Soil and Plant Testing Methods for Major and Minor Nutrients

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Abstract

Soil and plant testing are essential diagnostic tools for evaluating soil fertility and crop nutritional status and for developing sound fertilizer and amendment recommendations before yield losses occur. These methods assess the availability of major, secondary, and micronutrients through a combination of chemical, biological, and plant-based analyses. Soil testing estimates the plant-available fraction of nutrients using calibrated extractants such as Olsen, Bray, Mehlich 3, and DTPA, while plant analysis measures actual nutrient concentrations in diagnostic plant tissues to detect deficiencies, toxicities, and hidden hunger.

Keywords

Soil testing, Plant analysis, Nutrient diagnostics, Micronutrients, DTPA extraction, Rapid tissue test, Fertility management, Precision agriculture.

Introduction

Soil and plant testing refers to a set of diagnostic procedures used to estimate the nutrient-supplying capacity of the soil and the nutritional status of crops, so that fertilizer and amendment recommendations can be made before yield losses occur. These methods cover primary nutrients (N, P, K), secondary nutrients (Ca, Mg, S), and micronutrients (Fe, Zn, Mn, Cu, B, Mo, Cl, Ni), and are now standard tools in fertilizer advisory services, precision farming, and soil health monitoring.

Concepts of soil and plant testing

Soil testing provides an index of plant-available nutrients by extracting a fraction of the nutrient pool that correlates with crop response, rather than measuring total nutrient content. Plant testing (leaf or tissue analysis) measures the actual concentration of nutrients in diagnostic plant parts and is particularly valuable for confirming deficiencies, toxicities, and hidden hunger that may not be obvious from soil tests alone.

Soil tests are most effective for relatively immobile nutrients such as P, K, Ca, Mg, and many micronutrients, because these nutrients remain in the sampled soil volume between testing and cropping. In contrast, plant analysis is often more reliable for mobile or environmentally dynamic nutrients such as S and several micronutrients, whose availability can change quickly with rainfall, leaching, and mineralization.

Major nutrients: soil testing methods

For nitrogen, routine soil tests commonly estimate nitrate–N and sometimes ammonium–N using colorimetric, ion-selective electrode, or spectrophotometric methods after extraction in solutions such as KCl or $CaCl_2$, although interpretation is complicated by rapid N transformations in soil. Phosphorus is usually determined by chemical extractants tailored to soil pH, such as Bray and Mehlich solutions in acidic soils and Olsen ($NaHCO_3$) in calcareous soils, with colorimetric measurement of phosphate in the extract.

Potassium, calcium, and magnesium are commonly extracted with ammonium acetate or universal extractants like Mehlich-3, followed by quantification using flame photometry, atomic absorption spectrometry, or ICP-based techniques. These tests generate calibrated critical ranges or categories (low, medium, high) that are linked to field response data, making it possible to convert soil-test indices into fertilizer recommendations.

Secondary nutrients and salinity-related parameters

Calcium and magnesium status is often assessed through the same ammonium acetate or Mehlich-3 extracts used for K, together with measurements of cation exchange capacity and base saturation to understand soil structural stability and liming needs. Sulfur is usually measured as sulfate-S extracted with $Ca(H_2PO_4)_2$ or $CaCl_2$, but soil tests alone are less reliable because they do not capture atmospheric deposition, irrigation inputs, or rapid mineralization of organic S.

Salinity-related parameters such as electrical conductivity and sodium adsorption ratio (SAR) are determined from saturation paste extracts, and are interpreted alongside Ca, Mg, and Na measurements to evaluate risks of osmotic stress and sodicity that can impair nutrient uptake. These secondary-nutrient and salinity assessments are essential to understand nutrient imbalances that might arise even when NPK levels appear adequate.

Micronutrient soil testing methods

Micronutrients such as Fe, Mn, Zn, Cu, and B are typically extracted with chelating solutions like DTPA (diethylenetriaminepentaacetic acid) or hot-water extraction (for B), which aim to solubilize the plant-available fraction across a range of soils. Critical limits for these micronutrients are expressed in mg kg^{-1} (ppm) and are used to classify soils into deficient, marginal, and sufficient categories for specific crops and soil types.

Some systems also use universal extractants, such as the Mehlich-3 solution, to simultaneously extract multiple macro- and micronutrients, simplifying laboratory routines and enabling multi-element fertility evaluation from a single soil sample. Biological tests, including microbial growth assays like Azotobacter and Aspergillus methods, have also been explored as indirect approaches to evaluate the biological availability of certain nutrients.

Plant analysis and rapid tissue tests

Plant analysis generally involves sampling defined plant parts (often the youngest fully expanded leaf) at a specific growth stage, digesting the dried tissue, and quantifying macro- and micronutrients using spectrochemical techniques such as flame AAS, ICP-OES, or MP-AES. These measurements help identify deficiency, sufficiency, or toxicity, optimize fertilization strategies, and validate or refine soil-test based recommendations.

In addition to full laboratory analysis, rapid tissue tests use simple colorimetric reagents on fresh leaf sap or tissue extracts to provide immediate qualitative or semi-quantitative assessments of N, P, K, Mg, and Fe status in the field. For example, diphenylamine reagent gives a blue colour with nitrate indicating N sufficiency, while specific molybdate, cobalt nitrate, and titan yellow reagents are used to detect P, K, and Mg, enabling quick corrective fertilization through soil or foliar applications.

Soil testing for micronutrients

Micronutrients like Fe, Mn, Zn, Cu and B occur in very small amounts in soil and are strongly affected by pH, organic matter and redox conditions, so special extractants are used to estimate the plant-available fraction. Chelating solutions such as DTPA (diethylenetriaminepentaacetic acid) are designed to dissolve the portion of each micronutrient that behaves similarly to what plant roots can access, across a range of soil types. Critical limits for each micronutrient are then expressed in mg kg^{-1} (ppm), and these values are used to categorize soils as deficient, marginal or sufficient for specific crops and soil conditions.

Steps: DTPA soil test for Fe, Mn, Zn, Cu

1. Soil sampling and preparation
2. Extraction with DTPA solution
3. Filtration and measurement
4. Interpretation using critical limits

Steps: Hot-water soluble B test

1. Soil preparation
2. Hot-water extraction
3. Filtration and B determination

Universal extractants and biological tests

Some laboratories prefer universal extractants, like Mehlich-3, that can simultaneously extract many macro- and micronutrients from a single soil sample, making the process faster and more economical. Mehlich-3 contains a mixture of acids, salts and chelating agents, so when it is shaken with soil, it dissolves portions of P, K, Ca, Mg, and several micronutrients together, and all of these can then be measured in one analytical run. This multi-element approach simplifies laboratory routines and supports integrated fertility evaluation because the same soil test report can show both major and minor nutrient status. In addition to purely chemical tests, biological tests have been explored to assess the biological availability of nutrients, especially where microbial processes are important. Methods using organisms such as Azotobacter or Aspergillus rely on the growth response of these microbes in or on soil as an indirect indicator of nutrients like nitrogen or phosphorus being biologically accessible.

Plant analysis: Laboratory procedure

Plant analysis focuses on what is actually inside the crop rather than only what is in the soil, and is especially useful for diagnosing hidden deficiencies, toxicities and imbalances. It usually targets a defined plant part (often the youngest fully expanded leaf) at a specific growth stage, because nutrient concentrations vary with age and position on the plant.

Steps: Laboratory plant analysis

1. Selection and sampling of plant tissue
2. Cleaning, drying and grinding
3. Digestion of plant tissue
4. Measurement of nutrients
5. Interpretation and use in management

Rapid tissue and sap tests

Rapid tissue tests are designed for quick, on-farm diagnosis using simple reagents and visual colour changes rather than full laboratory digestion and instrumental measurement. They focus mainly on nutrients such as N, P, K, Mg and Fe and are particularly useful for making fast decisions about top-dressing or foliar sprays.

Steps: Rapid tissue test

1. Field sampling of fresh leaves
2. Preparation of leaf extract or sap

3. Application of specific reagents
4. Visual comparison and simple rating
5. Immediate corrective action

Conclusion

Soil and plant testing constitute the cornerstone of precise nutrient management by enabling accurate assessment of soil fertility and plant nutritional status. Through the integration of chemical, biological, and plant-based diagnostic approaches, these techniques optimize fertilizer application, minimize nutrient imbalances, and foster sustainable agricultural productivity.

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