to effectively devise fertilizer prescriptions for specific yield goals.

Generated basic data are transformed into workable adjustment equations for required fertilizer nutrient for a given yield target i.e cured leaf (q ha^{-1}):

Fertilizer $N/P_2O5\ /K_2O = NR/\ (Cf\ /100) \times T - Cs/Cf \times STV$

Where, F = Fertilizer (kg ha^{-1}); NR = Nutrient requirement; Cs = Per cent contribution from soil; Cf = Per cent contribution from fertilizer; STV = Soil test value (kg ha^{-1}); T = Yield target (q ha^{-1}).

ii. Diagnosis and recommendation integrated system (DRIS Method) : DRIS, a novel approach to interpreting leaf or plant analysis, was pioneered by Beaufils in 1973, termed as Diagnosis and Recommendation Integrated System (DRIS). This comprehensive system identifies all nutritional constraints on crop production, enhancing the likelihood of achieving high yields through improved fertilizer recommendations.

The DRIS method emphasizes nutrient ratios over absolute or individual nutrient concentrations for tissue analysis interpretation. Optimum ratios among nutrient elements (*e.g.*, N/P, N/K, or K/P) within a given plant are crucial for promoting plant growth.

DRIS primarily employs the nutritional balancing concept to detect nutritional deficiencies or excesses in plants. Nutrient balance plays a pivotal role in the proper interpretation of the DRIS system, as nutrient interactions significantly influence crop yield and quality.

Nutrient ratios facilitate the derivation of special indices known as “Nutrient Indexes” or “Beaufils Nutrient Indexes” (BNI). These indexes essentially reflect the relative nutrient supplies to each other. The concentration of each nutrient in the plant influences the index value of other nutrients. An unusually high concentration of one or more nutrients will lower the index values of other nutrients, indicating deficiency.

Nutrient indexes can exhibit positive or negative values. Positive indexes suggest nutrient excess, while negative indexes indicate nutrient deficiency in plants.

DRIS is a mathematical method that utilizes plant analysis data, specifically nutrient concentrations, to identify the most limiting nutrient in a production system.Enhanced comprehension of the interplay between crops and soils has also contributed to maintaining realistic expectations and discerning the attainable capabilities of agroecosystems (Izac, 2003).

Agronomic strategies for enhancing soil fertility Top of Form

Agronomic practices play a crucial role in enhancing soil fertility, which is essential for sustainable crop production. Proper soil management techniques, such as crop rotation, cover cropping, and incorporating organic matter, help replenish nutrients and improve soil structure. Conservation tillage methods minimize soil erosion and preserve soil moisture. Judicious use of fertilizers, based on soil testing, ensures optimal nutrient availability while preventing over-fertilization. Integrated nutrient management, combining organic and inorganic sources, promotes a balanced supply of nutrients. Additionally, practices like mulching and intercropping help suppress weeds, conserve moisture and maintain soil health. By implementing these agronomic practices, farmers can enhance soil fertility, increase crop yields and promote long-term sustainability of agricultural systems. Some of the agronomic strategies used to enhance soil fertility are as follows:

1. **Crop Rotation :** Alternating crops with different nutrient needs replenishes soil nutrients, prevents soil degradation, and reduces pest and disease pressures, contributing to sustainable soil fertility management.
2. **Cover Cropping :** Planting cover crops during fallow periods protects soil from erosion, adds organic matter, fixes nitrogen, and improves soil structure, enhancing fertility and long-term productivity.
3. **Conservation Tillage :** Minimal or no-till practices reduce soil disturbance, preserve soil structure and enhance organic matter retention, promoting soil health and fertility while minimizing erosion risks.
4. **Organic Matter Addition :** Incorporating organic materials like compost, manure, or crop residues enriches soil with essential nutrients, enhances microbial activity, improves soil structure and increases water retention capacity, fostering soil fertility.
5. **Green Manuring :** Cultivating green manure crops and incorporating them into the soil boosts soil fertility by adding organic matter, increasing nitrogen fixation, improving soil structure and promoting beneficial microbial activity.
6. **Nutrient Management Planning :** Precision nutrient management ensures optimal fertilizer application based on soil test results, crop requirements, and environmental considerations, maximizing nutrient use efficiency and sustaining soil fertility.
7. **Balanced Fertilization :** Applying fertilizers containing balanced ratios of essential nutrients (NPK) replenishes soil fertility, meets crop demands, and maintains nutrient balance, supporting healthy plant growth and sustainable agricultural production.
8. **pH Management :** Adjusting soil pH through liming or acidification optimizes nutrient availability, enhances microbial activity, and improves soil structure, promoting efficient nutrient uptake and overall soil fertility.
9. **Soil Amendments :** Applying amendments like gypsum or elemental sulphur corrects soil deficiencies, balances nutrient levels, and improves

soil structure, fostering optimal conditions for plant growth and soil fertility.

10. **Crop Residue Management :** Proper management of crop residues minimizes nutrient tie-up, accelerates decomposition, and enhances nutrient recycling, enriching soil fertility and promoting sustainable agricultural practices.
11. **Integrated Nutrient Management (INM) :** INM combines organic and inorganic nutrient sources with biological inputs to optimize nutrient use efficiency, improve soil health and sustain soil fertility, ensuring long-term agricultural productivity and environmental stewardship.
12. **Agroforestry :** Integrating trees or shrubs into agricultural systems enhances soil fertility by increasing organic matter accumulation, nutrient cycling and erosion control, fostering resilient and productive agroecosystems while conserving natural resources.

Conclusion

Soil fertility is a crucial aspect of sustainable agriculture, encompasses various soil properties that directly influence crop production. These properties typically include levels of soil nutrients, organic matter and moisture content. Thus, the assessment of soil fertility relies on first determining these related soil characteristics, followed by the development of a model that evaluates overall soil fertility based on these parameters. Various evaluation techniques like plant tissue analysis, biological tests, infrared spectroscopy, soil test values, STCR, DRIS along with agronomic practices like crop rotation, green manuring, conservation tillage, cover cropping, brown manuring etc. can be holistically applied for better management of nutrients in our soil. Thus, ensuring higher nutrient use efficiency and crop yield while preventing nutrient depletion and erosion.

Future thrust

Future innovations in soil fertility are poised to revolutionize agriculture, addressing challenges such as population growth and climate change. Advancements in precision agriculture, including sensor technology and data analytics, will enable targeted nutrient management, reducing waste and environmental impact. Biofertilizers and microbial amendments hold promise for enhancing soil health and nutrient availability sustainably. Genetic engineering may yield crops with improved nutrient uptake efficiency, further optimizing fertilizer use. Embracing regenerative agriculture practices will restore soil health and resilience, ensuring sustainable food production for future generations. In essence, future perspectives in soil fertility focus on holistic, innovative approaches to nourishing soils and feeding the world.

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