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# Soil Sampling and Analysis

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This publication provides information on techniques of soil sampling and analysis for horticulture and agriculture. Soils are sampled to determine physical conditions, fertility (nutrient) status, and chemical properties that affect their suitability as plant growing media. Through a combination of field and greenhouse research, analytical methods have been developed which provide quantitative estimates of plant-available nutrients. Field research determines the optimum soil test levels for various nutrients for specific soil and crop combinations. Optimum fertilizer practices can be determined by knowing the optimum test level of each nutrient for a specific crop and soil, and by knowing how much fertilizer is required to change soil test values.

Soil testing is comprised of four steps:

- Collection of a representative soil sample
- Laboratory analyses of the soil sample
- Interpretation of analytical results
- Management recommendations based on interpreted analytical results

This publication focuses on the first two of these steps. The reader should gain an understanding of the proper methods for collecting soil samples, and of the potentials and limitations of soil testing.

## Soil Sampling

The first and most critical step in soil testing is collecting a soil sample. A soil analysis can only be as good as the sample sent to the laboratory. It is important to recognize what a tiny portion of a field is actually analyzed in the laboratory. For example, a 1 lb soil sample collected from a 5 acre field represents just 1/10,000,000 of the field! Therefore, it is vital that the soil sample be representative of the entire field.

The most common and economical method for sampling an area is composite sampling, where sub-samples are collected from randomly selected locations in a field, and the sub-samples are composited for analysis. The analytical results from composite sampling provide average values for the sampled area. The actual number of sub-samples depends on field size and uniformity. Generally, a larger field or a less uniform field should be more intensively sampled than one that is small and uniform. No less than 5 sub-samples should be taken from a sampled area, and 15 to 25 are preferable.

Alternatively, areas can be grid-sampled in a regular pattern. Each sample is analyzed separately, so that variability in soil properties can be determined. With data provided by grid sampling, maps of soil test values can be constructed. This information can be entered into a geographical information system (GIS) and combined with additional geospatial data, such as soil texture, crop yields, leaf analyses, etc. and used in precision agriculture systems for variable application of fertilizers and other crop inputs. This is a much more expensive method of soil analysis because of the large number of analyses required, although it provides valuable information about geospatial uniformity which can be used in precision agriculture.

Ideally, samples should be collected with a soil probe or auger (a small shovel or trowel can also be used), to the depth of tillage (usually 6 to 8 inches) or to the effective rooting depth of plants. Deeper samples may be collected for evaluation of subsoil properties, such as salt or nitrate accumulation. It is helpful to sample to the same depth each time a soil is sampled, so that year to year samples can be directly compared to monitor changes over time. Each sub-sample should be approximately equal in size. The sub-samples should be placed in a clean plastic bucket and mixed thoroughly. The desired sample amount is then removed from the bucket and the remainder discarded. Check with your testing laboratory to find out how large a sample they require.

The area or size of the field sampled is dependent upon management practices. Sample the smallest unit that will be managed separately. For example, if a field has two distinctly different sections, perhaps one half level and the other sloped, then sample the two areas separately, and fertilize each half separately to obtain optimum results. However, if each half of the area will not be fertilized or managed individually, there is no need for separate sampling. A single, representative sample will be less expensive and just as useful. Sample the smallest management unit.

Soil samples should be air-dried or taken to a test laboratory as soon as possible. To dry a soil sample, spread the soil out in a clean, warm, dry area, and let it dry for two to three days. It is best not to heat or dry soil samples in an oven because soil chemical properties may be altered. Bag the sample and send it

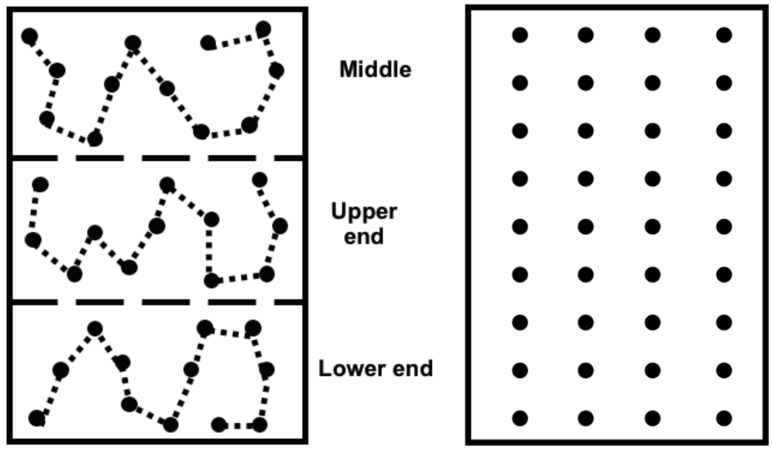


Figure 1. On the left: dividing and sampling scheme for a sloped field with distinct upper, middle, and lower areas. Circles represent sub-sample locations which are composited for each of the three areas. On the right: grid-sampling a field. Each sample is analyzed separately to evaluate field variability.

to a laboratory for analysis. Soil samples can be refrigerated for several days if they cannot be dried immediately.

When is the best time of year to collect soil samples? Soil test values change slightly during the year, but the primary consideration for timing for most soil sample collection is convenience (nitrogen tests are an exception, see below). Collect samples early enough in the cropping cycle to allow results to be used to adjust management practices.

How frequently should soil samples be collected? The frequency with which soil samples should be collected depends on the specific soil test, environmental conditions, and value of the crop. Status of some soil nutrients can change quickly, whereas others do not. For example, phosphorus levels in soil are unlikely to change rapidly and annual testing may be unnecessary. Nitrogen levels, on the other hand, change very quickly and frequent tests are required to obtain accurate determinations of plant-available levels. A new soil analysis might be necessary after heavy rains or after a prolonged period of water-logging if one needs an accurate measure of soil nitrogen.

When making substantial changes to soil fertility levels, it is a good idea to make the change over a period of two to three years, retesting the soil annually. If a crop does not have a high economic value, then occasional soil testing (once every 3 to 4 years) may be adequate in the absence of any noticeable nutritional problems. In contrast, commercial production of high value crops may warrant annual testing to ensure maximum yields.

## Soil Analyses

After soil samples are received at a laboratory, a number of tests can be performed. A general understanding of soil testing will help you know how the results can be interpreted and to appreciate the accuracy of analytical results.

Soils supply most of the mineral nutrition for higher plants through the plant's root system. The root system extracts nutrients from the soil over a long period of time; two to three months for most annual crops, years for perennial crops. In contrast, a soil test determines the soil's nutrient supplying capacity by mixing soil for only a few minutes with a strong extracting solution (often an acid or a combination of acids). The soil reacts with the extracting solution, releasing some of the nutrients. The solution is filtered and assayed for the concentration of each nutrient. The nutrient concentration is then related to field calibration research that indicates the yield level reached with varying soil nutrient concentrations. This method works very well for some nutrients, but is less accurate for others, for example those nutrients supplied largely from organic matter (OM) decomposition such as nitrogen and sulfur. This is primarily due to the difficulty of estimating or predicting the rate at which OM will decompose and release these nutrients in plant-available forms.

Individual analyses included in a 'standard' or 'routine' soil test varies from laboratory to laboratory, but generally include soil pH, and available phosphorus (P) and potassium (K). They sometimes also include available calcium (Ca) and magnesium (Mg), salinity, and often include an analysis of OM content and soil texture. Most laboratories offer nitrogen (N), sulfur (S), and micronutrient analyses for additional cost.

The methods used to test soils vary depending on chemical properties of the soil. For example, tests used for measuring soil P are quite different in the acidic soils common in the southeastern U.S. than those used in the alkaline soils of the southwest. Analysis of southwestern soils with methods tailored for acidic soils will provide erroneous results. Therefore, it is important to be aware of the methods used by test labs, and to select methods that are regionally appropriate. Local laboratories will generally use methods appropriate for your soils and your laboratory should provide you with test method information. A listing of local soil test laboratories may be found in the University of Arizona publication, "Laboratories Conducting Soil, Plant, Feed or Water Testing" (AZ1111) **http://cals.arizona.edu/pubs/garden/az1111.pdf .**

Nutrient levels are usually expressed on a mass (weight) basis using units of parts per million (ppm). These can be converted to a molar basis by dividing ppm by the molecular weight to get mmol/L (for liquids) or mmol/kg (for solids). Another useful unit for expressing nutrients is centimoles of charge per kilogram of soil ($cmol_c/kg$). To calculate $cmol_c/kg$, divide ppm by the molecular weight and then multiply this value times the charge on the nutrient ion. Older literature uses meq/100g, which is identical to $cmol_c/kg$.

| Element | K | Ca | Mg | Na |
|---|---|---|---|---|
| Molecular Wt | 39.1 | 40.1 | 24.3 | 23 |
| Charge/molecule | 1 | 2 | 2 | 1 |

## STANDARD SOIL TESTS

### pH

Soil pH is a measure of the acidity or alkalinity of a soil. The term pH applies to solutions, so the analysis must be conducted on a soil/water mixture. The soil sample is mixed with water, allowed to equilibrate for at least an hour, and then the pH measured. Several factors affect pH measurement. Primary among these is the salt concentration of a soil (a salt is any molecule that, when placed in water, separates into positively and negatively charged components or ions). The salt concentration of a soil may vary with the season or with fertilizer application, and is generally greater immediately following fertilizer application than before. The result may be an apparent pH drop up to one-half a pH unit.

When samples are collected frequently or at various times of the year it may be noted that pH values tend to increase and decrease, seemingly at random. This can lead to questions regarding the reliability of soil pH measurements, but the fluctuations may be due to changes in soil salt levels and do not usually present a serious problem in the use of the analysis. Some laboratories measure pH in a dilute salt solution to mask salt-induced variations. This method gives lower pH values for which the laboratory should provide interpretation guidelines.

Arizona soils are generally alkaline (high pH), and pH adjustment is not a common practice. In most other parts of the country, ground limestone is routinely added to soil to raise soil pH. In those parts of the country, "lime requirement" (amount of lime required to adjust the soil pH to a desired level) is determined. This test is not needed for alkaline Arizona soils.

### Electrical Conductivity (EC)

Electrical conductivity (EC) of a soil extract is used to estimate the level of soluble salts. The standard method is to saturate the soil sample with water, vacuum filter to separate water from soil, and then measure EC of the saturated paste extract. The result is referred to as $EC_e$ and is expressed in units of deciSiemens per meter (dS/m). Older literature will likely use units of millimhos per centimeter (mmho/cm), which are identical to dS/m. Some test laboratories use different soil:water ratios, and use a multiplication factor to convert results to an $EC_e$ equivalent.

EC is a very reliable test for soil salinity, and this is a routine test in the arid southwest. However, in wetter climates EC is not a standard test so, if soil samples are sent to a laboratory in another part of the country, EC may have to be specifically requested.

### Nitrogen (N)

Nitrogen analyses are not difficult to conduct, but interpreting results can be problematic. This is because a major portion of soil N is contained in the soil OM. Plant availability of organic N is dependent on OM breakdown, which is difficult to estimate. Therefore analyses of "total N", a sum of all forms of soil N, including organic N, are not routinely conducted. Instead, N in the nitrate form ($NO_3$-N) is assayed. Nitrate is directly available to plants, so this test provides an indication of short term N availability. However, $NO_3$-N can be quickly lost from soil, either leached past the rooting zone, or lost to the atmosphere in gaseous forms.

Nitrate analyses can provide an accurate determination of the N available to plants at the time of soil sampling, although this may not provide reliable information concerning N availability later in the growing season. If soil N analysis is to be used for making fertilizer recommendations, soil samples should be collected either shortly before planting time or during the growing season.

The extractant used to remove $NO_3$-N from the soil is not particularly important because of its high solubility. Some laboratories extract $NO_3$-N from soil with a salt solution, such as potassium chloride (KCl). However, other laboratories in the southwestern U.S. measure $NO_3$-N in the same extract used to measure soil P (see below) to reduce analysis costs. Results from these two kinds of extractants are directly comparable.

### Phosphorus (P)

Most soil P is tightly bound to soil particles or contained in relatively insoluble complexes. The P-containing complexes in alkaline soils are very different than those in neutral or acidic soils. The amount of P removed during soil extraction is very much dependent on the nature of P complexes and on the specific extractant used, so it is critical that P extractants be matched to soil properties.

The Olsen or bicarbonate extractant, a dilute sodium bicarbonate solution, is used to extract P from calcareous, alkaline, and neutral soils, and is appropriate for Arizona soils. In contrast, most other P extractants, such as the Mehlich extractants, are suited for acidic soils, and may not be suitable for arid-region soils. If an appropriate extractant is selected, P analysis is a reliable and useful soil test. On a soil test report, the analysis may be reported as $PO_4$-P.

### Potassium (K), Calcium (Ca), Magnesium (Mg), and Sodium (Na)

The four major exchangeable cations in arid-region soils are K, Ca, Mg, and Na. All except Na are essential plant nutrients; however Na is included here because it plays an important role in soil physical properties. Soil Na level is needed for calculations of cation exchange capacity (CEC) and exchangeable sodium percentage (ESP), discussed later.

An ammonium acetate extractant is used to extract exchangeable K, Ca, Mg, and Na from arid-region soils, but it does not extract less plant-available forms. Some difficulty may be encountered in soils containing Ca or Mg carbonates (calcareous soils) because the ammonium acetate extraction may remove some Ca or Mg from these minerals along with the exchangeable forms. In these situations, the analytical results may indicate slightly elevated levels of these nutrients. Some laboratories adjust the pH of the ammonium acetate extractant to 8.5 to minimize this error. However, this is not usually a large problem and K, Ca and Mg tests generally provide excellent estimates of plant available levels of these nutrients.

## Cation Exchange Capacity (CEC)

Cation exchange capacity is often estimated by summing the major exchangeable cations (K, Ca, Mg, and Na) using units of $cmol_c/kg$. Most laboratories do not routinely conduct a separate analysis for CEC, but use the ammonium acetate extractable levels of these elements (discussed above) for this calculation.

## Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR)

ESP and SAR are measures of soil Na content relative to other soil cations. ESP is the concentration of Na divided by the CEC. As described above, the CEC is often estimated as the sum of the major exchangeable cations, so ESP = Na / (K+Ca+Mg +Na), in units of $cmol_c/kg$. SAR is roughly comparable to ESP, but is a ratio of Na to Ca plus Mg. For this calculation, concentrations of Na, Ca, and Mg are measured in a saturated paste extract (see discussion of EC, above). The equation used for calculation of SAR is:

$$SAR = \frac{[Na^+]}{\sqrt{[Ca^{2+}] + [Mg^{2+}]}}$$

where concentrations are in units of mmol / kg or mmol / L. SAR and ESP are both very useful measures of the influence of Na on soil properties. The choice between the two is based largely on the type of extraction used for cation analyses. SAR can be used with either soil or water samples, whereas ESP is applicable only with soils.

## Free Lime

Free lime is a measure of soil carbonates (salts of $CO_3^{2-}$). When combined with an acid, carbonates release gaseous $CO_2$. The test usually performed for soil carbonates is semi-quantitative. A weak acid solution is applied to the soil sample, and the degree of 'fizzing' or release of $CO_2$ gas is determined visually and categorized as 'none', 'low', 'medium', or 'high'.

# OPTIONAL SOIL TESTS

## Sulfur (S)

Sulfur, like N, may be contained primarily in the soil OM, but plants absorb only the inorganic sulfate ($SO_4^{2-}$) form. Measuring total soil S does not provide a good estimate of S plant availability because rates of release from OM cannot be accurately predicted. Instead, S in the sulfate form is a more common measure. Sulfate can be extracted from the soil with several extractants, including water or weak salt solutions. Analysis of $SO_4$-S is relatively easy, but it usually provides a measure of immediately available S, and not the soil's long-term ability to provide S to a growing plant. Some desert soils contain large quantities of sulfates, in which case sulfate analysis gives a good indication of the soil's ability to supply S.

## Micronutrients

**Copper (Cu), Iron (Fe), Manganese (Mn), and Zinc (Zn) —** Micronutrient analysis is optional at most laboratories. Most laboratories in our region use a DTPA-TEA (diethylenetriamine pentaacetic acid - triethanolamine) extractant which uses the chelating agent DTPA to extract available Fe, Cu, Mn, and Zn from soils.

Analyses of these micronutrients are probably less accurate for predicting the likelihood of plant deficiencies or of crop responses to supplemental application of these nutrients than analyses of macronutrients such as K, Ca, and Mg because of 1) the influence of dynamic soil conditions, and 2) the importance of genetically controlled plant micronutrient uptake mechanisms. For example, Mn availability can change substantially if soil drainage status is altered, becoming more available in waterlogged soils, and less available in dry soils. Iron availability is also affected by soil moisture and irrigation practices. Furthermore, availability of Cu, Fe, Mn, and Zn are greatly affected by soil pH, so soils may need to be re-tested if soil pH is significantly altered. Soil testing can not reliably predict the effects of altering management practices on availability of these nutrients. Additionally, plants vary considerably in their ability to extract metal micronutrients from soil. For example, it is not unusual for a tropical plant to exhibit iron deficiency while an adjacent desert adapted plant does not, even though soil conditions are identical for both plants.

**Boron (B) —** The most common method of extracting B from soils is with hot water. This is an accurate test, but soil B levels can change rapidly. Boron is highly water soluble and can quickly be leached from the rooting zone, or moved laterally during monsoon rainfall events. Therefore, extractable soil B provides estimates of plant availability that are less reliable than those of many other nutrients, not because of shortcomings with the analytical method, but because of rapid B movement in the soil.

**Molybdenum (Mo)—** Few laboratories conduct soil Mo analysis. Molybdenum is present at very low levels in most soils, much lower than most of the other nutrients, making an accurate determination difficult. Most plants have a low requirement for Mo, and slight differences in soil Mo levels can impact plant performance. Therefore soil tests for Mo are of limited use and are seldom conducted.

## Organic Matter (OM)

The OM level of a soil can be determined by several analytical techniques which are quite accurate. All measure the amount of soil OM or the carbon it contains, but most do not determine its nature or how it will contribute to soil fertility. Levels of nutrients contained in the soil OM can be determined, but usually are not because rates of mineralization (nutrient release) from OM which are influenced by weather and climate cannot be reliably predicted. Organic matter content is not routinely determined in southwestern soils because the levels are relatively low, and normally change very little.

## Summary

Soil analyses can provide information that is important for maximizing nutrient use efficiency and agricultural productivity. A historical record of soil properties provided by long-term soil testing is useful for determining the effectiveness of fertilizer management strategies in maintaining soil fertility and sustainable agricultural productivity. Soil testing is also a useful tool for indentifying the causes of nutrient related plant growth problems.

Soil sampling is the critical first step in a soil testing program. The second is selection of a laboratory that will utilize analysis procedures appropriate for regional soils and conditions. However, an understanding of the accuracy and limitations of individual procedures and of the meaning of soil test results is essential. This publication provides information on these components of a soil testing program. The last steps, interpreting soil analysis values and developing a fertilizer management program, are crop specific and sometimes dependent on additional soil and climatic properties, and are beyond the scope of this document.

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