

Diagnosing Apple Tree Nutritional Status: Leaf Analysis Interpretation and Deficiency Symptoms

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Essential mineral nutrients are necessary in annual supplies either from those that exist in the environment (soil and air) or as supplemental applications by the fruit grower. Without these nutrients the goals of promoting rapid development of young trees and the consistent production of significant quantities of high quality fruit in established orchards cannot be achieved. There are 17 known essential elements which are categorized either as “macronutrients” including carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), or as “micronutrients” including sulfur (S), iron (Fe), boron (B), manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), chlorine (Cl), and nickel (Ni).

Nutritional requirements vary among orchard sites, within the seasons, and can be affected by light, temperature, and available water supply. Nutrient shortages can occur that can create immediately observable effects that severely limit fruit and/or tree quality. Many of the micronutrients are more readily available in the environment and in most cases require less frequent supplementation. For optimum growth and fruiting, essential nutrients must be kept within definable limits. Levels that are too low result in obvious visual symptoms and a reduction in fruit and tree quality. Levels that are too high result in toxicity symptoms, often with the same results as deficiency.

Mineral nutrition of tree fruit has been studied extensively for many years. There are several valuable references available for the fruit grower (Stiles and Reid 1991, Petersen and Stevens 1994, Childers 1966) that outline the details of tree nutrition.

Methods of Assessing Orchard Nutritional Needs

There are several useful methods available for determining an orchard’s nutritional needs. These include: 1) the use of analytical methods to assess the nutrient content of tissue, fruit, or soil; 2) observations of growth and foliage quality; and 3) the use of deficiency symptoms. These methods should never be used alone but must be combined and evaluated together to make sound decisions when developing nutritional programs for orchards.

Leaf and soil analyses are the most accurate methods available for determining nutrient requirements. They are based on regular, precise sampling and measured against a set of standards developed over time and have been proven to be accurate. These standards have been specifically developed to assess the quality and quantity of fruit needed to meet the standards of particular markets. Advantages include precise knowledge of nutrient quantities in the tree and in the soil, and an easy method for making comparisons year to year. The disadvantages are cost and the additional time required to collect and process the samples.

Soil tests are important to measure pH and to get a general sense of nutrient content available to the tree in the orchard. Leaf analysis integrates all factors contributing to an orchard’s nutritional status including soil nutrient content, tree and root nutrient carryover, ability of the root system and conductive tissue within the tree to transport nutrients to where they are needed, and the tree’s ability to use available nutrients when they arrive at needed sites.

Orchardists use several methods for determining an orchard’s nutritional needs. These include soil, leaf and fruit nutrient analyses, observations of growth and foliage quality, and the use of deficiency symptoms. Although leaf analysis has become the most common method of assessing an orchard’s nutritional needs, interpretation of leaf analysis results should not be done without concurrent field evaluations of growth, foliage quality and deficiency symptoms to make sound decisions when developing nutritional programs for orchards.

Visual deficiency symptoms have been used extensively by orchardists and consultants to adjust orchard nutritional programs by comparing leaf or fruit symptoms in the orchard to published color plates readily available in the literature. This method can provide a fast and inexpensive diagnostic tool for determining nutrient problems in the orchard. Unfortunately, by the time foliar or fruit symptoms occur and a diagnosis is possible, fruit quality and tree growth has already been compromised. Deficiencies can result in poor fruit quality including: small fruit, soft fruit, poor soluble solids; premature fruit drop, physiological disorders of the fruit such as bitterpit, watercore, corkspot, core breakdown; poor storage quality and poor tree growth. Deficiency symptoms can be confused with many other types of injury which cause similar symptoms. In addition, deficiencies of one element can mask deficiencies of another so that in some cases it is only possible to solve nutrient deficiencies one at a time.

Careful observations of terminal shoot growth are also used to assess an orchard’s

TABLE 1

Leaf analysis standards for tree fruits (dry weight basis).

Element	Crop	Desired level
Nitrogen	Young nonbearing apples and pears	2.4-2.6%
	Young bearing apples and pears	2.2-2.4%
	Mature soft apples and pears	1.8-2.2%
	Mature hard apples and processing	2.2-2.4%
Phosphorus	All crops	0.13-0.33%
Potassium	All crops	1.35-1.85%
Calcium	All crops	1.3-2.0%
Magnesium	Apples and pears	0.35-0.50%
Boron	Apples and pears	35-50 ppm
Zinc	All crops	35-50 ppm
Copper	All crops	7-12 ppm
Manganese	All crops	50-150 ppm
Iron	All crops	50+ ppm

nutritional status. Non-bearing trees should have 15-18 inches of growth seasonally, bearing trees 8-12 inches of growth. It is an important observation when combined with analytical analysis. This observation can only be made after growth has stopped for the year so it is not timely enough to make same season corrections. Also, observations are often flawed and/or inconsistent, and unless accurate records are kept, they cannot be compared from year to year. In addition, growth outside these stated limits can also be caused by factors other than nutritional imbalances such as drought, root impairment or insect and disease damage.

Leaf Sampling Procedure

Timing of leaf sample collection. Nutrient levels in the leaf change over the season. The levels of most elements also vary between leaves along the shoot. The recommended sampling time represents a compromise between the best sampling times for various mineral elements. Leaf samples should be collected when the concentrations of most elements are relatively stable. The most stable time for sampling has been determined to be between the end of shoot growth and the start of export of nutrients from the leaves to the shoots (typically during mid-July through August) or between 60 and 70 days after petal fall. Leaf samples collected much earlier tend to contain higher concentrations of elements such as nitrogen and potassium, and lower levels of calcium. Conversely, samples collected much later tend to have lower nitrogen and potassium and higher levels of calcium. After harvest, levels of mineral elements in leaves decline. After September 1, the rate of decline increases and leaf analyses can no longer be a reliable indicator of nutrient status. In order to compare leaf samples to established standards, the leaves sampled must be comparable in physiological age to those used in developing the standards.

Method of sample collection. Samples should consist of 100 leaves collected from several trees in the area being sampled. Trees may be selected at random, or by following a predetermined pattern. Sampled trees should be uniformly representative of the general condition of the orchard in terms of vigor, crop load, pruning, etc. Avoid areas with distinctly different soil conditions or tree vigor. If more specific information about such areas is desired sample those areas separately. Collect samples from blocks no larger than five acres. For trouble spots, take separate composite samples from five affected trees and five non-affected trees and label bags accordingly.

Collect only mid-shoot leaves from current-season terminal shoots on the periphery of the tree. No more than two leaves should be taken from an individual terminal shoot. On larger trees, shoots sampled should be approximately 4 -7 feet above ground level. Shoots sampled from young trees and high-density plantings should be representative of the majority of the foliage.

Leaves of different varieties may differ greatly in nutrient composition. Sample the major variety in the orchard. Do not mix leaves from two varieties because the sample will not be representative of either. If more detailed information is desired on varietal differences, they should be sampled separately.

It is essential that careful records be kept. At the time that leaf samples are collected, record observations of such factors as length and thickness of terminal shoot growth, relative size and appearance of leaves, incidence of disease or insect damage, visual symptoms of deficiencies, crop load, severity of pruning, and effectiveness of weed control. These factors are essential in interpreting the results from the leaf analysis.

Sample preparation. In most cases, the content of elements such as nitrogen, phos-

phorus, potassium, calcium, magnesium, or boron is not affected appreciably by washing samples prior to drying. Surface contamination by dust, soil, pesticide sprays, or foliar nutritional sprays may result in significantly higher levels of iron, manganese, zinc, and copper in samples that are not washed prior to drying. For example, leaves treated with manganese-containing fungicides often have elevated levels of this element and interpretation is difficult without direct observation of the orchard for low pH, poor drainage, and visual symptoms such as "measles" showing manganese toxicity. Washing samples in a mild detergent solution (most dish-washing liquids are suitable), and then rinsing three times in distilled water is helpful in reducing contamination. Caution: Some domestic water supplies contain various amounts of iron, manganese, copper, or zinc. Using distilled water for washing leaf samples helps to avoid this source of contamination. After the final rinse, samples should be drained (spread out on paper toweling) before being placed in paper bags for drying. These bags should be placed in a location conducive to rapid drying with tops open to prevent mold formation. Samples should be stored until processing, in a dry location to prevent rehydration.

Interpretation of Leaf Analysis Results

The first step in evaluating the nutritional status of orchards is to compare results of the leaf analysis with a set of standard values. Standards currently in use in the Leaf Analysis Service Program in New York State are summarized in Table 1. Other companies that offer leaf analysis use their own standards. It is important to know what those standards are for proper interpretation. For example, some Midwestern companies have used corn as their standards values. These values are not appropriate for apples and interpretations using these standards will result in less than successful outcomes.

Nitrogen (N) levels must be considered according to the type of fruit, tree age and variety, crop load, tree vigor, and the purpose for which the fruit is intended. The most desirable nitrogen management program provides a relatively high nitrogen status early in the season to encourage rapid leaf development, fruit set, and flower bud formation, and then allows nitrogen to decline gradually as the season progresses to favor fruit color development and winter hardening of the tree. Optimum growth of young trees is associated with leaf nitrogen values of approximately 2.4 to 2.6 percent. As trees mature, less vegetative growth is

desired and the “satisfactory” level of nitrogen is generally reduced to improve color development and fruit firmness. Points to consider in judging nitrogen status from leaf analysis include:

1. *Rapid growth of young trees* is desirable to develop the fruiting system and encourage early cropping. During the developmental period, rate of tree growth is directly correlated with nitrogen status, but excessive late-season growth must be avoided to allow the trees to develop cold hardiness.

2. *Fruit color* development in bearing age trees (red and yellow varieties) is delayed when nitrogen levels are too high. If other factors are equal, the percentage of red color is reduced by about 5 percent for each 0.1 percent increase in leaf nitrogen. This relationship is particularly significant with the less-highly colored fruit varieties or strains. Yellowing of Golden Delicious fruit shows a similar reduction as leaf nitrogen increases.

3. *Fruit size and flesh firmness* are usually inversely related, and both are influenced by the nitrogen status of the tree. Size generally increases with higher nitrogen levels if the crop load is not excessive and other factors are not limiting. Since flesh firmness decreases as fruit size increases, the optimal nitrogen level would be that which provides the best combination of size and firmness determined by the requirements of the market.

4. *Varietal differences* in fruit color and/or flesh firmness must guide evaluation of leaf nitrogen status. To accommodate such differences, various apple varieties are grouped into two general categories for interpreting leaf nitrogen status in mature orchards. Soft varieties intended for fresh market should have a leaf nitrogen concentration of 1.8-2.2 percent for mature trees, and hard varieties intended for either the fresh or processing market and soft varieties intended for the processing market should have a leaf nitrogen of 2.2-2.4 percent for mature trees.

5. *Biennial bearing* tendencies of mature apple trees become more pronounced as leaf nitrogen falls below approximately 2.2 percent. Careful attention must be given to fruit thinning to minimize the biennial tendency in Golden Delicious and varieties such as McIntosh when leaf nitrogen is reduced to levels of 1.8-2.0 percent to favor color development.

6. *Vigor of shoot growth* offers an additional guide if all other nutrients are adequate. Excessive waterspout growth frequently results from excessive pruning, particularly heading cuts, and is not a reliable indicator of vigor of the fruit-bearing shoots. Interpretation of leaf nitrogen levels in trees

that are producing very limited amounts of new growth should be done with caution. In such trees, nitrogen accumulates to adequate or higher-than-desired levels because of the limited growth. This condition is often associated with deficiencies of metals such as copper and zinc.

Phosphorus (P) levels in leaf samples vary according to fruit type and variety. Leaf phosphorus levels above 0.13 percent usually indicate an adequate supply within the tree. McIntosh leaf samples generally contain lower concentrations of phosphorus than those of Delicious. Since the availability of phosphorus is strongly influenced by soil pH, low leaf-phosphorus values frequently indicate a low soil pH condition that is limiting uptake of phosphorus. At the other extreme, high values frequently result from the accumulation of phosphorus when growth and leaf expansion are limited by deficiencies of other elements such as zinc.

Potassium (K) values in the range of 1.3 to 1.8 percent are generally considered to be adequate for tree fruit crops. Fruit set on potassium-deficient trees may be normal, but the fruit is smaller than normal, has poor, dull color, and an insipid flavor due to lack of acidity. Trees that are low or deficient in potassium are more susceptible to winter cold injury and spring frost damage to buds and flowers. Leaf potassium shows an inverse relationship with crop load. Thus, a value of 1.3 percent potassium may be adequate in a sample from a heavy cropping orchard, but might indicate a marginal supply in a light cropping or nonbearing orchard. Leaf potassium levels of 2 percent or greater are not uncommon with young nonbearing trees; such levels decline as trees mature and the level of cropping increases. Fruit size and color are correlated positively with leaf potassium, and levels in the range of 1.5-1.8 percent must be sustained to achieve optimum production and fruit size and color. High N/K ratios usually indicate that potassium supply is inadequate, while low ratios might indicate either that the nitrogen supply is too low or that the potassium supply is too high.

In addition to tree age and level of cropping, soil moisture supply and soil management practices affect leaf potassium status. If the soil potassium supply is adequate, moisture stress may limit availability of potassium and result in low leaf potassium levels. Soil management practices such as the use of clean-cultivation or herbicide strips along the tree row, or mulching generally result in higher leaf sample potassium. Any reduction in moisture stress and soil temperature favors uptake of potassium.

Calcium (Ca) content of leaf samples is

considered adequate when in the range from 1.3 to 2.0 percent. Low leaf calcium is often, but not always, associated with low soil calcium supply and low pH, particularly in the subsoil. This usually reflects inadequate lime application prior to planting the orchard and/or failure to maintain an adequate liming program throughout the life of the orchard. When adequate soil calcium is available, low leaf calcium may be the result of boron deficiency and/or zinc deficiency. Normal applications of potassium or magnesium have little effect on calcium unless soil calcium supply is low.

Calcium in leaves is positively correlated with leaf nitrogen under normal growth conditions. This relationship exists because a large part of the calcium and nitrogen are taken into the tree and moved to the leaves as the result of water movement due to transpiration. Increasing nitrogen by increasing growth and leaf surface raises total transpiration. Excessively high nitrogen supplies, however, frequently promote development of a high leaf-to-fruit ratio that compounds the problems associated with low calcium in the fruit. This is particularly important when soil moisture is inadequate because calcium is removed from the fruit as water is moved from fruit to leaves under moisture stress conditions.

Magnesium (Mg) concentrations within the range of 0.35-0.50% are usually satisfactory, but Mg should be considered in relation to potassium (K). The requirement for magnesium increases as the potassium status of the tree increases. For practical purposes, a ratio of the percentages of K to Mg in the leaf sample of 4:1 or greater usually indicates that the magnesium supply is not adequate. Premature fruit ripening and accentuated preharvest fruit drop are often associated with magnesium deficiency. Blind wood, a lack of bud development, and weak, brittle spurs are also frequently associated with magnesium deficiency.

Boron (B) shortages frequently occur in orchards, particularly on coarse-textured soils and during dry seasons. Leaf concentrations of 30 to 50 ppm boron are required for normal tree performance. Low boron levels are often associated with calcium deficiency problems. Interpretation of leaf boron values must be done with past boron application practices kept in mind. If no foliar sprays of boron were used prior to leaf sample collection, a leaf level of 30 to 50 ppm usually indicates an adequate boron supply. However, if post-petal-fall boron sprays were used, leaf levels in the 30 to 50 ppm range indicate a need to continue boron applications with a combination of soil and foliar treatments. Fruit analysis is considered to be

the most reliable means of diagnosing boron status.

Zinc (Zn) is involved in the regulation of growth and fruiting and is an essential element in the production of growth-regulating hormones within the tree; it has also been shown to play a role in pollen tube growth. Zinc also influences calcium metabolism. Shortages of zinc are prevalent in the Northeast. Zinc has been shown to influence the degree of cold hardiness of trees and frost hardiness of flowers.

Interpretation of leaf zinc levels is complicated by zinc-containing materials in foliar applications and by interactions with phosphorus. If no foliar sprays containing zinc have been applied, levels of 35-50 ppm indicate adequate zinc; levels of 20-35 ppm indicate a low zinc status; levels less than 20 ppm indicate a zinc deficiency. Relying strictly on these levels to judge zinc status may be misleading for two reasons: 1) growth is reduced as zinc becomes limiting. This limited growth results in accumulation of zinc to higher concentrations than would occur with normal growth; and 2) high levels of phosphorus tend to reduce the availability of zinc within the tree as the result of the formation of inactive zinc phosphate precipitates. When zinc is limited, the reduced growth also tends to result in higher concentrations of phosphorus within the leaf tissue, making the problem even worse. An evaluation of the ratio of phosphorus to zinc in the leaf tissue provides a second means of determining relative zinc status. This ratio is calculated by dividing the ppm of phosphorus by the ppm of zinc. A P/Zn ratio of 150 or greater indicates that zinc is deficient, while 35 ppm or higher zinc levels with P/n ratios of 100 or less usually indicate an adequate supply of zinc.

Manganese (Mn) deficiency is found more frequently on high-pH soils and on coarse-textured soils. The primary effect of manganese deficiency is reduced photosyn-

thesis. Manganese availability is strongly influenced by soil pH. Toxicity, measles in Delicious apple trees, occurs at low pH, usually near 5.0 or below, in soils not adequately limed. Manganese is usually more readily available in poorly drained soils where aeration is limited. For example, manganese availability may be excessive in a poorly drained soil at pH 5.5, but normal in a well-drained soil at the same pH. Necrosis of the phloem as a result of manganese toxicity is frequently confused with other problems such as oil spray damage, or deficiencies of copper or boron. Concentrations of 50 to 150 ppm of manganese indicate adequate amounts of this element in leaf samples from trees that have not been sprayed with manganese-containing materials. When excessively high manganese levels are found in leaf samples, it is advisable to verify that this is not related to a low pH problem.

Iron (Fe) content of leaf samples fluctuate over a considerable range, often in response to variations in soil and weather conditions and with contamination of samples by dust. Iron status of orchards in New York State is generally not a problem.

Copper (Cu) shortages can be a problem on coarser-textured soils and on soils with a pH 6.3 or higher. Levels of 7-12 ppm in leaf samples generally indicate a satisfactory copper level. Symptoms of copper deficiency are associated with leaf contents of Cu of 3.5 ppm or less.

Multiple deficiencies involving two or more elements are not uncommon. Potassium-magnesium, calcium-magnesium, boron-zinc, zinc-manganese, zinc-copper and other combinations have been encountered. In many such cases, tree growth is restricted and the levels of all elements in the leaf samples may be within the ranges considered to be satisfactory for normal tree performance. Visual examination of the trees, past performance, soil tests, and trial applications of the suspected problem elements

may be necessary before the cause or causes of such problems can be determined. When the supplies of two or more elements are marginal, correction of one deficiency usually accentuates the appearance of symptoms associated with deficiencies of the other element(s)

Other factors such as the condition of the roots and conducting tissues, abnormal soil conditions, and damage to the roots from nematodes or diseases, may affect the results of leaf sample analysis and should be considered in the interpretation of results. Physical damage to limbs, trunks, or roots, whether by mechanical means or injury by rodents, or insect or disease problems may also affect nutrient uptake or translocation within the tree. Likewise, injuries to buds or foliage as a result of low temperature during winter, spring frosts, herbicides, or various pesticides can influence the growth and nutrient content of leaf samples.

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