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Soil-Testing Procedures for Southern Idaho Soils

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Introduction

SOIL SAMPLING AND TESTING are critical for maximizing grower returns in field crop production. This is due to the fact that crops require seventeen essential nutrients derived from either the atmosphere, soil, or an applied nutrient source. An essential plant nutrient is defined as a nutrient that a plant needs to complete its growth cycle; no other element can substitute for it completely. A wide range of publications about soil-testing procedures that test for different nutrients are available or are currently being evaluated. This Extension publication adds to the literature by focusing on the most commonly tested soil nutrients and the associated soil tests that are appropriate for fertilizer recommendations in southern Idaho using current University of Idaho Extension guidelines.

Using the appropriate soil test is important because applying those developed for use in other regions, particularly in areas that contain alkaline calcareous soils, might provide inaccurate readings and thus inaccurate fertilizer recommendations. Additionally, crop correlation and calibration studies are necessary to assure accurate fertilizer recommendations. More often than not, researchers will not have carried out studies like these with nonstandard soil tests in a region on a specific crop of interest. While each crop grown in Idaho has different nutrient demands, the nutrients needed and the UI Extension recommended soil test used for each nutrient are the same within the state and, thus, applicable for all growers.

Soil Nutrient Analyses and Recommendations

Routine soil tests for soil fertility assessment and crop production for soil nutrients like nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) have been developed with various extractants that help to assess the amount of each nutrient available to a plant. Some of the extractants are dependent on the soil characteristics within a region in which

a test is done. The measured values from these extractants are then related to crop response to establish nutrient recommendations. Establishment of recommendations is dependent on correlation and calibration via field-based, crop-specific response trials for selected nutrients and soil test procedures. The first step, correlation, involves determining the relationship between a crop response parameter (for example, yield) and the soil test values. If a soil test can be successfully correlated to crop response, the next step is calibration, which determines the rate of fertilizer to optimize crop response. In many crops, yield goals must be balanced with optimal quality characteristics. Thus, usage of appropriate extractants and sampling protocols play an important role in ensuring that the values obtained result in the correct fertilizer recommendations based on the current UI Extension recommendations for individual crops.

General Procedure of Soil Extraction

Soil samples are extracted by using a specific solution that will influence the release of the nutrient to be measured. In general, researchers place a specific mass of a soil sample in a container and add the extractant solution, shake the sample for a prescribed time, filter the sample solution through a specific filter size, and finally, analyze the nutrient via appropriate methodologies. Soil tests for nutrients such as P and K are reported as mg/kg and are used as an index of nutrient availability in soil that is used for making nutrient recommendations. In contrast, inorganic-N (ammonium; NH_4 and nitrate; NO_3) values are assumed to represent the actual availability of inorganic-N in the soil. Inorganic-N is often reported as mg/kg, where the value is multiplied by a factor based on the sample depth (e.g., for a 12-inch sample depth the multiplication factor is 4) to estimate the lb/ac of inorganic-N available in the soil.

Nitrogen is the nutrient needed in the largest quantities for crop growth since it is a key component of cells and an important factor in photosynthesis. N uptake originates primarily from the inorganic nitrate (NO_3^-) pool in the soil where organic-N and ammonium are converted to nitrate through mineralization and nitrification, respectively. Nitrogen deficiency results in yellowing (i.e., chlorosis) of plant tissue due to a reduction in chlorophyll. This yellowing is first observed in the oldest leaves of the plant. Inadequate N availability leads to stunted plants, reduced tillering in grains, and reduced grain protein levels. Nitrate is highly mobile in soils, and thus soil tests conducted closer to planting time provide more accurate information about the soil's nutrient content.

Currently, inorganic-N (NH_4 and NO_3) determined prior to planting is used as the main indicator for fertilizer N applications in Idaho. In grain crops and sugar beets, samples are collected from 0 to 24 in due to the mobility of N in the soil and the ability of roots to reach these deeper reservoirs; however, due to the shallower rooting depth of potatoes, only a 0–12-inch sample is collected. Soil organic matter (SOM) is often used as a factor for establishing mineralizable N in soils; however, previous research has often failed to accurately correlate this with plant response. Other rapid tests to measure soil N mineralization are being investigated, but at this time a predictive test is not available in southern Idaho soils.

Table 1. Mobility in plants, associated deficiency in plants, and the extraction procedure of the most commonly tested soil nutrients in southern Idaho.

Nutrient	Mobility in plants	Deficiency symptoms	Location of first visual symptoms	Extraction procedure	References
Nitrogen (N)	Highly mobile	Yellowing of plants or chlorosis	Older leaves	-2 M potassium chloride extraction	Mulvaney 1996
Phosphorus (P)	Highly immobile	Stunted growth and purpling of plants	Younger leaves	-Olsen -Bray -Bicarbonate	Olsen et al. 1954 Bray and Kurtz 1954
Potassium (K)	Highly mobile	Chlorosis in the leaf veins and tips	Older leaves	-Olsen -Ammonium acetate	Olsen et al. 1954 Miller et al. 2013
Sulfur (S)	Immobile	Pale green to yellowish leaves	Younger leaves	-Turbidimetry using calcium phosphate	Ajwa and Tabatabai 1993

How Does the Extractant Work?

Soil samples are extracted with a 2 M KCL solution where the K^+ and Cl^- ions dissociate (Table 1). In the soil, NH_4^+ ions are bound to negatively charged (-) clay particles and SOM. The high concentration of K^+ ions causes the exchange of NH_4^+ from these negatively charged surfaces and thus the movement of NH_4^+ into the solution.

Phosphorus is a key component in photosynthesis, a part of the energy transport system of plants, and plays a key role in cell division and enlargement. Uptake of P is primarily as orthophosphate, where the exact form is dependent on soil pH. Phosphorus is highly immobile in the soil and is bound tightly by clay particles and as iron-phosphate compounds at low pH and calcium-phosphate compounds in alkaline soils. It is essential for early stand development and in cereal crops the majority of the P exists in seed that is removed from a field. Deficiencies are typically observed as an overall stunted plant, where a "purpling" of specific crops can be observed. Soil P tests are based on the principle that the mineral or adsorbed P will dissolve and replenish soil solution P.

The soil test primarily used in southern Idaho is the Olsen or bicarbonate test that was developed for use on alkaline soils sampled from a depth of 0–12 inches. This test is based on the knowledge that a large portion of soil P is bound as calcium-phosphates, where the tests "free" a portion of this form of P, after which researchers analyze it. The Bray extractant developed for usage on acidic-pH soils is ineffective on alkaline soils with high free lime as it results in artificially low estimates of P. Crop-specific fertilizer guides (e.g., sugar beets) have established recommendations for use of the Bray soil test on soils where the pH < 6.5. Percent-free lime or calcium carbonate values are typically included in P recommendations in southern Idaho due to the strong affinity between P and calcium in alkaline soils. The percentage carbonate adjusts P applications where greater carbonate levels require greater amounts of P when soil test levels are equivalent. Several methods exist to measure calcium carbonate. One of the most common is the pressure calcimeter method, where an acid reacts with the calcium carbonate in a sealed vial. Calcium carbonate is typically measured based on the change in pressure that results from its reaction with the acid.

How Does the Extractant Work?

Olsen-P is extracted using a 0.5 M $NaHCO_3$ solution (pH 8.5). In alkaline soils, P is largely bound with calcium (Ca_{2+}). This solution reduces the activity of Ca_{2+} and Al_{3+}, thus increasing P in the solution. The Bray extractant utilizes 0.025 M HCL and 0.03 M NH_4F. In acidic soils this results in the release of P that is bound with aluminum/fluoride complexes; however, as noted above, in alkaline calcareous soils issues arise as $CaCO_3$ neutralizes the acidic solution and CaF_2 forms, resulting in artificially low estimates of P.

Potassium is another primary nutrient removed in large quantities by a crop. Usually, K release in soils occurs during the weathering of minerals, where the available form, K^+, can be used by crops. Potassium regulates many necessary crop physiological functions such as enzyme activation, protein/starch synthesis, stomatal activity, and water use within the plant. It is highly mobile in the plant and thus symptoms usually appear on older leaves and may result in chlorosis in the leaf veins and tips. Sufficient levels of K can improve a plant's health, including increased plant vigor. However, excess K fertilization can result in "luxury consumption," in which elevated plant K uptake occurs without an increase in yield or quality. Potassium is found in soils in three forms: trapped between clay layers ("relatively unavailable"), adsorbed on the surface of soil colloids ("exchangeable"), and in the soil solution ("available"). Ninety to 98% of K in soils is in crystalline-insoluble form, which is unavailable to plants due to fixation to soil minerals. Between 2% and 10% of K is fixed between layers of clay minerals, and is slowly available for plant uptake. Only about 0.1%–2% of K is contained within the soil solution and is readily available. Soil tests measure exchangeable K from a pool of exchangeable and nonexchangeable K in the soil solution. A major factor affecting K availability for crops in southern Idaho is wetting/drying and freezing cycles, and thus time-of-soil sampling in relation to field wetting and drying cycles may influence soil test K levels. The soil tests used to measure K in southern Idaho soils is either ammonium acetate or Olsen from a depth of 0–12 inches.

How Does the Extractant Work?

Exchangeable K in southern Idaho is measured with 1.0 M ammonium acetate (pH 8.5) or the Olsen/$NaHCO_3$ extractant described above for P. The ammonium acetate method is based on the knowledge that NH_4^+ replaces the K^+ on soil exchange sites. This allows K^+ ions to move from the soil exchange sites into solution and is reported as mg/kg of K. The Olsen extractant for K determination uses $NaHCO_3$ adjusted to pH 8.5 for mildly acidic to alkaline soils to estimate exchangeable K. The extraction is based on the CO_2 from bicarbonate being released and increasing the pH. This results in lower Ca_2^+ activity as $CaCO_3$ forms, increasing the quantity of K in solution.

Sulfur is a critical component of specific amino acids, which are the building blocks of protein. Sulfur is essential for chlorophyll formation and is important in plant N metabolism. Although S exists in many different chemical forms in nature, plants only absorb S through the roots in the sulfate (SO_4^{2-}) form. In soils, the majority of S is contained within SOM, in a form unavailable to plants. Plant-available S is released to soil solution via mineralization. Sulfur deficiencies are common in acidic, sandy soils with less than 2% SOM. Sulfur is immobile in plants; thus, symptoms are first seen in younger leaves. Symptoms of deficiency may include pale green to yellowish young leaves as well as an overall stunted plant. Most soils in southern Idaho are adequate in S (>10 mg/kg in a 0–24-inch sample); irrigation water often contains substantial S levels. The soil test used to measure S is calcium phosphate turbidimetry from a 0–24-inch depth.

How Does the Extractant Work?

Sulfate-S is measured by turbidimetric using 0.08 M monocalcium phosphate [$Ca(H_2PO_4)_2$] extracting solution. This method allows the determination of solubilized sulfate-S, releases adsorbed sulfate-S, and suppresses the dissolution of SOM that could increase measured sulfate (SO_4) concentrations. In the turbidimetric method, barium chloride is used to produce barium ions, which are used to precipitate SO_4 sulfate that was extracted with the monocalcium phosphate solution. Turbidimetry is based on measuring the cloudiness of a liquid and translating it into a concentration. After sulfate is converted to a barium sulfate suspension, the turbidity is measured. The results are reported in mg/kg of extractable sulfate-S in the soil.

Further Reading

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