

Secondary Plant Nutrients: Calcium (Ca), Magnesium (Mg), and Sulfur (S)

*Allan Fulton, Farm Advisor, Tehama County and
Roland D. Meyer, Extension Soils Specialist Emeritus*

This article (Part 3) discusses the use of soil tests to evaluate levels of the secondary nutrients calcium (Ca), Magnesium (Mg), and sulfur (S) in orchard soils. These nutrients are considered secondary because while they are essential to crop development, seasonal crop uptake is usually lower than for the primary nutrients N, P, and K but considerably higher than the micronutrients zinc (Zn), iron (Fe), Manganese (Mn), copper (Cu), boron (B), and chloride (Cl).

Calcium and Magnesium

Plant uptake, cation adsorption and desorption in soil, leaching from rainfall and irrigation, and weathering of minerals all contribute to the concentration of water soluble Ca and Mg available to meet tree nutritional needs. Water soluble cations are determined from the saturated paste extract soil test procedure while the exchangeable cations are determined with the ammonium acetate procedure. Also important are the concentrations of exchangeable (non-water soluble) Ca and Mg which help to promote favorable soil structure. Soil chemistry is in a constant state of change attempting to reach equilibrium between the soluble and non-soluble (exchangeable and mineral) phases. The May 2009 newsletter discussed this dynamic process. Calcium and magnesium share similar chemical properties in soils. Both Ca and Mg are “double positively charged (divalent) cations in the soil-water phase and on soil cation exchange sites. Calcium is adsorbed to soil exchange sites preferentially and more strongly than Mg. When Ca and Mg are abundant in the soluble phase tree roots absorb these nutrients by mass flow. If Ca and/or Mg are less abundant or limited by soil moisture, uptake occurs more slowly through diffusion.

Table 1 provides ranges of exchangeable Ca and Mg levels that may be observed in soils in the Sacramento Valley. The ranges are expressed in three different reporting units that may be used by agricultural laboratories. The levels of exchangeable Ca and Mg can vary widely in soils and may correlate closely with levels of water soluble Ca and Mg (i.e. when exchangeable levels are high, water soluble levels are also usually high and conversely). The amount of organic matter as well as the type and amount of clay largely determine the cation exchange capacity (CEC) of a soil. The cation exchange capacity can be thought of as a measure of the reservoir of Ca, Mg, K, and other cations adsorbed to the soil in the non-soluble phase that are available to replenish the nutrients taken up in the water soluble phase or may be absorbed directly by nearby roots. Soils which have a large amount of sand with very little clay or organic matter have little CEC or a reservoir to hold cationic nutrients. Adding large amounts of calcium, magnesium and potassium or even anions such as boron, sulfates or nitrates can be easily leached from sandy soils, those having low organic matter content or low CEC.

Table 1. Common ranges in exchangeable calcium (Ca) and magnesium (Mg) in soils in California expressed in three different soil test reporting units.

Element	meq/100 g soil¹	ppm (mg/kg)²	lbs/ac-ft soil³
Calcium (Ca)	5 – 50	1000 – 10,000	4000 – 40,000
Magnesium (Mg)	2 - 30	240 - 3600	960 – 14,400

¹The units of meq/100 g soil imply the determination of exchangeable cations with the ammonium acetate procedure. The units for saturated paste extract determinations are expressed as meq/L.

²The units of meq/100 g soil are converted to ppm with the use of the equivalent weight of the cation.

³The ppm concentration is multiplied by 4 using the assumption that one acre foot of soil weighs four million pounds and one acre 6 inches weighs two million pounds.

Many California soils are alkaline (pH above 7.0) with an abundance of Ca and Mg bearing minerals in the soil. Under these conditions, Ca and/or Mg deficiencies are generally uncommon. In contrast, some orchard soils in the Sacramento Valley are acidic (pH 5.0 to 6.5) with a high concentration of hydrogen ions on the cation exchange sites causing growers to have more management questions about Ca and Mg levels in the soil.

Most agricultural laboratories utilize two soil test methods to evaluate soil cations and their relationships. The saturated paste extract procedure is used for salinity evaluation, particularly the Ca, Mg and Na concentrations. Evaluating soil salinity will be a topic in a future article. The ammonium acetate procedure is used to determine the exchangeable Ca, Mg, K (potassium) and Na (sodium) concentrations as well as the base saturation percentages.

In general, field research has shown that plant growth is not affected over a wide range of Ca to Mg ratios, from 6:1 to 1:1. Either the saturated paste extract concentrations (meq/L) or the base saturation percentage (%) can be used to determine the Ca:Mg ratio. Magnesium deficiencies are likely to occur if Ca:Mg ratios are greater than 8:1. Unfavorable plant growth along with poor soil structure may occur when Mg concentrations are greater than twice those of Ca. Blossom end rot and white or pink centers in tomato is an example of a crop in the Sacramento Valley that may develop severe problems resulting from higher magnesium concentrations. Economic benefits from the application of gypsum as the most desired source of Ca to orchard soils when Ca:Mg ratios are in the range of 1:1 to 1:2 is highly unlikely.

Base Saturation is estimated and reported by some but not all agricultural laboratories in California. It is an estimate of the proportions of Ca, Mg, K, Na, and H cations that occupy the cation exchange sites of a soil. Some laboratories also suggest desirable Base Saturation ranges of 60-80 percent for Ca and 10 to 20 percent for Mg. The concept of base saturation and the associated target levels stems from soil testing, and field observations conducted on acidic soils in the Central and Eastern U.S. that date back to the 1940's. Relationships between crop response and specific base saturation percentages of Ca and Mg levels or other cations in soils have not been helpful in improving crop yields or quality. Soil scientists have learned that more general ranges in the base saturation percentages are appropriate for soils. Even though some soils in the Sacramento Valley are acidic like soils in the southeastern and eastern U.S., they consist of different clay minerals that have much higher cation exchange capacities, which can lead to recommendations of extraordinarily high and uneconomical rates of Ca amendments to maintain the "Base Saturation" within the specific desirable ranges often suggested.

Sulfur

Sulfur (S) undergoes numerous transformations in the soil involving biological, chemical, and atmospheric processes, similar to the nitrogen cycle. Plant uptake, mineralization, immobilization, soil anion exchange reactions, volatilization, leaching, oxidation and reduction, and mineral weathering all affect the availability of sulfur to trees. Soil properties such as water content, pH, temperature, and aeration also affect these processes.

Trees absorb sulfur from soil in the water soluble, inorganic form of sulfate (SO_4^{2-}). Usually less than 10 percent of the total S in the soil is in the water soluble SO_4^{2-} form. Sulfate (SO_4^{2-}) taken up by the trees or lost to leaching is replenished by mineralization of organic matter, oxidation of reduced S, and other processes such as weathering of minerals that contain S.

Sulfur (S) containing soil amendments are more often applied to lower the pH of orchard soils above 8.0. Sulfur deficiency has been observed in wheat and other cereals in the Sacramento Valley during late winter-early spring when rainfall is high for several weeks, soils become saturated, sulfur is chemically reduced, and the supply of SO_4^{2-} -S becomes insufficient to meet crop needs. As soon as the soils dry out and warm up for bacteria to convert the sulfur to the SO_4^{2-} -S form, the sulfur deficiency disappears. Sulfur nutrient deficiency is uncommon in orchard crops grown in the Sacramento Valley and other areas of California. Still, S fertility levels are evaluated and reported in soil tests. Water soluble SO_4^{2-} may be measured in the saturated paste extract using a barium chloride turbidimetric method or estimated by subtraction if electrical conductivity (ECe), chloride, bicarbonate, and carbonate have been measured in the saturation paste extract. Alternatively, SO_4^{2-} -S may be measured and reported for a soil sample using a calcium phosphate extraction method. Both of these methods of soil testing have limits in predicting favorable crop responses to sulfur applications in orchards. These methods are subject to the time of sampling because S availability changes in the soil due to mineralization and leaching and is complicated by the fact that several sources of S besides the soil itself (i.e. atmosphere, rain, and foliar applications such as fungicides) can contribute to the needs of trees. As a result, if S tree nutrition is in question, tissue testing should be used for a more positive diagnosis.