Interpreting Soil Tests for Efficient Plant Growth and Water Use

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Denise McWilliams, Extension Agronomist

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Rio Grande Regional Soil and Water Series

Optimizing Plant Growth for Efficient Water Use
Contain, retain and conserve. Water resources—worth recouping.

Using soil test results allows growers to maintain the fertility status of a field or area sampled; predict the probability of obtaining a profitable response to fertilizer; provide a basis for fertilizer application recommendations; and evaluate the soil fertility and tilth of a field or area. This evaluation is especially useful when several tests are conducted over time, and the historical summaries document the soil's status. In other words, soil testing allows a nutritive soil value to be obtained that can help predict the amount of fertilizer needed to supplement the soil for optimal plant growth and yield.

The test report from an analyzed soil sample shows the lab results, the nutrient rates recommended and any additional information from the lab that might be pertinent to the sample.

Most labs provide the codes and descriptions of soil test interpretation categories for phosphorus, potassium and other mineral elements on a scale, which is accompanied by a probability of yield increase similar to that shown in table 1.

Table 1. General soil test result interpretations for soil nutrient levels.

Category			Probability of
Name	**Symbol**	**Description**	**Yield Increase[1]**
Very Low	VL	Substantial amounts of nutrients are required to optimize crop yield. Buildup occurs over five to eight years. Response to secondary or micronutrients is likely for high- or medium-demanding crops.	>90
Low	L	More nutrients are required than are removed during crop harvest. Response to secondary or micronutrients is possible for high-demanding crops but unlikely for medium- or low-demanding crops.	60-90
Optimum	Opt	This is economically and environmentally the most desirable soil test category. Nutrient additions are approximately equal to amounts removed during crop harvest. Response to secondary or micronutrients is unlikely.	30-60
High	H	Some nutrients are required, and returns are optimized at rates equal to about one-half of that removed by the crop.	5-30
Very High	VH	Used only for potassium. Soil tests are above optimum. Gradual drawdown is recommended. The rate should be about one-fourth of the nutrient removed.	~5
Excessively High	EH	No fertilizer is recommended, ample supply will last in most soils for at least two to three years.	<2

[1]Percentage of fields that can expect to show a profitable yield increase when recommended nutrients are applied.

Table 2. General soil pH crop preferences.

Crop	Minimum pH Limit	pH Range Preferred	Maximum pH Limit[1]
Alfalfa	5.5	6.2-7.8	8.5
Beans (dry)	5.0	6.0-7.5	—
Beets (sugar)	5.5	6.5-8.0	8.5
Cabbage	—	6.0-7.5	—
Cantaloupe	5.5	6.0-7.5	—
Carrots (garden)	5.0	5.5-7.0	—
Celery	—	5.8-7.0	—
Clover	—	5.0-6.0	—
Corn (Indian)	5.0	5.5-7.5	—
Corn (pop)	—	6.0-7.5	—
Corn (sweet/field)	5.0	5.5-7.5	—
Cotton	—	5.0-6.0	—
Cowpea	4.5	5.0-6.5	7.0
Eggplant	—	5.5-6.5	6.0
Grass (Bermuda)	—	6.0-7.0	—
Grass (buffalo)	—	6.0-7.5	—
Grass (orchard)	5.5	6.0-7.0	8.0
Grass (pampas)	—	6.0-8.0	—
Grass (perennial rye)	5.0	6.0-7.0	8.0
Grass (Timothy)	—	5.5-8.0	—
Kohlrabi	—	6.0-7.5	—
Lettuce	5.5	6.0-7.0	8.0
Oats	4.5	5.0-7.5	—
Pea (field)	5.5	6.0-7.5	—
Peanuts	—	5.3-6.6	—
Pecans	—	6.4-8.0	—
Peppers (sweet)	—	5.5-7.0	—
Radishes	5.0	6.0-7.0	—
Rye	4.5	5.0-7.0	8.0
Soybeans	5.5	6.0-7.0	—
Sunflowers	—	6.0-7.5	—
Vetch (hairy)	4.5	5.2-7.0	—
Wheat	5.0	5.5-7.5	—

[1]Some of the maximum pH limits are set for disease control.

Source: Spurway, C.H. 1941. Soil reaction (pH) preferences of plants. Spec. Bull. 306, Mich. State College, East Lansing, Mich.

Table 3. Soil analysis interpretations for secondary nutrients.

Element	Very Low (VL)	Low (L)	Optimum (Opt)	High (H)	Excessively High (EH)
Calcium	0-200	201-400	401-600	>600	—
	0-300	301-600	601-1000	>1000	—
Magnesium	0-25	26-50	51-250	>250	—
	0-50	51-100	010-500	>500	—
Boron	0-0.2	0.3-0.4	0.5-1.0	1.1-2.5	>2.5
	0-0.3	0.4-0.8	0.9-1.5	1.6-3.0	>3.0
	0-0.5	0.6-1.0	1.1-2.0	2.1-4.0	>4.0
Zinc	0-1.5	1.6-3.0	3.1-20	21-40	>40
Manganese (organic matter, O.M.<6%)	—	0-10	11-20	>20	—
Sulfur[1] (avail. index)	—	<30	30-40	>40	—

[1]Sulfur availability index includes estimates from organic matter, precipitation, subsoil sulfur and sulfur in manure if applied, as well as SO_4-S by soil test.

Nutrient shortages can lower crop yield and quality markedly. For example, potassium deficiencies can be linked to poor winter survival of alfalfa, lowered disease resistance, and increased lodging in corn and other grains. On the other hand, excess elements can reduce yields by causing imbalances. Excessive boron, manganese, copper and zinc can be toxic. Once soil testing reveals that nutrients are at a "high" level, adding more is of little benefit.

Most standard soil tests give no interpretations for nitrogen, organic matter or pH. Recommended fertilizer application rates are estimates of average crop needs. The optimum pH for many crops grown in New Mexico and West Texas are listed in table 2.

Crops differ in their nutrient demands and rooting depths. Therefore, the subsoil can contribute significantly to crop nutrition. In deep-rooted crops, the phosphorus and potassium levels in the plow layer where the sample soil was taken are not good indicators of nutrient status. Instead many labs use the subsoil fertility groups to estimate probable nutrient load available for a specific crop. So, if the soil type is known, it is best to include it on the information form accompanying the soil sample to the lab. If the soil name is not given, the lab may select a soil group based on soil pH, soil texture, organic matter and county of origin. These subsoil fertility groups also may be used to determine nutrient buffering capacities to indicate how much phosphate or potash is required to raise soil test P or K to an optimum level.

More detailed soil tests than the standard are available for secondary nutrients (calcium, magnesium and sulfur) and trace nutrients (zinc, boron and manganese). Some general test interpretations are included in table 3.

Some labs may not have soil test calibrations for copper, molybdenum or chlorine, depending on where the majority of their soil samples originated. Such deficiencies usually are rare. But if they are suspected due to plant symptoms, find a laboratory that can test for these nutrients.

General Soil Analyses and Terms

Boron is extracted using hot water with adequate levels ranging from 1 to 1.5 parts per million (ppm). Boron deficiencies are more common on sandy, low organic matter soils and soils with pH levels of 7 or above. Treatments usually are broadcast or foliar applied as boron's spectrum from deficiency to toxicity is very narrow.

Cation exchange capacity (CEC) and percent base saturation are terms used to describe a soil's nutrient exchange characteristics. CEC is determined by both the soil's clay and organic matter fractions. CEC is related to soil texture; sandy soils with small amounts of clay have low CEC values, and heavier-textured soils (silts, loams, clays) have higher CEC values. The type of nitrogen fertilizer is affected by the CEC value, low CEC (<5 meq/100 grams) soils, the retention capacity within the application zone, and ammonia loss to the atmosphere. Deeper application depths may be required in these soils. Indeed, nitrogen losses are a greater concern on low CEC soils. Also, potassium may leach more readily in these soils, possibly leaving the root zone because there aren't enough exchange sites. High CEC soils, on the other hand, also may have slow permeability to water and poorer internal drainage due to the classic high CEC soil characteristics. During warm periods in the field, denitrification can occur readily and available nitrogen losses may occur rapidly as nitrogen converts to nitrate. Also, in high CEC soils, nitrogen's ammonium form is immobile and, thus, not so readily available throughout the rooting region. High CEC soils also make potassium quite immobile. Ideally, a soil contains 65-85 percent exchangeable calcium, 6-12 percent exchangeable magnesium, 2-5 percent exchangeable potassium, and 5-20 percent exchangeable hydrogen ions on the soil surface, so that nutrients are readily available for plant use.

Calcium, magnesium and sodium analyses commonly are reported in ppm, pounds per acre (ppa), or milliequivalents (meq) per 100 grams of soil. The testing commonly involves an extraction technique that displaces the adsorbed cations with a concentrated salt solution. Calcium does act as a buffer cation. So in either sodic or acid soils, additional calcium is required to neutralize the condition.

Magnesium is associated with calcium and deficiencies usually occur only in acid, sandy soils where excessive leaching or recent lime or potassium applications have further reduced availability. Sodium can be a concern when it becomes a dominant cation, as in association with alkaline soils, such as those found regionally in New Mexico.

Copper extraction uses diethylenetriaminepentaacetic acid (DTPA), a compound that has the ability to chelate or sequester metallic ions, with sufficient levels of availability to plants from soils in the 1.2 to 1.8 ppm test range. Soil pH above 7, higher organic matter soils and even soils receiving high rates of nitrogen, phosphorus and zinc can all contribute to copper deficiencies. The need for copper also is very crop dependent. Once applied to deficient soils, however, applications are effective for several years.

Iron is extracted with DTPA; the optimum range in soil generally being 12 to 22 ppm. Soil pH is a factor that influences the interpretation of iron tests. Iron reacts quickly to become unavailable in soils, so chelated forms are more effective as soil treatments and foliar applications generally provide immediate results to plants.

Manganese is extracted using the DTPA process. Optimum levels range from 14 to 22 ppm. Soluble when applied, manganese quickly becomes insoluble and unavailable. Therefore, row or band treatments are more successful, especially if applied with other foliar fertilizer treatments.

Nitrate nitrogen (NO_3) analyses from laboratories are reported in ppm, ppa of actual nitrogen, or ppa of NO_3. Use table 4 to convert one reporting system to another.

Determining organic matter is useful for establishing herbicide rates and assessing nitrogen returns or credits in soils (although here in semiarid conditions, nitrogen return is low).

The Olsen test is used for determining phosphorus (P) levels by testing with calcium carbonate for alkaline soils. Or P may be tested with a weak acid extractant (one of the Bray P test procedures) for acid soils. This Olsen test is best for much of New Mexico and measures a portion of the readily available phosphorus in soil. The results are reported in parts per 2 million (pp2m) of P or ppm, equal to pounds per acre in a plow furrow slice 6 2/3 inches deep. Very high test values receive no recommendation because of the danger of plant nutritional problems, such as zinc deficiency, and because additions are simply uneconomical. Soils generally contain from 2,000 to 3,000 pounds per acre of total phosphorus (as P_2O_5) in the plow layer, but the amount contained in the soil solution normally is only 0.01 to 0.5 ppm (one pound per acre). The phosphate molecule reaction with calcium in alkaline soils, such as found in New Mexico, and with iron and aluminum in other acid soils further limits phosphorus solubility. In the soil's organic matter, phosphorus can be tied up even more. However, plants can use only a fraction of phosphorus present in the soil. So a total phosphorus measurement does not correlate with phosphorus availability. Thus, the process used to determine phosphorus records only a portion of the nutrient in the soil.

A normal neutral ammonium acetate extractant is used to measure water-soluble and exchangeable potassium (K). Samples run at field-moisture (undried) give lower soil test values but are better measures of available potassium. Results are in pp2m or ppm of K, equal to pounds per acre in a plow furrow slice 6 2/3 inches deep. Very high testing values receive no recommendation because of the danger of creating other nutritional problems, such as magnesium deficiency, in some crops. It also is uneconomical. Generally, labs give both buildup K application recommendations and maintenance K application suggestions based on the crop and the soil characteristics, primarily the cation exchange capacity (CEC).

Table 4. Nitrogen reporting conversions for ppm or ppa samples from a 6-inch soil depth soil sample.

NO_3-N (ppm)	NO_3-N (ppa)
5	10
10	20
20	40
40	80

Soil pH and buffer pH are two measures of soil acidity or alkalinity. The soil pH measures the degree of soil acidity or the active hydrogen in the soil solution. The buffer pH is a measure of the amount of soil acidity or the potential acidity, due to the hydrogen held by the negatively charged clay and organic matter particles in the soil. Thus, two soils may have the same soil pH, but the soil with more clay and organic matter will have a lower buffer pH. The pH scale ranges from 1 to 14. Soils with a pH value of 7 are neutral. Soils above 7 are alkaline, those below are acid. Most agricultural soils fall between 4 and 8, although some New Mexico soils are above 8. A soil with a pH of 7 is 10 times more acidic than a soil with a pH of 8. A soil with a pH of 6 is 100 times more acidic than one with a pH of 8. Depending on soil pH, nutrients may be more available or more tightly bound and less available for plant uptake (fig. 1).

Using fertilizers also can affect soil pH. Some fertilizers are more acid than others. Table 5 lists commonly used fertilizers and their effect on soils.

Also, soil texture can influence soil pH. Sandier soils are more prone to acidity, while clay soils tend to buffer the effects of fertilizer additions and other cations in the soil solution and to be more basic.

Soil salinity tests in the lab simply measure all of the ions present in the soil solution. Soil salinity is measured by the soil solution's electrical conductivity (EC). The more ions present, the greater the conductivity. In the lab, a solution is prepared by mixing soil with water. The system is allowed to reach equilibrium, and then the solution is removed by filtration. A conductance meter is used to measure the solution's EC, and the results are recorded in millisiemens (ms) per centimeter. Total salts in the soil are estimated from this EC value, where the EC value in mmhos/cm or ms/cm can be multiplied by 640 to give ppm of salt in the soil. A general interpretation of soil salinity measurements is given (table 6).

Table 5. Fertilizers and their analysis, commonly used rates of application within small turf or garden areas, speed of fertilizer creating change within the soil solution and the effect on pH.

Material	Analysis N-P-K	Application Rate per 100 Square Feet Dry	Liquid	Reaction Speed	Effect on pH
Ammonium sulfate, $(NH_4)_2SO_4$	20-0-0	1/2-1 lb	1 oz per 2-3 gal	Rapid	Very acid
Sodium nitrate, $NaNO_3$	15-0-0	3/4-1 1/4 lb	1 oz per 2 gal	Rapid	Basic
Calcium nitrate, $Ca(NO_3)_2{\cdot}2H_2O$	15-0-0	3/4-1 1/2 lb	1 oz per 2 gal	Rapid	Basic
Potassium nitrate, KNO_3	13-0-44	1/2-1 lb	1 oz per 3 gal	Rapid	Neutral
Ammonium nitrate, NH_4NO_3	33-0-0	1/4-1/2 lb	1 oz per 5 gal	Rapid	Acid
Urea, CO (NH_2)2	46-0-0	1/4-1/2 lb	1 oz per 5-7 gal	Rapid	Slightly acid
Mono-ammonium phosphate, $NH_4H_2PO_4$	11-48-0	1 lb	1 oz per 3 gal	Rapid	Acid
Di-ammonium phosphate, $(NH_4)_2$ HPO_4	18-46-0	1/2-3/4 lb	1 oz per 4-5 gal	Rapid	Acid
Triple superphosphate $Ca(H_2PO_4)_2H_20$	0-46-0	1-2 1/2 lb	Insoluble	Medium	Neutral
Superphosphate, $Ca(H_2PO_4$)2 + $CaSO_4$	0-20-0	3-5 lb	Insoluble	Medium	Neutral
Potassium chloride, KCl	0-0-60	1/2-3/4 lb	1 oz per 4-5 gal	Rapid	Neutral
Potassium sulfate, K_2SO_4	0-0-50	1/2-1 lb	Not advisable	Rapid	Neutral
Complete soluble (mixtures)	20-20-20	Not advisable as dry	1 oz per 3-5 gal	Rapid	Various
Complete soluble (mixtures)	20-5-30	Not advisable as dry	1 oz per 3-5 gal	Rapid	Various
Complete dry (mixtures)	10-10-10	2 lb	Relatively insoluble	Various	Various
Complete dry (mixtures)	5-10-10	2-3 lb	Insoluble	Various	Various
Limestone, $CaCO_3$	None	5-20 lb	Insoluble	Slow	Basic
Hydrated lime, Ca $(OH)_2$	None	2 lb	Relatively insoluble	Rapid	Basic
Gypsum (calcium sulfate), $CaSO_4$	None	2-5 lb	Insoluble	Medium	Neutral
Sulfur	None	1-2 lb	Insoluble	Slow	Acid
Epsom salts (magnesium sulfate) $MgSO_47H_2O$	None	8-12 oz	1 oz per 5 gal	Rapid	Neutral
Aluminum sulfate $Al_2(SO_4)_3$	None	1 tsp per, 6-inch pot (not advisable)	1 oz per 5 gal	Rapid	Very acid
Urea formaldehyde	38-0-0	3-5 lb	—	Slow	Slightly acid
Magnesium ammonium phosphate	7-40-6	Variable	—	Slow	Neutral
Activated sludge	Usually 5-4-0	3-5 lb	—	Medium	Acid
Dried blood	12-0-0	2-3 lb	—	Medium	Acid
Animal tankage	Usually 7-9-0	3-4 lb	—	Medium	Acid
Steamed bone meal	Usually 3-20-0	5 lb	—	Slow	Basic
Castor pumice	5-1-1	3-5 lb	—	Slow	—
Cottonseed meal	7-2-2	3-4 lb	—	Slow	Acid
Hardwood ashes	0-1-5	3-10 lb	—	Medium	Basic
Hoof and horn meal	13-0-0	2-3 lb	—	Slow	—
Seaweed (kelp)	Usually 2-1-15	2-3 lb	—	Slow	—
Linseed meal	5-1-1	3-5 lb	—	Slow	Acid
Soybean meal	6-0-0	3-5 lb	—	Slow	—
Trace elements, $MnSO_4$	—	3-6 oz	—	—	—
Iron sulfate, $FeSO_4$	—	8-12 oz	1 oz per gal	—	—
Chelated iron	—	1-2 oz	1 oz per 25 gal	—	—
Borax	—	1/2 oz	—	—	—
Copper sulfate, $CuSO_4$	—	1-2 oz	—	—	—

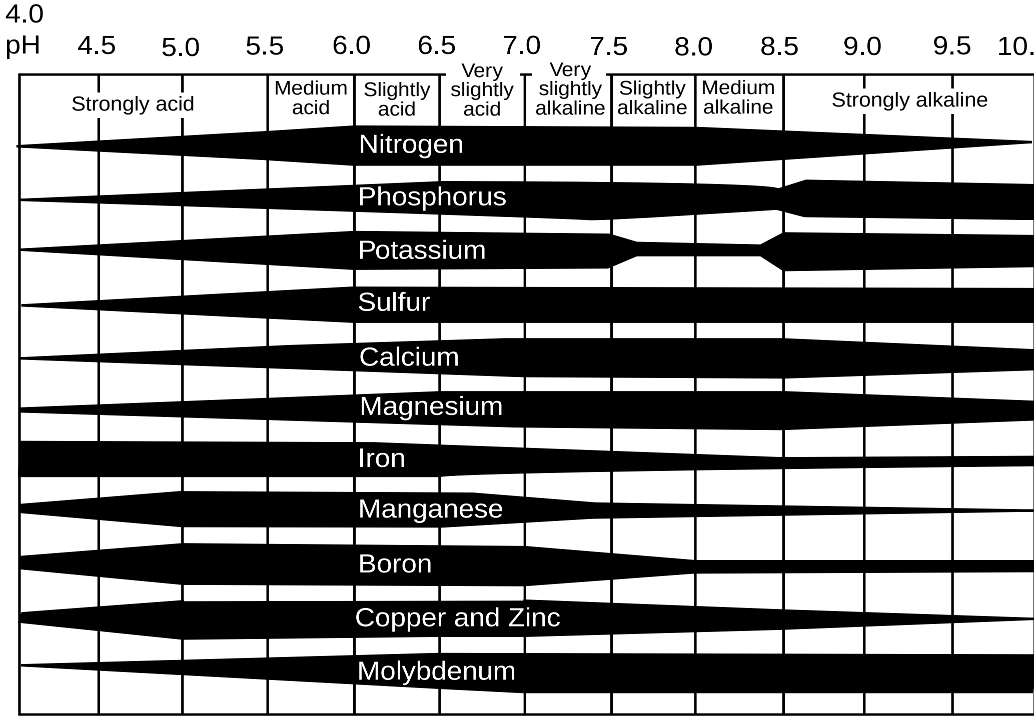

Figure 1. Nutrient availability for plant use as influenced by soil pH. Adapted from nutrient information from Brady, N.C. 1974. *The nature and properties of soils*, 8th ed. MacMillan Pub. Co., Inc., NY.

Sulfur (S) processing often uses a calcium phosphate extractant, which measures water-soluble and adsorbed sulfate with results reported in ppm of S or ppm sulfate sulfur (SO_4). However, there are several analytical techniques that may be used. Test values are listed as low (L), marginal (M) and adequate (H), with recommendations of 30, 20, or none for each, respectively. Determine sulfur needs based on soil and tissue analyses as well as crop response information. Generally applied broadcast, common fertilizer sources are elemental sulfur (85-99 percent S), gypsum or calcium sulfate (15-18 percent S), potassium sulfate (17-18 percent S), ammonium thiosulfate solution (20 percent S) and potassium magnesium sulfate (18 percent S).

Zinc (Zn) is extracted using an organic chelate, DTPA, with results reported in ppm of Zn. Often the test results are reported simply as low (L), marginal (M) and adequate (H). Interactions between zinc, soil phosphorus and soil pH can alter zinc application rate needs significantly in fulfilling a desired crop response. Recommendations for these categories are 10, 5 and none, respectively, and are based on the use of inorganic products, such as zinc sulfate. Zinc chelates may be used at about one-third the rate of inorganic products. Depending on the crop, application suggestions may include repeat treatments. If amounts greater than 10-15 pounds per acre are recommended, broadcast treatments are suggested. For lesser amounts like 3-8 pounds per acre or if the soil pH is above 8, row or band placement should be used. Even smaller amounts are more effective if combined with the field's N-P-K treatment.

Other analyses are available for chloride, molybdenum, ammoniacal nitrogen and cobalt, but they are rarely needed.

Table 6. Soil salinity crop restrictions based on EC value.[1]

EC Value	Interpretation
Below 2	No salinity problem, except for very sensitive crops.
2-4	Restricts growth of sensitive crops.
4-8	Restricts growth of many crops.
8-16	Restricts growth of all but salt-tolerant crops.
Above 16	Only a few very tolerant crops have satisfactory yields.

[1]Crops usually are more sensitive to salinity during germination and early seedling stages.

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