Soil Analysis and Interpretation

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Soil chemical analysis prior to planting a new orchard is essential. It provides the best information for proper soil nutrient improvement before planting. After planting, soil chemical analysis is used to supplement leaf tissue analysis in developing fertilization programs.

Before planting an orchard a thorough evaluation of the soil chemical conditions through soil testing provides the best information on which to base decisions concerning the need for and extent of modifications required. In established orchards, soil testing is critical to monitor pH and provides additional information needed for satisfactory interpretation of results of leaf analysis and developing fertilizer management programs.

Soil Sampling Procedures

How, when and where samples are collected all influence the results of soil analysis. Both topsoil and subsoil samples are needed to obtain the best analysis of conditions throughout the rooting zone. Topsoil samples (0 to 8 inch depth) reflect the effects of recent lime and fertilizer additions and are important in monitoring pH and nutrient availability in the upper portion of the rooting zone. However, topsoil samples alone are not representative of the total root zone and may not show good correlation with crop response. Subsoil (8 to 16 inch depth) samples indicate inherent problems such as low pH and lack of fertility, reflect the long-term response to lime and fertilizer additions, and supplement the information obtained from topsoil analysis.

During pre-plant soil preparation, soil samples can be taken at any time that is convenient. However, in established orchards the preferred time of sampling is in mid- to late-summer or in the fall after harvest. Samples collected in the fall usually show lower phosphorus (P) and potassium (K) as a reflection of crop removal. Those collected in the spring reflect winter "recharge" for various elements.

Thorough sampling is necessary if the results are to be meaningful. In a 10-acre orchard, a minimum of 10 to 20 sub samples are usually needed in collecting one soil sample for analysis. In established orchards these sub samples should be coordinated with leaf samples taken in the same area. Samples should be taken from within the tree row where most of the nutrient elements are taken up by the trees, not in the middle of the alleyways.

Soil pH, Cation Exchange Capacity and Base Saturation

Soil pH and Soil Acidity. The term "pH" is used to describe relative acidity or basicity and is a measure of hydrogen ion (H+) activity expressed in logarithmic terms. The pH scale covers a range of 0 to 14, with a value of 7 indicating neutrality. Values from 0 to 7 indicate acidity and those from 7 to 14 indicate basicity. Since this is a logarithmic scale, each 1.0 unit change indicates a 10-fold change in acidity or basicity. Soil pH can range from 4 to 9.

The term "active acidity" refers to concentrations of hydrogen ions in the soil solution and is measured using a suspension of soil in water. "Reserve acidity" (exchangeable acidity) includes hydrogen ions held on negatively charged soil particles of clay and organic matter plus other positively charged ions such as aluminum. Both "active" and "reserve" acidity are involved in determining the amount of lime that may be needed to adjust soil pH. In the Cornell soil test reports, "reserve" acidity is reported as meq of hydrogen (H+) per 100 grams of soil. Reserve acidity must be included when estimating total cation exchange capacity of the soil.

Problems associated with low pH (below 5.5) include measles associated with excessive uptake of manganese; calcium and magnesium deficiencies; restricted root growth or regeneration, particularly of new lateral roots affected by aluminum toxicity; reduced availability of phosphorus; reduced efficiency of nitrogen and potassium use; and poor response to applied nitrogen and potassium fertilizers.

High pH may be associated with soil parent materials, in some cases with excessive lime applications, or a reflection of carbonate accumulation due to poor internal soil drainage. High soil pH (>7.0) may reduce availability of manganese, copper, zinc and boron.

During pre-plant site preparation, suggested targets for pH adjustment are pH 7.0 for the topsoil and 6.5 for the subsoil. In established orchards, these targets should be 6.5 for the topsoil and 6.0 for the subsoil. Soil pH should be maintained in the range of 6.0 to 6.5 throughout the total root zone to optimize nutrient availability.

Soil pH is usually measured using a mixture of one part soil and one part water. In some cases pH may be measured using a mixture of one part soil and two parts CaCl2 solution, in which case the resulting pH is about 0.6 unit lower than with water. Likewise, pH measured using 1 Normal KCl (potassium chloride) solutions is somewhat lower than that obtained using soil:water suspensions.

Cation Exchange Capacity (CEC). Soil clay particles and humus, collectively called colloids, have negative charges. They adsorb positively charged ions (cations). Cation exchange capacity (CEC) is the sum total of exchangeable cations that are adsorbed on the soil colloids and is a measure of the ability of a soil to hold cations. CEC is expressed as milliequivalents of cations per 100 grams of soil. There are two types of cations on the soil colloids: acid forming cations (H^+, Al^{3+}, Fe^{3+}, Mn^{2+}) and base cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+). The sum of exchangeable acid forming cations is called exchange acidity or reserve acidity. It is expressed as milliequivalents of hydrogen ion per 100 grams of soil. The sum of exchangeable bases and the exchange acidity is equal to CEC. The percentage of CEC that is accounted for by exchangeable bases is base saturation. Cation exchange capacity is important in estimating the quantities of calcium and magnesium needed in managing the specific soil.

The term "equivalent" refers to the quantity of various elements that is equal to 1 equivalent of hydrogen. On a comparative basis, equivalent weights of common cations may be expressed as parts per million or as pounds per acre (Table 1). Soil test results reported in PPM are converted to pounds per acre by multiplying by 2, since a 6-inch depth of soil is assumed to weigh 2 million pounds.

The cation exchange capacity of a soil is determined by the type and amount of clay and organic matter content and is influenced by pH. Organic matter has a cation exchange capacity of approximately 200 meq/100 g, thus 1 percent organic matter in a soil provides about 2 meq/100g of cation exchange capacity. The cation exchange capacity of New York soils may range from as low a 3 meq/100g in very coarse sands to as high as 35 to 40 meq/100g in clayey soils (Table 2).

Cation exchange capacity can be estimated by calculating the total milliequivalents of the major basic elements (Ca++, Mg++, and K+) and adding the milliequivalents of reserve acidity (H+). If the value for reserve acidity is not known, CEC can be estimated by dividing the sum of the meq/100grams of the basic elements by the percent base saturation for the pH of the sample.

Base Saturation. Base saturation refers to the degree to which the cation exchange complex is saturated by basic elements such as calcium, magnesium and potassium. It is usually expressed in terms of percentages of the total exchange complex that is represented by these elements, individually or in total. As soil pH increases the percent base saturation also increases. At a given pH "sandy" soils have a higher percentage base saturation than the majority of soils because they have lower total cation exchange capacities and lower buffering capacities.

Calcium (Ca)

Calcium content of soil samples may be expressed as PPM, lbs/acre, meq/100g, or as percent saturation of CEC. Low levels of soil calcium are usually associated with low soil pH and low cation exchange capacity, particularly in sub soils. However, in some fine-textured soils calcium availability and uptake may be more directly related to exchangeable acidity than to pH or the total amount of calcium in the soil.

Imbalances of calcium, magnesium and potassium are frequently cited as problems in orchard soils. In most cases, inadequate amounts of one or more of these nutrient elements are of greater importance than an imbalance in tree nutrition. Such shortages are particularly important in the subsoil.

TABLE 1

Equivalent weight of various cations.

Element	Atomic weight	Equivalent weight	Parts per million	Pounds per acre (6-inch depth)
Hydrogen	1.008	1.008	10	20
Potassium	39.10	39.1	391	782
Calcium	40.08	20.04	200.4	400.8
Magnesium	24.32	12.16	121.6	243.2
Aluminum	26.97	8.99	89.9	179.8

Magnesium (Mg)

Magnesium content of soil samples may be expressed in various terms, as indicated for calcium. Most tree fruits have a high requirement for magnesium and, with some exceptions, most soils in the Northeast are low in magnesium content. Raising pH by applying calcitic (high calcium) lime increases the availability of the magnesium present in the soil but does not correct the long-term problem of low magnesium supply. Applying dolomitic limestones (high in magnesium content) is the usual method for correcting low magnesium supply.

Lime Requirement for Adjusting Soil pH and Soil Ca and Mg Levels

The amount of lime needed to adjust the soil reaction to the desired pH is referred to as the lime requirement. The lime requirement is related to the initial soil pH, the amount of pH change desired, and the cation exchange capacity. Since cation exchange capacity is largely determined by the amounts of clay and organic matter in the soil, the lime requirement is influenced by soil texture and increases as the desired pH for a given soil is raised. Various alternative methods may be used for estimating the lime requirement. (See article by Cheng and Stiles in this issue). Approximate amounts of calcium and magnesium desired in topsoil at pH 6.5 and in the subsoil at pH 6.0 for soils of various soil textures are given in Table 3.

The amount and type of lime to be applied should be determined on the basis of pH adjustment desired and the amounts of calcium and magnesium in both the topsoil and the subsoil, and the amounts of these elements required to achieve their desired concentrations. On an equivalent basis, a 5:1 ratio of calcium:magnesium is presently recommended as a target for most fruit crops in New York State. This is equal to approximately 8.23 pounds of calcium per pound of magnesium. These ratios are used in estimating calcium and magnesium requirements and should not be interpreted as precise requirements. Acceptable ratios may vary within broad ranges depending on the specific soil, crop, and environmental conditions at the individual site.

TABLE 2

Approximate cation exchange capacities of various soil types

	Approximate CEC (meq/100g)	
Texture	0-8 inch depth	8-16 inch depth
Sand, Gravel	5	3
Sandy Loam	12	8
Silt Loam, Loam	18	12
Silty Clay Loam	20	14
Clay, Silty Clay	25	18

TABLE 3

Approximate Amounts Calcium and Magnesium Needed in Both the Topsoil and Subsoil of Various Textured Soils

Texture	Calcium	Magnesium
Topsoil at pH 6.5 (lbs/acre 0 to 8-inch depth)		
Sand, Gravel	1,500	185
Sandy Loam	3,600	440
Silt Loam, Loam	5,500	660
Silty Clay Loam	6,100	740
Clay, Clay Loam	7,600	900
Subsoil at pH 6.0 (lbs/acre 8 to 16-inch depth)		
Sand, Gravel	800	100
Sandy Loam	2,100	260
Silt Loam, Loam	3,200	385
Silty Clay Loam	3,700	450
Clay, Clay Loam	4,800	580

Potassium (K)

Soil test results for potassium may be reported in various terms: milliequivalents per 100 grams of soil; parts per million; pounds per acre; or percent of potassium saturation of the cation exchange capacity. Results may vary considerably among different laboratories primarily because of the method of extraction employed.

The potassium that is readily available for use by plants occurs primarily as potassium ions in solution or as exchangeable

TABLE 4

Available Potassium of Some NY Soils

Soil type	Texture	K (lb/acre/yr)
Adams	Loamy fine sand	20-60
Arkport	Fine sandy loam	80-100
Elmwood	Fine sandy loam	80-100
Howard	Gravely loam	100-120
Dunkirk	Silt loam	100-120
Hudson	Silt loam/silt clay	120-140

TABLE 6

Boron Soil Test Levels for Soils of Different Textures and Recommended Amounts to Apply Preplant.

	Soil Texture			
Relative Level	Loam, Silt Loam (lb. B / a)	Sandy Loam (lb. B / a)	Loamy Sand (lb. B / a)	B to apply (lb. B/ a)
Very high	> 2.4	> 1.8	> 1.2	none
High	1.6-2.4	1.2-1.8	0.7-1.2	1
Medium	0.8-1.6	0.6-1.2	0.4-0.7	2
Low	< 0.8	< 0.6	< 0.4	3

TABLE 5

Desired Soil Potassium Levels for Various Soil Textures (lbs/acre)

Soil Texture	0 to 8-inches	8 to 16-inches
Sand, Gravel	150	100
Sandy Loam	350	220
Silt Loam, Loam	525	335
Silty Clay Loam	580	370
Clay, Silty Clay	730	465

ions on the cation exchange complex. The majority of potassium in most soils is present in mineral form as a constituent of clay particles. Potassium status, or the ability of a soil to release potassium in available form, therefore varies with soil texture (Table 4).

Soil texture influences potassium availability through its effect on root development. Since potassium is relatively immobile within the soil, extensive root development is required for efficient uptake.

Fine-textured soils, although they may contain larger amounts of potassium, may limit the extent of root development to the extent that the crop may not be able to efficiently access this supply. The more extensive root development by crops grown on coarser-textured soils provides more efficient uptake of the smaller amounts of potassium that they contain. Potassium availability and uptake is improved if an adequate soil moisture supply is maintained.

Potassium status of the soil must be considered in conjunction with that of pH, calcium and magnesium. Potassium availability generally decreases as pH decreases below about 6.0. Generally, liming acid soils increases availability of potassium and reduces losses of potassium by leaching. The percentage of the cation exchange capacity occupied by potassium should be considered in relation to calcium and magnesium. It is not likely that calcium or magnesium would depress potassium uptake, but the reverse may occur - particularly with magnesium.

Approximate values used in interpreting the Cornell soil test results for orchards on soils of different textures are presented in Table 5. Potassium needs approximate 5 percent of those for calcium on an equivalent basis, or about 10 percent of those for calcium on a weight basis.

Phosphorus (P)

Phosphorus needs of most perennial fruit crops are relatively low in comparison to those for nitrogen and potassium and with the needs of herbaceous plants. Soluble phosphorus is precipitated out of solution as insoluble iron, aluminum, or manganese phosphates, or oxides of aluminum, iron, or magnesium in acid soils, and as insoluble calcium phosphates in alkaline soils. Maximum availability of phosphorus occurs when soil pH is maintained between 6.0 and 7.0.

Various extractants may be used by different laboratories to test the availability of phosphorus in soil samples. This results in widely different values from different labs. In most cases, the amount of phosphorus obtained with these methods usually increases as the soil pH increases. Results of soil tests are usually reported in terms of either parts per million or pounds per acre of P (phosphorus).

In the Cornell soil tests, the amounts of phosphorus (pounds of P_2O_5 per acre 6-inch depth) required for pre plant incorporation is calculated as follows: [(10 - sample content) + 40], and for established plantings [(10 - sample content) + 20]. It is recommended that phosphate fertilizers be thoroughly incorporated into the soil during pre plant site preparation. Further soil surface applications after orchards have been established are not recommended unless leaf sample P values are less than 0.08 percent. Even then, low values of leaf sample P are more likely to be associated with low soil pH than with a lack of available soil phosphorus.

Boron (B)

Boron is very soluble and mobile in the soil and is relatively easily leached under humid conditions. Availability of boron decreases as soil pH is increased and liming acid soils to a pH of 6.5 to 7.0 reduces losses by leaching. Finer-textured soils have a higher buffering capacity and require higher concentrations of boron to meet crop needs than those of coarser texture. Likewise, toxicity problems from excessive applications of boron are less frequent in finer-textured soils. Boron availability is reduced when soil moisture supply is low. Leaching losses are increased by excessive rainfall or irrigation.

Various extractants have been used in analyzing soil samples for boron; the most common is hot water. Results of soil tests for boron are most often reported in terms of parts per million or pounds per acre.

Suggested rates of boron application vary with soil texture and the amount of boron already present in the soil (Table 6). Rates of boron application indicated are for apples and pears. Stone fruits, especially peaches, are more sensitive to excess boron and boron applications should be reduced by 50 percent for these crops unless leaf analysis indicates a greater need.

Zinc (Zn)

Availability of zinc in acid to neutral soils decreases sharply as soil pH is increased. For each unit (1.0) increase in pH between 5.0 and 7.0, zinc concentration in the soil solution may decrease by a factor of 30. High organic matter content of the soil may decrease availability of zinc through the formation of insoluble organic complexes. Zinc availability and uptake is inhibited by high levels of phosphorus through the formation of insoluble zinc phosphates. Several extractants have been used in determining zinc availability in soil samples, each providing different relative values. Results of these tests are usually reported in terms of parts per million or pounds per acre. For most fruit crops, standards for interpreting soil zinc values have not been well established.

Copper (Cu)

Copper availability is strongly influenced by soil pH, organic matter content of the soil, and levels of phosphates in the soil in manners similar to zinc. Like zinc, copper is not mobile in soil. Soil test methods used in estimating copper availability are similar to those used for zinc. Likewise, the standards for interpreting soil copper values for fruit crops are not well established.

Iron (Fe)

Availability of iron decreases as soil pH increases. Excessive levels of phosphates or carbonates reduce iron availability through the formation of insoluble iron compounds. Organic matter is a source of iron and also complexes and chelates iron. Soil tests for iron have not been well correlated with response of most fruit crops.

Manganese (Mn)

Excessive amounts of manganese are of concern because of toxic effects on crops. Soil pH has a major role in regulating manganese availability and raising pH of a soil from 4.5 to 6.5 has been shown to reduce the concentration of exchangeable manganese by a factor of 20 to 50 times. Most deficiencies of manganese are associated with higher soil pH or highly leached soils. The manganese content of plants is frequently more closely related to soil pH than to the concentration of manganese in the soil.

Aluminum (Al)

Aluminum is of concern because of its adverse effect on root development and consequently on uptake of other elements. Relatively low levels, 10 to 20 parts per million or less, of aluminum in the soil solution can adversely affect some fruit crops. Using the Cornell soil test methods, 200 pounds of aluminum or of a combination of aluminum, manganese and iron indicates a potential problem situation for these crops. Liming acid soils to a pH of 6.0 to 6.5 may be necessary to adequately limit availability of aluminum. Draining soils to improve aeration helps to reduce the severity of aluminum toxicity problems.

Organic matter

Organic matter serves a multitude of functions in soils. Under usual conditions, organic matter content tends to be lower in coarse-textured soils and higher in finer-textured soils. Organic matter usually accounts for most soil nitrogen. In general, one percent organic matter in the soil will result in the release of 20 pounds of plant-available nitrogen per year. Soils in New York State vary in nitrogen supplying ability, ranging from approximately 30 pounds to as much as 80 pounds per acre per year. Therefore, the contribution of nitrogen from organic matter must be considered in developing nitrogen management programs for fruit crops.

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