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Understanding Plant Mineral Nutrition

All plants require 17 elements to grow and develop properly. Those 17 essential elements are: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni) and zinc (Zn).

The first three elements — C, H, O — are acquired from water (H_2O) and carbon dioxide (CO_2) through the process of photosynthesis. During photosynthesis plants take in carbon dioxide from the atmosphere through small pores in their leaves called stomates. The carbon dioxide is combined with water absorbed by the roots to produce carbohydrates (CH_2O) and oxygen (O_2). Carbohydrates (sugars) are the plant's basic energy source and the oxygen is released to the atmosphere through the stomates.

The remaining 14 elements are known as essential mineral nutrients and are taken into the plant through its roots. An essential nutrient is defined as a nutrient without which the plant cannot complete its lifecycle. These nutrients are further subdivided into macronutrients — those required in relatively large quantities (N, P, K, Ca, Mg, S) — and micronutrients — those required in relatively small quantities (B, Cl, Cu, Fe, Mn, Mo, Ni, Zn). In plant nutrient analysis reports, the macronutrients are reported as percent of leaf dry mass, whereas the micronutrients are reported in parts per million (ppm). It's important to remember that the classification of a mineral nutrient as a macro or micronutrient does not make it any less essential to the plant.

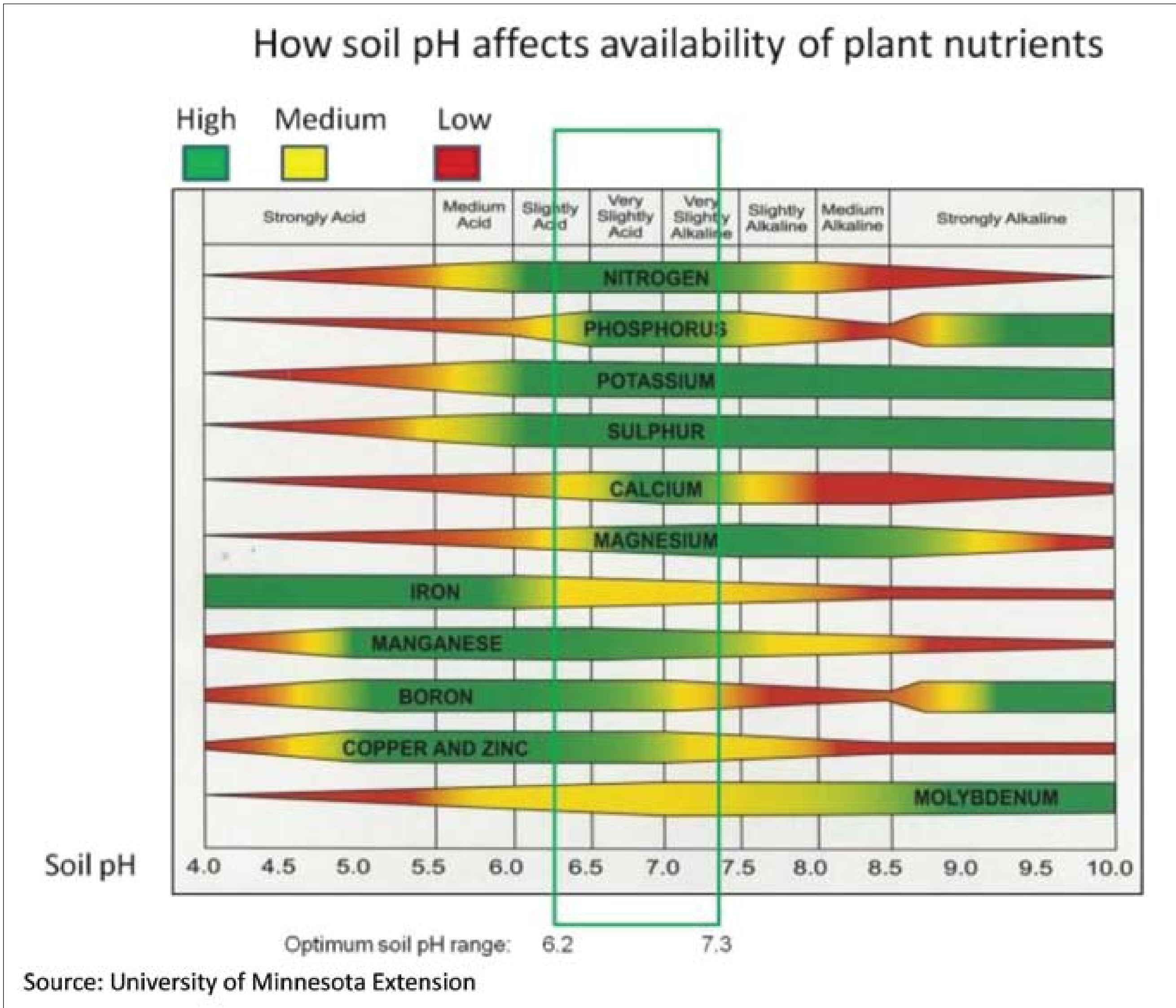
The 14 essential mineral nutrients required by plants, their chemical symbol, and their uptake forms in soil.

	Nutrient	Symbol	Uptake form in soil
Macronutrient	Nitrogen	N	ammonium ion (NH_4^+) or nitrate ion (NO_3^-)
	Phosphorus	P	phosphate ion ($H_2PO_4^-$, HPO_4^{2-})
	Potassium	K	potassium ion (K^+)
	Calcium	Ca	calcium ion (Ca^{2+})
	Magnesium	Mg	magnesium ion (Mg^{2+})
	Sulfur	S	sulfate ion (SO_4^{2-})
Micronutrient	Boron	B	boric acid (H_3BO_3) or borate ion ($H_2BO_3^-$)
	Chlorine	Cl	chloride ion (Cl^-)
	Copper	Cu	cupric ion (Cu^{2+})
	Iron	Fe	primarily ferrous ion (Fe^{2+}); some ferric ion (Fe^{3+})
	Manganese	Mn	manganous ion (Mn^{2+})
	Molybdenum	Mo	molybdate ion (MoO_4^{2-})
	Nickel	Ni	nickel ion (Ni^{2+})
	Zinc	Zn	zinc ion (Zn^{2+})

There are other elements that are currently known to be essential for only specific groups of plants. These include cobalt (Co), which is essential to the N-fixation process in legumes, and silicon (Si), which is essential in grasses like rice. Other elements, such as selenium (Se), are not essential to plant growth, but are essential nutrients for humans and many animals who consume plants and so are considered beneficial nutrients.

Nutrient Uptake

For plant roots to absorb nutrients, the roots must either go to the nutrients or the nutrients must come to the roots. Plant roots take up nutrients in one of three ways: interception, mass flow and diffusion. Interception is where roots growing through the soil encounter nutrients in the soil. This uptake method is entirely dependent on root growth — if roots are not actively growing then uptake by interception will be minimal. Furthermore, even in vigorously growing plants, roots may only be present in a small portion of the soil volume, maybe as little as one percent. Lastly, interception is dependent on good soil structure that can be easily penetrated by roots. Soil compaction or the presence of an impervious hardpan will limit the volume of soil the roots can explore. In avocados, which have a shallow root system, interception likely accounts for a small fraction of nutrient uptake because of the small soil volume the active roots explore.



Mass flow is the movement of nutrients in water to the root. As the plant extracts water from the soil, soluble nutrients are taken up along with the water. Soluble nutrients such as nitrogen, calcium, magnesium and sulfur are most likely to be taken up through mass flow. Nutrient concentration is very important for mass flow uptake — there must be a sufficient quantity of soluble nutrients in the soil to flow in the soil water. The more nutrients moving in the soil water (i.e., the higher the concentration) the more uptake by mass flow. However, the solubility of these nutrients also makes them highly susceptible to leaching if irrigation is not well managed.

Diffusion is the movement of a substance along a concentration gradient — from an area of high concentration to low concentration. As roots take up nutrients from the soil immediately surrounding them, the concentration of the nutrients decreases and nutrients from areas of higher concentration diffuse toward low concentration and toward the roots. Diffusion of nutrients in the soil takes place on a relatively small scale within the area immediately surrounding roots, known as the rhizosphere. Nutrients that are not highly mobile and don't move by mass flow, like P and K, move by diffusion. Thus, the concentration of these nutrients must be maintained at relatively high levels in the soil to drive diffusion.

How Soil Factors Affect Plant Nutrition

Cation exchange capacity (CEC) is a very important soil trait that affects plant nutrient availability. A cation is simply a positively charged ion. As you can see in the accompanying table, most essential nutrients are positively charged — they are cations — in their uptake form in the soil. CEC is a measure of a soil's capacity to hold cations on negatively charged soil components (e.g., clay particles, organic matter). A cation held by the soil's CEC is unavailable for plant uptake since it is not in solution. The addition of cations to the soil (e.g., fertilization or liming) will allow the bound cations to exchange places with the added cations, thus "dislodging" the bound cations into the soil solution where they become available for plant uptake. However, the freed cations in solution also become subject to leaching if they are not taken up by the plant. Knowing your soil's CEC helps you to manage nutrition on your soils and avoid nutrient leaching.

Soil physical properties also are important traits in managing nutrition. Texture is a description of the percentage of sand, silt and clay particles in a soil. Generally, plant nutrients are held by the clay fraction of a soil. Thus, the higher a soil's clay content, the higher its nutrient holding capacity. Soils high in sand typically have low nutrient holding capacity because sand particles have low CEC. Leaching of nutrients also increases as sand percentage increases since water moves more freely in sandy soils and can easily leach the weakly held cations.

Soil structure is the arrangement of soil particles into aggregates. Soil structure creates large pores that allow good water drainage and soil aeration, but a highly aggregated soil also is susceptible to nutrient leaching. However, a lack of structure decreases water infiltration and can lead to runoff and erosion problems, which also can lead to nutrient losses.

Soil pH is a measure of a soil's acidity or basicity (alkalinity), and pH has a tremendous effect on the availability of plant nutrients. As seen in the accompanying figure, some nutrients like potassium and sulfur are available to plants over a wide range of soil pH. But others, like phosphorous and calcium, are available over a relatively narrow pH range. Most nutrients are optimally available in a pH range very slightly acidic to very slightly basic. Soil pH can be affected by the type of fertilizer you apply and your irrigation water. The pH of an acid soil is typically raised by the addition of lime — calcium carbonate, $CaCO_3$. A basic soil's pH can be lowered by the addition of elemental sulfur, which slowly oxidizes in the soil to form sulfuric acid.

Soil temperature indirectly affects plant nutrition by influencing root metabolic activity. If temperatures are too low for active root metabolism then nutrient uptake will be slow. Temperature also influences the activity of soil microbes responsible for organic matter decomposition and, thus, the release of nutrients.

Fertilizer Application and Timing

In California, avocados are typically fertilized from April through October to ensure active root growth, which maximizes uptake efficiency, and to avoid winter rainfall. Fertilizing outside this window, when soil temperatures are generally cooler, will result in poorer uptake and possibly increase the risk of fertilizer leaching. However, fertilizer timing decisions should be made on an individual grove basis and may even be different for different blocks depending on microclimates.

The general recommendation is to divide your fertilizer application into at least three applications during the April to October window. There is no harm in splitting your fertilizer application into more, smaller doses, especially on highly leachable soils (e.g., sandy soils, low organic matter soils).

All fertilizer applications should be based on leaf and soil analyses. For avocados in California, leaf samples should be collected in mid-August to September, sampling the most recently expanded healthy mature leaves from the spring flush on non-fruiting branches. This is a relatively stable period of leaf nutrient content in avocado. Comparing leaf analyses year-to-year allows you to see if your fertility program is providing adequate nutrition. If leaf nutrient values are declining or are deficient, then your fertility program should be increased in the coming season. Likewise, leaf nutrient values in the excess range indicate that your program can be dialed back.

However, you need to evaluate your leaf analysis and fertility program in combination with a comprehensive soil analysis. Perhaps your fertility program is adequate, but if your soil pH is high (e.g., 8.0) you may see deficiencies in many of the micronutrients and adding more micronutrients will do little to correct these deficiencies. Or you may find that your soil has a very low CEC, in which case you should split your fertilizer program into as many small applications as reasonable since your soil is unable to hold the nutrients and serve as a reservoir.

Lastly, you need to evaluate your irrigation system and practices in combination with your fertility program. Most California avocado growers apply fertilizer by injection into the irrigation system. When was the last time you checked the distribution uniformity (DU) of your irrigation system? DU is just what it sounds like; it is a measure of how uniformly your irrigation system is applying water to your tree. Is every tree receiving the same amount of water? A DU of 1 means that your system is 100 percent uniform; in general, you should try to have a DU of 0.85 or better. If the amount of water being applied varies from tree-to-tree, then so will the amount of fertilizer being applied.

Editor's Note: *This article serves as a baseline for understanding general plant nutrition. Over the next couple of issues of From the Grove, follow-up articles will discuss in detail macro and micronutrient nutrition of avocados, including the role each nutrient plays in the tree.*