Understanding and Correcting Nutrients in Nut Crops

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Introduction

Deciduous trees require 14 elements for normal growth and reproduction. These essential elements are classified as either macronutrients (N, P, K, Ca, Mg, S) or micronutrients (Fe, Mn, Cl, B, Cu, Zn, Ni, Mo) based on the concentration at which they normally exist in plants. Each is essential for particular functions in the plant. Macronutrients are the basis for organic compounds, such as proteins and nucleic acids. They also serve in the regulation of pH and water status of plant cells. Micronutrients serve as the constituents of enzymes (compounds which provide a new chemical reaction pathway with a lower activation energy), plant growth regulators such as auxin, cell membranes, and the photosynthetic pathway. Sodium (Na), although present in plant tissue, is not an essential element for deciduous tree crops. Plant nutrients are also important in disease resistance and fruit quality, and the balance between the various elements can affect plant health and productivity. Certain elements (Cl, B, and Na) commonly reach toxic concentrations in plant tissue when excessive levels exist in the soil or irrigation water. This imbalance can lead to other deficiencies, and severely impact the productive ability of the plant. Optimization of nut crop productivity and orchard quality requires an understanding of the nutrient requirements of the tree, the factors that influence nutrient availability and demand, and the methods used to diagnose and correct deficiencies. This paper will discuss important principles of plant nutrition that are the basis for developing a sound nutrition management program.

Factors Affecting the Nutrient Supply to the Plant

Although nutrients are taken up into the tree along with water, the absorption of water and nutrients involve different physiological processes. Water uptake depends on physical forces in the soil and within the plant, which are passive and dependent upon a concentration gradient. In contrast, nutrient absorption is selective, requires expenditure of respiratory energy, and involves specialized cells and tissues located at the tips of roots. The efficiency and rate of nutrient absorption are greatest in the root tip region, but there is increasing evidence that other portions of the root are also capable of nutrient uptake. The fine, brown roots are also thought to contribute substantially to nutrient uptake because of their length and surface area.

Soil factors such as soil type and texture, soil moisture, pH and soil depth, as well as plant factors including root distribution and density, rootstock, fruit load and shoot growth, all influence deciduous tree nutrition. Soil pH is a measure of the hydrogen ions present in the soil nutrient medium readily available for plant uptake. Its log scale ranges from 1 to 14, with 1 being highly acidic and 14 highly basic, or alkaline. A pH of 7 represents equal amounts of acid and base and is therefore neutral. Soil pH has a significant effect on nutrient availability. High pH (>7.5) greatly limits the solubility of many elements (i.e. Zn, Cu, Mn, Fe), while low soil pH can lead to deficiencies of P or Ca and toxicities of Al, Fe or Mn. Similarly, low soil temperature, poor aeration, or the presence of a hardpan can limit the plant's ability to obtain nutrients by limiting root growth and health.

Since all nutrients are supplied as dissolved ions in the water flow to roots, poor irrigation practices resulting in low soil water content reduce the availability of nutrients for plant uptake. Dry soil conditions also limit the concentration of nutrients (such as potassium) in soil water readily available for plant uptake. Under these circumstances, addition of more nutrients may not alleviate the deficiency; the solution lies instead in correction of the soil conditions that limit nutrient availability.

Amendments intended to change pH or improve soil structure can influence nutrient availability to the plant. However, it is essential that all aspects of the orchard and the production system be considered before deciding on such a course of action.

Environmental factors such as temperature, disease, salinity and the presence of high levels of specific elements may also influence plant nutrition. Each factor affects plant nutrition by influencing either the availability of nutrients to the root or the effectiveness of root uptake of the elements. Disease and salinity affect nutrient uptake by limiting root growth, and hence, root volume. Excessive salts within the root zone also decrease the percentage of available water taken up by the tree before the energy gradient induces plant stress and limits productivity.

DIAGNOSING ORCHARD NUTRIENT STATUS

Soil analysis

Soil analysis provides information on nutrient content and the soil chemistry affecting its availability. Cation exchange capacity (CEC, the ability of a soil to retain cations for subsequent release into the soil solution), pH, and salinity all affect the availability of nutrients present in the soil. It is **CRITICAL** that adequate soil analyses be performed **PRIOR** to orchard establishment for accurate assessment of the site for nut crops. **These samples are directly, and almost exclusively, focused on the salinity characteristics of the soil**. **High salinity must be corrected prior to planting to avoid poor orchard performance and tree loss**. Other soil chemical conditions, such as high pH combined with high soil lime (calcium carbonate) limit zinc, iron, manganese, and copper availability. The saturation percentage (SP) can also be used as a general guide to soil texture and water holding capacity. Pre-plant soil assessment often reveals chemical or physical conditions unsuitable for tree crops and thus saves the investor from serious financial loss.

Established orchards benefit from soil analysis by assessing the impact of fertilization and irrigation management. Monitoring trends in soil nitrate-nitrogen concentration within the root zone are especially important to avoid groundwater contamination and excessive fertilizer expenditures. It is also essential for a proper investigation into the cause for isolated poor tree performance. Soil analysis is most valuable when combined with a visual symptom assessment of the tree and tissue analysis. **Trees are complex, long-lived perennial plants whose nutritional status represents an integration of age and cultural practices in addition to soil nutrient availability!** Of greatest concern is the nutritional status of the tree– and not the soil. Hence, soil analysis is usually recommended after a nutrient deficiency is suspected from the presence of foliar symptoms and tissue testing.

Collecting soil samples representative of the entire orchard is challenging and expensive. Deciduous tree roots engage a large volume of soil, and soil type often varies within the orchard. Soil chemistry also differs with depth from the surface. Surface soil chemistry and its nutritional status can be quite different from soil only one foot below it. Therefore, soil samples should be taken from the profile where roots are most active (typically the upper four feet of the profile). For a thorough analysis, soil samples should be taken in single-foot increments from five to ten different locations within the area of the orchard in question. The multiple samples taken from the same depth are then composited for submission to the laboratory. This process should then be repeated in other areas of the orchard, and compared to samples taken from the area of highest productivity. The number of areas sampled depends upon the different soil types occurring within the orchard. Nutrient deficiencies can be associated with soil differences (such as old creek beds), differences in topography, sand deposits, cuts or fills, or old coral and pasture sites.

When soil sampling, also consider the effect that irrigation method has on root distribution and soil fertility within the root zone. Flood or basin irrigation applies water over a large area relatively uniformly and results in wider distribution of roots and area for nutrient uptake. Hence, sampling near the edge of the tree canopy but to one side of where fertilizer applications are made provides a reasonable assessment of soil nutrient status. With mini-sprinkler systems, sampling should be performed within the wetted pattern, but avoiding its edge where salts may accumulate. Orchards under drip irrigation require sampling approximately half-way between the emitter source and the edge of the wetted area. Due to the large difference in soil water content with distance from the emitter source, sampling too close to the emitter can lead to erroneously low soil nutrient assessment of some elements, particularly nitrogen because it exists as a leachable form in soil solution.

Interpretive guides for soils

The value of soil analysis as a guide to fertilization practices is limited by the inability to predict the relationship between soil chemical analysis and plant nutrient uptake. **Soil analysis is best suited for assessment of pH, saturation percentage, CEC, and salinity**. Diagnosis of observed nutrient deficiencies can be aided by knowing the soil pH, because it affects the availability (not the quantity!) of mineral nutrients. Nutrients may be abundant in the soil, but in order for them to be available for plant uptake, they must be in “the soil solution”. Soil solution is defined as the elements present in the water readily available for plant use. A low pH (<5.5) may result in deficiencies of Ca, Mg, P or Mo and perhaps excesses of Mn, Fe or Al. High pH (>7.5) may immobilize Mn, Zn, Fe or Cu, making them unavailable to the plant. High levels of calcium carbonate (lime) in the soil can induce deficiencies of Fe, Mn or Zn and may also make pH adjustment of the soil difficult. The presence of any soil physical characteristic that limits root growth or water penetration is also likely to affect nutrient uptake.

Recent research on the effects of salinity in pistachio indicates it has significantly greater salt tolerance than other nut crops. No yield reduction was recorded using irrigation water with an EC_w (Electrical Conductivity) of 8.0 dS/m and soil with an EC_e (electrical conductivity of the saturation extract) of 9.4 dS/m (at 25^0 C). Soil chloride (Cl) and sodium (Na) in excess of 50 meq/liter were tolerated without negative effects. Experience in saline areas on the Westside of the San Joaquin Valley suggests pistachios tolerate 20-30 meq/l of Na and Cl and up to 4 ppm Boron (B) in the soil without adverse impacts on yield. Pistachios may be tolerant of exchangeable sodium percentages (ESP) as high as 15%. However, high exchangeable sodium levels in the surface soil can cause structural deterioration (soil particles repel one another and reduce the air space for water movement) and subsequent water infiltration problems. Hence, water stress can be an indirect but significant effect of high soil sodium levels in the surface soil.

The soil conditions under which pistachios can be successfully grown are **NOT** those suitable for walnuts, almonds or pecans! Walnuts thrive on the best alluvial soils existent in the San Joaquin Valley. Ideal walnut soils have total salt levels (ECe) of 1.5 dS/m or less, a sodium absorption ratio (SAR) less than 5.0, chloride concentration less than 5.0 meq/L, and boron levels of 0.5 ppm or less. Depending upon the rootstock selected, almonds can tolerate slightly higher salinity levels, but they should not be considered salt tolerant. Growing almonds in soils higher than optimal salinity presents significant problems associated with specific salt toxicity to plant tissues which limit productivity and longevity. Almonds grown on soils with elevated sodium or total salinity also experience major problems with soil water infiltration, resulting in sustained plant stress and reduced productivity, especially during the extended harvest period. Prolonged soil surface wetness associated with low infiltration also greatly increases the risk of crown and root rot diseases. Remember; roots need oxygen as badly as humans do!

Plant analysis

Leaf analysis is more useful in diagnosing mineral deficiencies and toxicities in tree crops than soil analysis. The mineral composition of a leaf is dependent on many factors, such as its stage of development, climatic conditions, availability of mineral elements in the soil, root distribution and activity, irrigation, etc. **Leaf samples integrate all these factors, and provide an estimate of which elements are being adequately absorbed by the roots**. The main limitation with leaf analysis is that it does not tell us **why** the nutrient is deficient. Leaf tissue can also vary significantly in nutrient content within individual trees, as well as between locations within a single orchard. **To maximize the value of leaf analyses, one must therefore adhere to strict standardization of the sample procedure and locations sampled**.

Sampling procedure

Concentrations of leaf nutrients vary with time, leaf age, position in canopy and the presence or absence of fruit. Trees within an orchard may also vary in their nutrient status as a result of differences in soil fertility, water availability or light exposure. Therefore, it is essential that sampling techniques be standardized if valid comparisons are to be made. **Choice of sampling method also varies depending on the purpose of the survey**. If the aim is only to identify the problem in an isolated tree or area, then sampling just a few poor and some good trees should suffice. If a determination of overall nutrient status in a large orchard is required, then more extensive sampling of trees from many sites will be required.

The correct leaf sampling procedure differs slightly by nut commodity. For pistachios, fully expanded sub-terminal leaflets (pistachios typically have five leaflets per compound leaf) are randomly collected from **non-fruiting branches** at about six feet from the ground. Four to ten leaves are typically collected per tree, and 10-20 trees are sampled in each orchard block. **Leaves sprayed with micronutrients typically cannot be analyzed for that nutrient since the surface contamination cannot be removed.** Hence, no leaves having received in-season nutrient sprays for the elements of interest should be sampled. This means sampling before a nutrient treatment, or sufficiently long after treatment to allow for new growth. Orchards with specific micronutrient problems may even justify the labor required to temporarily bag shoots prior to a nutrient spray for sampling at a later date. The challenges associated with acquiring an accurate tissue sample re-enforce the value of visual nutrient symptom assessment, especially in the case of zinc, copper, boron, and nitrogen. Samples should be kept in labeled **paper** bags and submitted to the analytical service within 24 hours of collection. Leaves are living organs! Process them promptly! Pistachios are sampled from late July through August. The pistachio critical levels established through experimentation and observations (Table 1) are based on this timing. However the comparison of good trees against poor ones can be done at any time. Samples collected at times other than from late July through August may have nutrient concentrations different than those recommended in the critical values table and must be interpreted with care.

For **walnuts,** the least change in leaf nutrient concentration occurs between late June and early July. The sample date is different from pistachio due to the large boron requirement of pistachio, which continues to rise in the leaf tissue until nut maturity. Walnut nutrient studies performed over decades by UC researchers have examined leaves, petioles, hulls, nuts, stems, and even bark as the basis for critical level establishment. It was determined that fully expanded leaves from spurs were the most reliable. **No designation is presently made between selection of fruiting over non-fruiting walnut spurs**. Select spurs from as high as possible, but at least six feet off the orchard floor. Each sample should consist of about 50 leaflets (a walnut leaf contains three to five leaflets on a single petiole or stem). Critical and adequate tissue levels for July can be found in Table 2.

UC guidelines recommend tissue **sampling almonds** from July through mid-August. The critical values reported in Table 3 are based on **nonfruiting spurs sampled in July**. Collect approximately 100 spur leaves at least six feet off the ground. Leaves within the sample must be from the same cultivar, on the same rootstock, and from trees of similar growth status. Sample different cultivars and trees of questionable condition separately to better assess orchard nutrient status. Label the samples so you can refer to their location later. Do not delay in delivery to the laboratory.

Pecans have multiple leaflets within a single leaf, and there are several leaves alternately opposed along a current season's shoot. **Sample two leaflets opposite one another mid-way on the leaf, and select a compound leaf that is mid-way along the shoot**. All four sides of the tree should be sampled, and a sample should represent about 60 leaves. July is the best time to sample in California. Table 4 provides the suggested nutrient levels typically used by California. Additional information is available at: http://cals.arizona.edu/pubs/diseases/az1410.pdf.

Table 1. Pistachio Critical and Suggested Levels for August Leaf Samples

Element	Critical Value	Suggested Range	Reference
Nitrogen (N)	1.8%	2.2 -2.5%	Weinbaum, et.al. 1988, 1995
Phosphorus (P)	0.14%	0.14-0.17%	
Potassium (K)	1.6%	1.8 - 2.0 %	Brown, et.al. 1999
Calcium (Ca)	1.3% (?)	1.3-4.0%	
Magnesium (Mg)	0.6% (?)	0.6-1.2%	
Sodium (Na)	(?)	(?)	
Chlorine (Cl)	(?)	0.1-0.3%	
Manganese (Mn)	30 ppm	30-80 ppm	
Boron (B)	90 ppm	150-250 ppm	Uriu,1984; Brown, et.al.,1993
Zinc (Zn)	7 ppm	10-15 ppm	Uriu and Pearson.1981, 1983,1984,1986
Copper (Cu)	4 ppm	6-10 ppm	Uriu, et.al. 1989

ppm = parts per million or milligrams/kilogram dry weight. *% = parts per hundred or grams/kilogram dry weight*

Table 2. Walnut Critical and Suggested Levels for July Leaf Samples

Element	Critical Value	Suggested Range
Nitrogen (N)	2.1%	2.2 -3.2%
Phosphorus (P)	0.10%	0.14-0.3 %
Potassium (K)	1.0%	1.2 -1.7 %
Calcium (Ca)	0.9% (?)	>1.0%
Magnesium (Mg)	(?)	> 0.3%
Sodium (Na)	(?)	< 0.1%
Chlorine (Cl)	(?)	0.1-0.3%
Manganese (Mn)	(?)	> 20 ppm
Boron (B)	20 ppm	40-300 ppm
Zinc (Zn)	<18ppm	20-30 ppm
Copper (Cu)	4 ppm	6-10 ppm

Table 3. Almond Critical and Suggested Levels for August Leaf Samples

Element	Critical Value	Suggested Range
Nitrogen (N)	2.0%	2.2 -2.5%
Phosphorus (P)	< 0.1%	0.1-0.3%
Potassium (K)	1.0%	1.4–1.8 %
Calcium (Ca)	(?)	> 2.0%
Magnesium (Mg)	(?)	> 0.25%
Sodium (Na)	(?)	< 0.25%
Chlorine (Cl)	(?)	< 0.3%
Manganese (Mn)	(?)	> 20 ppm
Boron (B)	30 ppm	30-65 ppm
Zinc (Zn)	15 ppm	18-30 ppm
Copper (Cu)	4 ppm	6-10 ppm

Table 4. Suggested Levels for Pecan Leaf Tissue Sampled in July

Element	Suggested Range
Nitrogen (N)	2.7 -3.0%
Phosphorus (P)	0.18-0.30%
Potassium (K)	1.25 – 1.5 %
Calcium (Ca)	1.0-2.5%
Magnesium (Mg)	> 0.30%
Sodium (Na)	< 0.10%
Chlorine (Cl)	< 0.3%
Manganese (Mn)	80-300 ppm
Boron (B)	30-80 ppm
Zinc (Zn)	50-200 ppm
Copper (Cu)	> 4 ppm

Interpreting leaf analyses

Results of tissue analysis are reported as the concentration of a nutrient on a dry weight basis. For **macronutrients**, concentrations are reported on a percent basis (grams of nutrient per 100 g dry weight), while **micronutrients** are reported in parts per million (microgram nutrient per gram dry weight). For each element, the laboratory will usually identify the 'Critical Value' (CV), or the 'Adequate Range' to aid in interpretation of the results. 'Critical Value' or 'Critical Level' refers to the nutrient concentration at which plant yield is estimated to be at 95% of maximum, or at which distinct symptoms of deficiency are present. Tissue nutrient concentrations below this level will result in poor plant growth and reduced yields. The 'Adequate Range' refers to the nutrient concentration range at which growth is optimal. Above this nutrient concentration, plant growth may be inhibited by certain nutrients such as Boron and Chloride, which burn plant tissue at high levels. There is no correlation between macronutrient concentrations above the adequate level and increased plant performance. In fact, several studies have shown predisposition to diseases and poor fruit quality with abnormally high nitrogen levels. Excessive nitrogen in the plant tissue is also indicative of soil applications which exceed demand and plant uptake capacity. The excess and highly mobile nitrogen can then be easily leached beyond the root zone and into precious groundwater. Excessive potassium fertilization is quickly bound to soil particles electrostatically, so leaching is not a concern. Over application of potassium is also less likely due to its high cost. Critical values are crop specific. It is essential that the nutrient recommendations supplied by the testing laboratory reflect comparison to the adequate and critical values for the nut crop in question, since nutrient requirements differ significantly between crops. This is especially true for pistachio, since it has a much higher boron and potassium requirement than other deciduous tree crops and also tolerates more salinity.

Although valuable as a tool to assess orchard nutritional status, critical values are **not** absolute. They are often based on detailed visual assessment of general tree health and not necessarily on yield or crop quality research. Some nutrients, such as boron and zinc during bloom and potassium and nitrogen during pistachio kernel filling, may also require temporary supplementation to optimize production (Brown, 1993, 1999; Weinbaum, 1995). Ideally, scientific fertilization practices would replace that amount consumed by the plant in growth and crop production. To achieve this objective, the total annual requirement of each nutrient would have to be determined, as well as the percentage removed from the orchard system as crop. Critical values for nitrogen, potassium, boron, zinc, and copper have been established for most nut crops from research projects conducted over the decades. Others are estimates from field observation and levels deemed acceptable in other deciduous crops. Armed with knowledge of visual symptoms, soil and tissue sampling procedures, and results from studies assessing specific annual nutrient consumption, growers and crop consultants should be capable of developing effective nutrient management programs which result in highly productive and healthy orchards.

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