Soil Testing

by Dr. Paul Fixen

SECTION CONTENTS:

Introduction

In a broad sense soil testing is any chemical or physical measurement that is made on a soil. The agronomic purpose of soil testing is to determine the relative ability of a soil to supply crop nutrients during a particular growing season, to determine lime needs, and for diagnosing problems such as excessive salinity or alkalinity. Soil testing is also used to guide nutrient management decisions related to manure and sludge application with the objective of maximizing economic/agronomic benefits while minimizing the potential for negative impacts on water quality.

Soil test results provide the basic facts on which fertilizer and lime needs are determined. The results can be expressed in such a way that they permit an economic evaluation of the suggested lime and fertilizer recommendation.

Soil testing, therefore, is an important tool in high yield farming. Confidence in soil tests must be maintained. Yet, we must avoid creating the impression that soil tests and the resulting fertilizer recommendations are something they are not. The soil test is a helpful diagnostic tool just like a thermometer or a stethoscope for the doctor. But all such tools require skill plus common sense in their use and interpretation-plus a realistic approach to the needs and goals of the grower.

Sampling

The soil testing program starts with the collection of a soil sample, or samples, from a field. The first basic principle of the soil testing program is that a field can be sampled in such a way that chemical analysis of the soil sample or samples will accurately reflect the field's true nutrient status. This does not mean that all of the samples must, or will, show the same test results, but rather that the results must reflect true variations within the field. Remember that soil test lime and fertilizer recommendations can never be more accurate than the accuracy of soil sampling.

(Note: A separate chapter in the EFU Manual is devoted to soil sampling.)

Extraction and Chemical Analysis

Once the soil samples have been collected and prepared, the level of available nutrients in each sample must be determined. Many chemical methods have been suggested, and are being used, for the measurement of essential plant nutrients. The criteria for chemical extracting and analysis of plant nutrients are that it must be rapid, accurate, and reliable.

Most chemical extracting methods allow the extracting solution, which may consist of water, alkali, weak or strong acid or combinations of these chemicals, to react with the soil sample a relatively short time. The sample is then filtered and the solution analyzed for the available nutrients.

Most Mid-Atlantic and southeastern states use a weak acid extracting solution which consists of 0.05 M HCl and 0.0125 M H_2SO_4. This solution is named Mehlich No. I (or Double Acid) and is used to extract P, K, Ca, Mg, Mn and Zn. Other extracting solutions, and usually a separate one for each determination, are used to measure sulfur, boron, organic matter, and copper. A more recently developed procedure in use in some states and being considered by others is the Mehlich No. III. It consists of 0.015 M NH_4F + 0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.013 M HNO_3 + 0.001 M EDTA and extracts Cu as well as the elements extracted by Mehlich No. I.

Most Midwestern states use the Bray I solution for extracting phosphorus. This solution consists of 0.03 M NH_4F in 0.025 M HCl. Potassium, calcium and magnesium are usually extracted with 1 M NH_4OAc at pH 7.0. Zinc is usually extracted with 0.1 M HCl or DTPA (0.005 M DTPA + 0.1 M TEA + 0.01 M $CaCl_2$).

In regions having calcareous soils, such as the western Corn Belt and Great Plains, the Olsen test is usually used to extract P. This procedure utilizes a base, 0.5 M $NaHCO_3$, which is not neutralized by the free lime in calcareous soils as is often the case with acid extracts such as the Bray I. Calcareous soils will often cause the Bray procedure to give a false low test level because the acid extractant is neutralized before it has a chance to dissolve soil P.

Distilled water and 2 M KCl are the most common extractants for soil nitrate. Since nitrate is highly soluble in water, stronger reagents are not required.

The extracting solution for manganese in most Midwestern states is 0.033 M H_3PO_4 or DTPA. Measurements of soil sulfur, boron, organic matter, and copper require additional and usually different extracting solutions than for the other soil test measurements.

In addition to extracting solutions, several other parameters of each soil test are important in determining the final number that is printed on a soil report for any one soil sample. These parameters include ratio of soil to extractant, shaking time, action and speed, method of expressing the results (e.g. lb/acre, ppm, index systems), "cut-off" levels for high test results, and overall techniques used in the lab. For those with more interest in this area, a good reference is Handbook on Reference Methods for Soil Analysis, third edition, 1992, The Soil and Plant Analysis Council, Inc., Georgia University Station, Athens, GA 30612-0007.

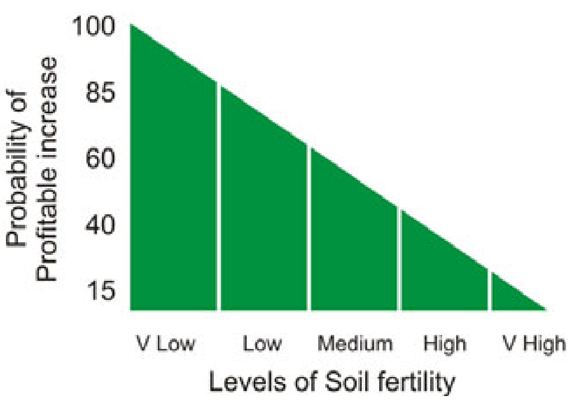
The extractants containing the dissolved plant nutrients are analyzed to determine the concentration of the plant nutrient(s). Results are usually reported as parts per million (ppm), or pounds per acre (lb/acre). For most nutrients, ppm may be converted to lb/acre by multiplying by two (40 ppm of potassium = 80 lb/acre). For nitrate, sulfate and chloride, essentially all the nutrient form present in the soil is extracted and depth increments other than the standard 6 to 7 inch surface layer are sampled. For these measurements, ppm is converted to lb/acre by the following formula: lb/acre = ppm x 0.3 x depth increment in inches. For example, a 10 ppm nitrate N test on a soil sample taken to a 24 inch depth would convert to 72 lb/acre (10 ppm x 0.3 x 24 inches). In this case 72 lb/acre of nitrate nitrogen were present in the top 24 inches of the soil sampled.

Laboratory techniques in soil testing methods vary widely. Actually, techniques are important only to the extent that they lead to an accurate measurement of the available plant nutrients. There are many ways of chemically determining a nutrient in a soil extract and many techniques for extracting available nutrients from the soil, but only those combinations of methods and techniques that lead to accurate and reproducible results are acceptable.

In summary, extracting available plant nutrients helps give an educated estimate as to the amounts of plant nutrients that will be available to a particular crop during the growing season. The amount of plant nutrients extracted will depend on the strength of the extracting solution and the various other parameters mentioned earlier. A strong acid extracting solution will dissolve more plant nutrients from the soil sample than a weak acid extracting solution. The soil test that works best is determined by results of correlation research which determines crop response to applied amounts of plant nutrients at varying soil levels of the plant nutrient being measured. Consequently, it is erroneous to interpret soil test values in pounds per acre as a real number. This is a relative number and should be interpreted as low, medium or high for a particular plant nutrient. Extracting plant nutrients gives numbers, but unless these numbers are correlated with crop response to applications of the plant nutrients measured, the results are agronomically meaningless.

Calibration and Interpretation

Perhaps the greatest challenge in a soil testing program is calibration of the tests. It is essential that the results of soil tests be calibrated against crop responses from applications of the plant nutrients in question. This information is obtained from field and greenhouse fertility experiments conducted over a wide range of soils. Yield responses from rates of applied nutrients can then be related to the quantity of available nutrients in the soil.



The probability of a response to fertilization is related to soil test results as illustrated in the figure below.

In this example more than 85% of the fields testing very low in a particular plant nutrient may give a profitable yield response to the added nutrient while at the very high level there is only a 15 percent probability of a profitable yield increase to the applied nutrient. These values are arbitrary, but they illustrate the idea of expectation of response.

The results of long-term soil test calibration studies on different soil types are then utilized to establish recommended amounts of plant nutrients to apply to a particular crop at a given soil test level. For instance, if the soil test P level is in the range of 0-10 ppm (which is low), the P recommendation for a 150 bu/acre corn crop may be 100 lb/acre P_2O_5; whereas if the soil test P level is above 40 ppm (very high) the recommendation may be 0 to 20 lb/acre.

Recently researchers have determined that the soil test level variability within the field area from which a composite soil sample is collected can markedly influence optimum fertilizer rates. The response probabilities reported in the above figure are based on small research plots where variability within the area sampled is minimal. Research has shown that as variability within the area sampled increases, fertilizer response or need also increases. For example, in an extensive Ontario study, the standard K recommendation for corn based on small plots dropped to zero at a soil test of 135 ppm but approached 60 lb/acre K_2O for fields of high soil test variability. The scientists concluded that calibrations obtained from sites with low variability would "under-predict" the optimum fertilizer rate for maximum economic yields for sites with high variability of soil tests.

Since cultural factors such as tillage system, hybrid or variety, and planting date can influence crop response to nutrients, soil test calibration must be an on-going process where the calibration is modified as cropping systems and practices change. The potential also exists for a direct impact of yield potential on soil test calibration. Classical theory states that for soil immobile nutrients like phosphate or potassium, the relationship between soil test level and relative yield should not vary with yield potential. Since roots normally occupy less than one percent of the soil volume, an increase in size of the root system translates into a greater volume of soil phosphate or potassium being available for uptake. Therefore, as long as the size of the root system increases proportionally with yield, a higher yielding crop should not need a higher phosphate or potassium concentration at the root surface and should not need a higher soil test level for a given relative yield. However, if shoot growth increases exceed root growth increases as yields climb, higher soil test levels could be required to meet nutrient inflow demands. This uncertainty underscores the importance of relevant soil test calibration research conducted in an appropriate yield range for today’s progressive farmers. For example, soil tests calibrated for 140 bushels of corn per acre, when farmers are interested in 200 bushels, may not be valid.

The tools of site-specific precision management now allow growers to manage more homogenous areas within fields. Some of those areas have much higher yield potentials than the database with which most of today’s soil tests were calibrated. This lack of calibration for high yielding areas of fields is one of the factors driving the increased interest in using yield monitors and global positioning satellites to conduct strip trials to determine the adequacy of existing soil fertility programs.

When interpreting soil test results, several things should be kept in mind:

- The chances of getting a profitable response to fertilization are much greater on a soil that tests low in a given nutrient than on one that tests high.
- This does not rule out the possibility of a profitable response from nutrient application at a high level of fertility or lack of a profitable response on soils of low fertility.
- Soil tests are better at predicting the probability of a profitable response to nutrient application than they are at predicting the actual quantity of nutrient that will be needed in any one year.
- Research in the U.S. and Europe shows that in any one season, a soil testing low in a nutrient often will not yield as well as a soil testing at an optimum level no matter how much fertilizer is applied that year.
- Interpretation of soil test results and recommendations often becomes a matter of how to improve the fertility status of soils testing less than optimum. How much will be needed to change the soil from low to medium or high in that element? What will be the most economical level at which to maintain the nutrient status of the soil?
- With top-level management practices, yields increase and the probability of a response at any given soil test likewise increases.
- Because of the above facts, wise use of soil testing incorporates a long-term approach to fertility management in which site-specific soil test target levels are established for each field or field area and nutrient management plans developed to attain and maintain the target levels.

Recommendations

The basic philosophy of soil test fertilizer recommendations is to:

- Base them on soil test results;
- Recommend that lower testing soils be built up to higher test levels by adding extra fertilizer;
- Apply maintenance amounts of plant nutrients to higher testing soils to keep them there and to keep productivity high;
- Not apply specific nutrients to soils testing very high in these nutrients.

Likewise, the goal of a soil testing program is to help farmers achieve economical optimum yields while protecting the environment.

At one time recommendations from soil tests were made only by highly trained technical people who also ran the chemical tests. Now, other groups make these recommendations after receiving special training. This offers certain advantages. It can permit recommendations from a person with first-hand knowledge of the farmer and the farmer's problems - a person who can follow up on results obtained.

Also, many farmer-businessmen want more than a fertilizer recommendation. They want a complete set of plans to meet a high yield goal. This calls for the inclusion of all relating factors - proper variety, cultural practices, time of planting, proper use of pesticides, etc. Under these circumstances, crop advisers may be used by farmers to sample the soil, and also the plant, and to monitor the crop throughout the season. This has added a new dimension to soil test interpretation, but the crop adviser should be well informed and experienced in the use and interpretation of soil tests.

Two scientists could recommend different rates of nutrients from the same soil test, depending on many factors such as yield goals, nutrient building or depleting plans, and especially the type of farmer for whom the recommendations are being made. It is hard to visualize a medical doctor making a diagnosis on the basis of a blood sample mailed in by a patient, analyzed, and run through a computer. The doctor would want to see the patient, ask questions, get a history, and use the blood analysis as a diagnostic aid. Likewise, the person making a fertilizer recommendation should consider all available facts, not just the soil test. In addition, some interpreters use soil tests to see how much fertilizer can profitably be applied, while others use soil tests to see how little fertilizer the farmer can get by with.

The objective of individualization of fertilizer recommendations is to substitute site and grower information for many of the assumptions and generalizations inherent in any laboratory generated recommendation. Computer programs are available that facilitate the personalization of recommendation development by considering the following factors:

- Soil test calibration relevancy. How appropriate is the calibration used in the standard recommendation for the field in question? Unusual soil types, a different climate, no-till or ridge-till culture, crop variety, cropping history, and field variability are examples of factors that could cause differences.
- Yield potential. This determines the economic value of each percentage change in relative yield and may influence the shape of the calibration curve as discussed earlier.
- Fertilizer placement. Band placement often reduces lost yield as sub-optimal soil test levels are built to optimum levels because the short-term recovery of applied fertilizer by crop plants is improved. Some recommendation systems reduce the rate recommended when banding is used compared to broadcast application. However, rate studies have shown that the optimum rate when banding is sometimes equal to or greater than the optimum broadcast rate. The wise producer builds soil test levels to optimum regardless of placement method used.
- Farmer financial circumstances. The financial objective of farmers, like other investors with limited capital, is to maximize the return on the last dollar invested considering all possible investment alternatives and their associated risk. Therefore, the cash flow of the farmer influences fertility management decisions. A farmer with very limited capital has high opportunity costs and often needs

to follow a relatively conservative nutrient management plan. A well-established farmer with abundant capital and relatively low opportunity costs such as those typical of mutual fund returns could follow a more aggressive plan.

- Land tenure. Land tenure in this sense refers to the period of time the grower will be farming the field. Soil test phosphate and potassium are capital investments and build-up costs should be amortized over the expected time of ownership or operation. The longer the period of time benefits will be accrued from build-up, the lower the cost of buildup becomes and the higher the optimum soil test level becomes. Land owners and operators, as well as the environment, benefit from the development of agreements where the costs and returns of soil test buildup are equitably shared. Such agreements can help avoid the loss of productivity and accelerated erosion typical of run-down farms having impoverished soil fertility.
- Soil test buffer potential. This is the quantity of fertilizer required to change the soil test level and is usually expressed as lb P_2O_5 or K_2O required per ppm of soil test level change. Some low pH and some high pH soils fix applied phosphate readily and increasing soil test phosphate is more costly, decreasing the optimum soil test level. Soil test phosphate and potassium levels are usually easier to change in sandier soils than on medium or fine-textured soils except with very sandy soils where potassium leaching becomes significant.
- Goals of the farmer. We usually assume the goal is to optimize profitability by making nutrients non-limiting to yield and quality for the field in question but that is not always the case. Individual goals may be influenced by land ethic, tax management strategy, attitudes concerning risk, over-all management style, and other considerations.

Today's successful farmer wants to keep soils in shape to produce high yields. Most do not want yields to decrease due to a deficiency or imbalance of elements. Most do not want to fall back to an "average" yield and then get response to nutrient application. Rather, the objective is to build nutrient levels to an optimum and maintain them once there.

Recommendations When Levels Are High

One might ask, "If my soil tests high in a plant nutrient, should I add more?" This depends on what is meant by "high." If it means there is an abundance of the nutrient present to the extent that there is almost no chance of response even if the nutrient was not applied for several years, then it might be well not to apply any more, at least for the current crop.

However, some laboratories assign the value "high" not to such very high conditions but to a level at which the odds point to little or no response to applications of that nutrient that year.

Failure to apply any of these nutrients will result in soil test depletion. Also, under some conditions crops will respond profitably to a nutrient even with a high test. For example, on early-planted corn the addition of N, phosphate and potassium as a row application may produce response on soils testing high.

Fertilizer application when soils test in the "high" range, as defined in the previous paragraph, is influenced substantially by the factors discussed in the section on individualization of recommendations. Maintenance in the high soil test category will be appropriate for some growers and sites but not for others.

Summary

- A soil test measures the relative soil fertility level of a field or area within a field.
- Soil tests are very useful diagnostic tools and that is just what they are …tools. To consider a soil test as an infallible predictor of optimum nutrient rates is to misuse it.
- For soil testing to be even more helpful and reliable in high yield agriculture, there must be more long-term calibration research at high yield levels where the optimum fertility levels for the soil profile can be defined. This becomes even more important in site-specific management where we must learn how to manage the highest yielding areas of high yielding fields as well as the lower yielding areas.
- Generally in fertilizer recommendation development, the goal is to maintain plant nutrients at a level where the supply will not be a limiting factor at any stage of plant growth from germination to maturity.
- Soil test interpretation and recommendation development should be done on a site-specific long-term basis where the characteristics of both the site and the farmer are considered.
- Soil tests are important in planning a long-term fertility program. Sampling periodically and maintaining records of fertility levels, yields, and all management practices is a must.

LINKS TO OTHER EFU CHAPTERS			
• Appendices • Authors • Environment • Fertigation • Fluid Dry Fertilizers	• History of Fertilizer • MEY – Maximum Economic Yields • Micronutrients • Nitrogen • pH	• Phosphorus • Potassium • Soil Sampling • Secondary Nutrients • Site Specific Farming	• Soil Defined • Soil Testing • Tillage Systems