DIAGNOSING AND CORRECTING NUTRIENT DEFICIENCIES

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Pistachio 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 normally present in plants. Each is essential for particular functions in the plant. Plant nutrients are also important in disease resistance and fruit quality, and the balance between the various elements can affect plant health and productivity. In addition to the essential nutrients, several elements (Cl, B, Na) may be toxic to the tree if present at excessive levels in the soil or irrigation water. Optimization of pistachio productivity and quality requires an understanding of the nutrient requirements of the tree, the factors that influence nutrient availability and the methods used to diagnose and correct deficiencies. This chapter will discuss important principles of plant nutrition to assist in utilization of specific recommendations provided at its conclusion.

THE SUPPLY OF NUTRIENTS TO THE PLANT

Although nutrients are taken up into the tree along with water, the absorption of these two essential plant requirements involve different physiological processes. Water uptake depends on physical forces in the soil and within the plant. Selective and active absorption of nutrients requires expenditure of respiratory energy and the existence of cells and tissues found within 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 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, rootstock, fruit load and competition, all influence the nutrition of the tree. Environmental factors such as temperature, disease, salinity and the presence of high levels of other ions may also influence plant nutrition. Each 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.

Plants may be deficient in one or several nutrients as a result of the following conditions.

Unfavorable soil conditions for nutrient uptake

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, low soil water content simultaneously reduces the availability of nutrients for plant uptake.

Low soil water content has the additional effect of limiting 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.

DIAGNOSING ORCHARD NUTRIENT STATUS

Soil analysis

Soil analysis typically provides information on available nutrient levels as well as soil conditions such as pH, cation exchange capacity (CEC, the ability of a soil to retain cations for subsequent release into the soil solution), and salinity that may be important in determining the cause of a deficiency. Soil analyses performed prior to orchard establishment allows for accurate assessment of the site for pistachios and identifies soil related issues requiring correction. Certain conditions, such high pH combined with high soil lime (calcium carbonate) can be predicted to limit zinc, iron, manganese, and copper availability. Established orchards benefit from soil analysis by assessing the impact of fertilization and irrigation management and aiding investigations into the cause for isolated poor tree performance. Soil analysis is most valuable when conducted in combination 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 not the soil. Hence, soil analysis is usually recommended after a nutrient deficiency is suspected from foliar symptoms and tissue testing.

Collecting soil samples representative of the orchard as a whole is challenging. Pistachio tree roots spread through a large volume of soil, and soil type is usually variable within the orchard. Soil chemistry differs with depth. Surface soil can be quite different from the soil just a foot down. Soil sampling should be taken from the site of most active root growth, which is commonly the upper four feet of the profile. For a thorough analysis, soil samples should be taken from three to ten different spots around the tree and composited. Replicate samples should then be taken across the orchard. It is quite common for different soil types to occur within a single orchard. Nutrient deficiencies can be associated with localized soil differences, such as those associated with old river beds, differences in topography, sand deposits, cuts or fills, or old coral or pasture sites. In these cases, it is necessary to sample from within each soil type and to relate the findings only to trees growing in that soil type. This difference in soil type can be very localized and may only impact a few trees in an orchard (Reisenauer, et al. 1983).

It is also important to consider the effect 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 of 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

The value of a 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.

In general, determination of soil pH can aid in the diagnosis of nutrient deficiencies. Soil pH affects the availability of mineral nutrients. 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. Recent research on the effects of salinity in pistachio indicates it has significantly greater salt tolerance than other nut crops (see Managing Salinity, chapter 15). 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 suggest 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. The long-term effect of excess soil boron (>4 ppm) may be reduced photosynthesis from leaf necrosis that can affect 50% of the total area. 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 that lead to water infiltration problems. Hence, water stress can be an indirect but significant effect of high soil sodium levels.

High levels of calcium carbonate (lime) in the soil can induce deficiencies of Fe, Mn or Zn and may also make acidification of the soil difficult. The presence of any soil physical characteristic that is likely to limit root growth or water penetration is also likely to affect nutrient uptake.

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).

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 accepted leaf sampling procedure is as follows: Fully expanded sub-terminal leaflets 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. Samples should be kept in labeled paper bags and submitted to the analytical service within 24 hours of collection.

Sample from late July through August. The critical levels established through experimentation and observations (Table 1) are based on this timing. However the comparison of good tree against poor ones, can be done at any time. Samples at times other than from late July through August may have nutrient concentrations different than those recommended in the critical values tables and must be interpreted with care.

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 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 nutrient toxicity, or the soil concentration may be so high that plant uptake capacity is exceeded and the risk of leaching beyond the root zone exists. Nitrogen is the element of greatest concern, because of its potential to reach the groundwater. 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 pistachio, since nutrient requirements can differ significantly between crops. This is especially true for pistachio, since it has a much higher boron 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 based on general tree health and not yield or crop quality. Some nutrients, such as boron during bloom and potassium and nitrogen during kernel filling, may require supplementation for short periods to optimize production (Brown, 1993; 1999; Weinbaum, 1995). Ideally, fertilization would replace that amount consumed by the plant in growth and crop production. To achieve this objective, the total annual requirement of each nutrient must be determined, as well as the percentage which is removed from the orchard in the form of crop. A model has been developed for mature pistachios that is useful in predicting the nitrogen and potassium requirements and fertilization strategies (Rosecrance et al). It can be accessed at the following website: http://fruitsandnuts.ucdavis.edu/PistachioNKModel/pistachio_nk_model.html.

Critical values for nitrogen, potassium, boron, zinc, and copper have been established from several research projects. Others remain estimates from field observation and levels acceptable in other deciduous crops (Table 1). For several elements (nitrogen and boron and the toxic elements Na and Cl), it is equally important to ensure that nutrient concentrations do not exceed the optimum, as impaired plant growth may occur.

IDENTIFYING COMMON NUTRIENT DISORDERS

Nitrogen (N)

The macronutrient, nitrogen, is the most widely needed fertilizer element in pistachios. Nitrogen is used by plants to synthesize amino acids and nucleic acids that are necessary for all functions of the plant. Nitrogen deficiency symptoms will eventually appear in most orchards if N is withheld. Annual leaf tissue analysis can ensure that sufficient N is applied to meet the crop needs without wasting money on unnecessary application, without encouraging vegetative growth at the expense of reproductive growth, and without polluting surface and ground water supplies.

Shoot growth is reduced in nitrogen deficient pistachios. Shoots are thinner, shorter and in more severe deficiencies have reddish bark. Nitrogen is mobile and new leaf production is at the expense of older leaves if N is deficient. Young leaves pale as older leaves turn yellow and drop from the tree early. Excessive leaf drop results in a tree with sparse foliage. The petioles and midribs of N deficient leaves become red (Gonzales, 1985). Nut yield will decrease with increasing N deficiency. Over or under irrigation or Verticillium wilt disease can produce similar symptoms.

Table 1. 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 (Bo)	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

Potassium (K)

The macronutrient, potassium, is an activator of many plant enzymes. Potassium has important functions in plant water relations where it regulates ionic balances within cells. Potassium regulates the leaf stomata opening and subsequently the rate of transpiration and gas exchange. Plants also need potassium for the formation of sugars and starches, for the synthesis of proteins, and for cell division. It increases the oil content of pistachios and contributes to its cold hardiness.

Mature, heavy bearing pistachio trees have been shown to take up approximately 200 pounds/acre of K during the on-year and 100 pounds/acre during the off- year. Much of this K is in nuts and is removed from the orchard at harvest (Brown, et.al. 1999). Since potassium is used in large quantities by the developing crop, there is considerable potential for K deficiency to develop if fertilizer is not applied for many years. Deficiencies are more likely to appear in lighter soils where reserves are less. Potassium deficiency has been found in limited areas in California including the Chico area, southwestern Santa Clara Valley, some sandy soils of the San Joaquin Valley, and some soils of Santa Barbara County.

Potassium-deficient leaves begin showing symptoms in early to mid-summer. Leaves become pale (resembling N deficiency) and the edges of the leaflets later fold upward and curl in revealing a grayish cast. The symptoms are most pronounced on older leaves of current shoots. Potassium-deficient trees slow in growth and produce smaller leaves. More severe deficiency symptoms include yellowing of the leaf, which starts at the tip and progress down the curled leaf margins. The affected area widens with time. The yellow leaf tissue eventually turns brown and dies resembling sodium and/or chlorine toxicity. Trees moderately deficient in K may look normal but produce yields below their potential.

Magnesium (Mg)

Magnesium, also a macronutrient, is an activator for many enzymes involved in energy transfer and growth processes. It is a component of chlorophyll and thus is essential for photosynthesis. Magnesium deficiency has not been widely reported in pistachio. Deficiencies are more likely to occur in sandy and acid soils. On the west side of the San Joaquin Valley pistachios are grown on alkaline, highly calcareous and boric soils. These soils may fail to provide sufficient available magnesium for optimal tree growth due to antagonistic competition for uptake by excessive calcium and other cations present on the soil colloids. In a similar manner, high rates of gypsum may induce magnesium deficiency in some soils.

Deficiency symptoms appear mid-season on the lower leaves of shoots as tip and lateral margin yellowing, or as interveinal yellowing. The leaf margins may later become scorched. The scorching progresses inward, leaving a green, inverted 'V' at the base of the leaf. In severe deficiency, the interveinal yellowing may turn to scorching. Scorched leaves will then drop. Magnesium deficiency may be confused with potassium deficiency. Suspected Mg deficiency should be confirmed by leaf tissue analysis.

Zinc (Zn)

The micronutrient, Zinc, is the third most common deficiency in deciduous trees. It is needed in a number of enzymes as well as in membrane integrity and hormone synthesis. Zinc is required to make auxin, the plant hormone responsible for cell elongation and growth. Zinc also is needed to make chloroplasts, the leaf component that contains chlorophyll.

Zinc deficiency is widespread throughout all pistachio growing areas. It is prevalent in sandy and older, oxidized soils of the San Joaquin, Sacramento, and southern interior valleys. Old corral sites and orchards with regular applications of animal manure are prone to zinc deficiency due to their high phosphorous levels. Zinc is rendered less available for plant uptake in soils with pH values of 8.5 and greater. Zinc deficiency prevails in younger tissue due to its immobility.

Zinc deficiency symptoms appear early in the season, especially when levels are quite low. Newly planted and early bearing trees are particularly prone to zinc deficiency. Spring symptoms are delayed opening of vegetative and flower buds, that can be delayed as much as a month. This gives the appearance of cold injury to the one year-old wood in the upper canopy. When vegetative buds do open, the terminal leaves are small, chlorotic (i.e. yellow) and appear in tufts, giving rise to the term "little-leaf." Severe deficiency also causes dieback of young terminal shoots. Marginally deficient leaves are only slightly reduced in size and show chlorotic areas between the lateral veins. These symptoms can be masked by growth later in the season. However, deficient leaves remain so the entire season. Zinc deficient leaves have a distinct wavy leaf margin. Nuts on Zn-deficient shoots are markedly smaller in size and much redder than normal. The number of nuts per cluster is also dramatically reduced and most of them can be blanks.

Symptoms of Zn deficiency may be restricted to terminal leaves on individual branches of a tree. A tree may have several Zn-deficient limbs while the rest of the tree appears healthy. This pattern of Zn deficiency further demonstrates the immobile nature of Zn within the tree.

Boron (B)

Boron, also a micronutrient, is required for cell wall structure and may also have a role in maintaining cell membrane integrity. Reproductive structures have been shown to be particularly sensitive to B deficiencies. Their demand is higher than that of vegetative growth (Brown et al. 1993). The boron requirement in pistachio is the highest known for any tree crop. Boron appears to be extremely important in pistachio flowering, pollen viability and nut set. Severe B deficiency has been recognized in limited areas including the Sierra Nevada foothills of central California and sometimes in Lake and Mendocino Counties. Moderate deficiencies are common in orchards on the east side of the San Joaquin Valley, especially on sandy and moderately acidic soils.

Boron deficiency symptoms appear early in the season as tip dieback of growing points and deformity in young leaves. Shoot tips die back or the terminal buds remain dormant. Lateral, normally dormant buds, sprout into growth with short internodes. This new growth may then also dieback. In some shoots brown-gray areas of bark distributed irregularly over the shoot may precede this dieback. These shoot-growth abnormalities produce a tree that is stunted with a bushy appearance.

Pistachio leaves deficient in boron are yellow and crinkled. The leaf tips curl upward and sometimes become so misshapen that they appear bract-like in form. Mature leaves are thick and feel leathery to the touch. They are can also become brittle and drop prematurely. The petioles and stems may also be thickened, corky, cracked and shortened. Entire flower clusters on young, boron-deficient pistachios often drop during bloom and litter the orchard floor.

Toxicity resulting from excessive boron is occurring more frequently as growers are increasingly forced to use lower quality water. Symptoms begin showing in mid to late summer as boron accumulates in the leaf tissue. First the tip, and then the margin of the leaves become brown and necrotic. In severe cases, the necrotic tissue progresses into the interveinal areas, and the margins of the leaflets curl upward. Every leaf on the tree may be so severely scorched that the tree appears as if it were injured by fire.

Copper (Cu)

Like zinc, copper is a component of many enzymes in the plant and plays a role in energy metabolism. Deficiencies of copper are relatively common in pistachio. Like zinc, copper deficiency is more likely in newly planted and early bearing orchards. Commonly zinc and copper deficiency symptoms occur together.

Copper deficiency can be quickly differentiated from zinc because its symptoms appear in mid-summer, not during early spring. The immature leaves near the shoot terminal first develop tip burn and become somewhat heart-shaped. Slight shriveling of the shoots then occurs, and small dark lesions develop near the shoot tip. Scorched leaves defoliate. Terminal dieback subsequently occurs in late summer. Some affected shoot terminals curl downward, resembling a Sheppard’s crook. Kernels are often badly shriveled.

Chlorine toxicity (Cl)

Excess of chlorine produces leaf symptoms similar to B toxicity. Both produce leaf tip and marginal burn. In severe cases, dead tissue at the tip increases during the growing season such that the terminal half or more of the leaf may die by late summer. Because of the similarities between B and Cl toxicity, it is necessary to conduct leaf analysis when these symptoms are observed. Analysis of soil and irrigation water is necessary to identify the source. Some evidence suggests that pistachio may be able to exclude the uptake of sodium and chlorine from the soil. Thus leaf tissue samples may not accurately indicate high salt levels present in the soil. Thus, the salinity effect on limiting water availability to the tree can be overlooked as the cause for water stress symptoms.

Sodium (Na) toxicity

Sodium toxicity is difficult to separate from chlorine toxicity as the two ions often occur together. Symptoms of excessive sodium are similar to potassium deficiency symptoms.

CORRECTING COMMON NUTRIENT DISORDERS

Nitrogen (N) deficiency

April is a good time for nitrogen fertilization. The efficiency of nitrogen uptake from the soil before early leaf out is essentially zero, because nitrogen uptake occurs simultaneously with water use. Consequently, applications made in the winter are subject to leaching beyond the major root zone at three to four feet, especially in production areas averaging 15 or more inches of rainfall. Pistachios beginning the off-year are lower in stored N than on-year trees (Weinbaum, 1995). Nitrogen uptake in pistachio occurs primarily between mid-May to late August. Nitrogen uptake efficiency improves with multiple applications at lower rates under drip or low volume compared to "slug" treatments. Experience suggests that only about half the nitrogen rate is required under drip and low volume compared to furrow. As much as 50% of the N applied by water run or furrow can be lost from volatilization and leaching past the root zone.

The total N requirement for on-year trees was calculated at about 175 pounds. Research suggests reducing off-year applications by one-third of the on-year rate. The demand for N and the tree's capacity to take N up from the soil is greater in the on-year. Nitrogen uptake is largely driven by crop load since nut fill accounts for 90% (about 100 pounds,) of the accumulated seasonal nitrogen. Since off-year trees are lower in stored N, one might consider applying half the season's N prior to shell hardening and the remainder in July and August. (Weinbaum, et.al.,1988, 1991,1993,1995)

For on-year trees, apply between 200 and 225 pounds of actual N depending upon crop load, tree size, vigor and method of application. Shortly after bloom, assess the crop load, check past tissue analyses in on-years and then begin N fertilization in April at 30 to 75 pounds depending upon irrigation method. Avoid N application and excessive irrigation during June when neither shell or kernel development is occurring. By the third week in June, irrigate heavily (assuming your infiltration rates are not limiting water intake) to refill the upper three feet of the soil profile in preparation for kernel filling. This irrigation might be accompanied by 50 to 75 pounds of actual N per acre. Subsequent, frequent irrigations would have nitrogen applied up to the first week in August. Depending upon crop load, nitrogen application during kernel filling could reach 175 pounds.

Adding high levels of N to the soil early in the season during an on-year will not result in greater plant uptake unless the tree is deficient. Available data indicates pistachio growth and yield is not improved with July tissue levels above 2.5 percent. Results from a six-year field experiment in which annual nitrogen application rates reached 500 pounds of N showed no yield increase above the 3,750 pounds of split nuts obtained with only 200 pounds of N (Ferguson et al, 1987). Sampling by Dr. Kay Uriu, UCD Professor Emeritus in Pomology indicates mid-April levels would need to be 4.25% to have 2.5% in July. The suggested range in August tissue samples is presently 2.2-2.5% (Weinbaum, et. al. 1988, 1995).

A more scientific approach to pistachio nitrogen fertilization involves monitoring soil and tissue nitrogen levels in the spring before applying nitrogen. Soil levels of 25 ppm nitrate nitrogen per foot of soil would be considered high in deep, well-drained soil with a rooting profile of four to five feet. Five ppm nitrate-N would generally be low. Soil texture must also be considered in this method. Visual observations of plant growth and leaf color should be included in your nitrogen management program. Soil nitrogen testing only provides an indication of nitrogen availability. Plant uptake is dependent upon root health, water management, soil temperature, crop load, and overall plant demand.. In addition to providing adequate nitrogen for optimal tree performance, it is also important to minimize nitrogen leaching past the root zone and into the groundwater. Rising material cost and possible future regulation of usage are reasons for more scientific nitrogen fertilization practices.

Potassium (K) deficiency

Injecting or soil banding K fertilizers in neutral, loam soils at rates of 100 to 200 pounds per acre of K_2O was found to increase soil and leaf K concentrations. Increases in nut weight and split nut percentage along with reduced blanking resulted in higher yield (Brown and Zhang, 1999). The positive response to K fertilization was found regardless of whether potassium chloride (KCl), potassium sulfate (K_2SO_4) or potassium nitrate (KNO_3) was the source of the K. This research was conducted on San Joaquin, Yolo and Arbuckle soil series. The greatest response to K fertilization was on the San Joaquin soil series in which applied K is not readily fixed to the Koalinite clay predominant in that soil type. Young, alluvial soils such as those on the west side of the San Joaquin Valley contain Montmorillonite clay. This clay type fixes applied K readily and makes it less available for rapid plant uptake. Some soils will reduce the plant availability of applied K fertilizers through soil chemical processes, hence soils high in certain clay minerals may not respond as positively to K fertilization as those described. To optimize the response to K fertilization, inject it into the irrigation water during periods of greatest tree demand (nut fill). Potassium fertilizer rates can be adjusted based on a suggested leaf tissue concentration of 2.0 percent by weight. Excessive K fertilization can interfere with the uptake of other nutrient cations like Ca and Mg.

Zinc (Zn) deficiency

Most soils are not truly low in zinc. Rather, the chemistry of the soil prevents Zn from being sufficiently available to the plant. Correcting Zn deficiency through soil applications can therefore be excessively slow and expensive. Soil texture and pH are the primary factors affecting the efficacy of Zn fertilization. In sandy soils, trenching 2 to 6 pounds zinc sulfate 36% **per tree**, depending on size, has produced good response. Soil treatment becomes less effective in fine-textured soils or soils with high pH. Fertigating 70 pounds per acre of zinc sulfate annually for two years in a clay loam soil (pH 7.5) on the west side of the San Joaquin Valley increased soil Zn levels but did not increase zinc concentration in leaf tissue. Fertigating zinc sulfate in sandy loam soils (pH 6.5) did result in some uptake by the tree (Kallsen, et.al. 1998). Treating alkaline soil with acidic or acid forming chemicals may release substantial amounts of Zn chemically bound in the soil and thus, increase tree uptake. Nitrogen fertilizers like ammonium sulfate, ammonium phosphate, urea and urea-ammonium nitrate have an acidifying effect on the soil but their free hydrogen content is insufficient to make large changes quickly. Sulfuric acid, urea-sulfuric acid, and phosphoric acid provide a more rapid response and they can be applied uniformly through most low-volume irrigation systems. Elemental sulfur also acidifies soil, but its reaction time depends upon granular size. It is also best applied as a band to localize acidification and improve response.

Foliar sprays applied post-bloom when leaves are 50% expanded (end of April to early May) are effective at increasing tissue Zn concentrations. Absorption decreases markedly as leaves mature and acquire a fully developed waxy cuticle that binds the applied Zn. Spring applications are made with 2.1 pounds zinc sulfate 36% per 100 gallons of spray solution per acre adjusted to a pH of 4.5 to improve solubility and absorption. A single application is usually sufficient for the growing season. Foliar sprays of Zn provide only temporary correction, however, and must be repeated to prevent deficiency (Brown, Zhang, and Beede, 1996).

Zinc deficiency and the risk of fall cold injury is greatly reduced in young trees by inducing dormancy with high zinc rates in late October. Rates of 40 pounds zinc sulfate 36% per acre are commonly applied between late October and early November without tree damage. Unlike the spring timing, fall application provides zinc nutrition in advance of bloom, when deficiency effects fruit set and nut development. Another efficacious timing for this high rate is in late February and early March during swelling of the bud scales (Beede, et al., 1991).

Copper (Cu) deficiency

A limited survey showed no correlation between soil copper level and pistachio tree deficiency (Beede, 1989). Copper sulfate ($CuSO_4$ 25%) injected at a rate of 40 pounds. per acre annually for two years increased soil copper concentration but did not increase Cu concentration in pistachio leaf tissue (Kallsen, 1998). Soil treatments with copper sulfate and CuEDTA over several years provided highly variable responses (Uriu, et.al. 1989). Some showed no correction whatsoever, some provided correction, and still others showed phytotoxicity. This variability is most likely linked to soil pH and texture. Lighter, slightly acidic soils might be more responsive. The risks associated with soil treatment are also not justified since foliar treatment has proven highly effective.

Post-bloom foliar application of chleated copper (CuEDTA 10-15%) applied at ½ to ¾ of a pound in 100 gallons of water per acre when leaves are 50% expanded (end of April to early May) are extremely effective in correcting copper deficiency before symptoms appear in mid-summer (Uriu, et.al. 1989).

Application of copper sulfate at ½ to 1 pound per100 gallons of spray solution per acre during this same time period have been successful, but they occasionally cause phytotoxicity. In many cases, treatment for copper deficiency is only required during orchard and canopy development. Once the trees are mature, the incidence of copper diminishes substantially, presumably because of increases in root density.

Boron (B) deficiency

Soil or foliar spray application can correct boron deficiency. Similar to other micronutrients, boron is most available in lighter, acidic soil. There are a number of B fertilizer materials containing different amounts of actual B. Soil application of Borax (11% B) by the first week in September at the rate of 50 to 75 pounds per acre has given correction lasting from three to five years. Soils lighter in texture and low in buffering capacity require the addition of less boron for correction. Applications through drip systems may be reduced by 25-30% due to higher efficiency from concentrated treatment.

A foliar spray of soluble B (e.g. Solubor®, 20.5% B) at the rate of 2-3 pounds in 100 gallons of spray solution per acre can be applied anytime B deficiency is detected. Spring applications during shoot extension are more effective in correcting current season deficiency than treatments in June or July. Boron is not readily translocated by the tree vascular system.

If B concentration is low in August, application of 5 pounds of solubor in 100 gallons of spray solution per acre in late February to early March (bud swell) is effective in supplying B to developing flowers and pollen for improved fruit set. Boron can also be applied post-bloom at 50% leaf expansion. Apply 3 pounds of Solubor in 100 gallons of water per acre. Solubor creates a strongly buffered solution of 8.2 pH. If mixed with zinc and copper fertilizers, the tank mixture should be acidified to pH 4.5 to 5.5 with citric acid to maintain the uptake of zinc and copper by the pistachio leaf.

The best long-term correction can be expected from a combination of soil and foliar treatments applied as yearly maintenance.

Boron, chlorine and sodium excesses

If any one of these elements is present in high amounts in the irrigation water and is causing toxicity, the water source should be changed. If toxicity is from an excess in the soil, irrigation water in excess of Etc (consumptive use) can leach some of the toxic element and reduce injury. Adding a “leaching fraction” to the amount of applied water is also important if moderate levels of B, Cl or Na exist in the irrigation water.

EFFECT OF ROOTSTOCK ON TREE NUTRITION

Pistachio rootstocks differ significantly in their ability to take up nutrients from the soil. Trees planted on Atlantica rootstocks are less likely to show B, Cu or Zn deficiency than other rootstocks (Brown, Zhang, and Ferguson. 1991).

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