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Good Fertilization Practices:

A Tool in the Fight Against Pests and Disease

Every grower knows that mineral nutrients are essential for the growth and development of trees in order to achieve maximum yield. And they understand the necessity for balanced fertilization as it relates to replacing the nutrients carried off by crop harvest. However, it's probably safe to say that most growers don't think about the myriad effects fertilizer nutrients have on tree health beyond growth and yield, or about the delicate balance between various nutrients within the tree. Here we discuss the essential plant nutrients, the balance between them and their general effects on plant health, as well as general fertilization program guidelines.

Essential Plant Nutrients

In addition to carbon (C), hydrogen (H) and oxygen (O), which plants take up through the fixation of carbon dioxide (CO_2) via photosynthesis and water (H_2O) uptake via roots, there are 14 mineral nutrients that are recognized as essential for normal growth and development of all plants. An essential nutrient is defined as follows:

- A given plant must be unable to complete its life cycle in the absence of the nutrient (life cycle = vegetative state, flower, seed production)
- The function of the element must not be replaceable by another element
- The element must be directly involved in plant metabolism or must be a component of an essential plant constituent (e.g., nitrogen (N) is a constituent of proteins and chlorophyll)

Essential nutrients are usually broken into two categories — macro-nutrients and micro-nutrients — based on the relative quantity of each needed by the plant. These 14 nutrients, their general relative abundance in plants and some of their basic functions in plant biology are shown in Table 1.

Although some of these nutrients are needed in very minute quantities — and except in specific soil types or under certain conditions,

Table 1

The 14 essential mineral nutrients required by all plants for normal growth and development. The general abundance of each nutrient, relative to nitrogen, and key functions are shown.

	Nutrient	Chemical symbol	Relative abundance (%)	Function in plant
Macro-nutrients*	Nitrogen	N	100	Component of proteins and amino acids
	Potassium	K	25	Catalyst, ion transport
	Calcium	Ca	12.5	Cell wall component
	Magnesium	Mg	8	Part of the chlorophyll molecule
	Phosphorus	P	6	Nucleic acids, ATP
	Sulfur	S	3	Amino acids
Micro-nutrients	Chlorine	Cl	0.3	Photosynthesis reactions
	Iron	Fe	0.2	Chlorophyll synthesis
	Boron	B	0.2	Cell wall component
	Manganese	Mn	0.1	Activates enzymes
	Copper	Cu	0.01	Component of enzymes
	Zinc	Zn	0.03	Activates enzymes
	Molybdenum	Mo	0.0001	Involved in N metabolism
	Nickel**	Ni	0.00005	Involved in N metabolism

*Ca, Mg and S are sometimes broken out from the macro-nutrients and categorized as secondary nutrients.

**Ni is the newest identified essential plant nutrient. The data establishing its essentiality were published in 1987; it was recognized as essential by the American Association of Plant Food Control in 2004.

A leaky barrel illustrates Liebig's law of the minimum. Just as the capacity of a barrel with unequal length staves is limited by the shortest stave, so too are a plant's growth, yield and health limited by the nutrient in shortest supply.

they do not need to be applied as part of a regular fertilizer program — they are no less important than the other elements. For example, molybdenum (Mo) is the element needed in the second smallest quantity, but it is critically important to N metabolism, the element needed in the greatest quantity. In many instances of Mo deficiency the symptoms are expressed as N deficiency because N is not being properly metabolized.

Nutrient Balance

The example of how Mo impacts N metabolism is a perfect example of nutrient balance. *No nutrient functions in isolation from others within a plant.* This principle was first developed in agricultural systems by German botanist Carl Sprengel in 1828 and later popularized by the German chemist Justus von Liebig, and is commonly known as Liebig's Law of the Minimum. In its simplest form, Liebig's Law tells us that the most abundant nutrient is only as functionally available as the most limiting nutrient.

The complex interactions of nutrients is the reason why complete tissue analyses are so important to proper tree management. Plants often suffer from "hidden hunger" – a nutrient being deficient without any outward symptoms of deficiency. Again, Mo is a good example of a nutrient whose deficiency can often be hidden. A tree may have symptoms of N deficiency and a grower will assume the normal course of action may be to apply more N. But if that deficiency is caused by too little Mo affecting N metabolism, the application of N will not correct the problem and may actually worsen it by creating a greater nutrient imbalance.

Plant Nutrition and Tree Health

In order to complement disease and pest control methods, it is helpful to know how mineral nutrients affect disease resistance in plants. Altering how plants respond to pest or disease attacks can increase resistance. There are two primary resistance mechanisms that mineral nutrition can affect:

- The formation of mechanical barriers, primarily through the development of thicker cell walls.
- The synthesis of natural defense compounds, such as phytoalexins, antioxidants and flavonoids, which provide protection against pathogens.

As a rule, plants with an optimal, balanced nutritional status exhibit optimal growth and the highest tolerance to pests and diseases. Susceptibility increases as nutrient concentrations deviate from this optimum. The interaction between higher plants and disease organisms and pests is complex. However, the roles of mineral nutrients are well established in some areas of host-disease interaction. Our goal, as growers and horticulturists, is to recognize these interactions and maximize the potential for disease and pest control by proper grove management. What follows is a brief summation of how plant nutrition affects different types of plant diseases and insect pests based on a few specific nutrient examples.

Fungal Diseases: Thinner, weaker cell walls leak nutrients from within the cell to the apoplast (the space between plant cells). This can create a fertile environment for the germination of fungal spores on leaf and root surfaces. Mineral nutrient levels directly influence the amount of leakage as well as the composition of what is leaked. For instance, potassium (K) deficiency causes cell walls to become leaky, resulting in high sugar and amino acid concentrations in the leaf apoplast. Calcium (Ca) and boron (B) deficiencies also cause a buildup of sugars and amino acids in both leaf and stem tissues. Nitrogen (N) is a key component of amino acids; therefore, an excessive supply of N can bring about higher amounts of amino acids and other N-containing compounds in plant tissues. These mineral imbalances lower resistance to fungal diseases by creating a more favorable environment for pathogens.

Most fungi invade the leaf surface by releasing enzymes that dissolve the middle lamella (the "glue" that bonds adjacent cells). The activity of these enzymes is strongly inhibited by Ca, which further explains the close correlation between the Ca content of tissues and their resistance to fungal diseases.

Plant tissues contain and produce a variety of defense compounds, which hinder fungal attacks. Boron plays a key role in the synthesis of these compounds. Borate-complexing compounds trigger the enhanced formation of a number of plant defense chemicals at the site of infection. The level of these substances and their fungistatic effect also decreases when the N supply is too high.

Mineral nutrition also affects the formation of mechanical barriers in plant tissues. For example, copper (Cu) is a plant nutrient widely used as a fungicide. However, the amount required as a fungicide is much higher than the nutritional requirement. The action of Cu as a fungicide relies on direct application to the plant surface and the infecting fungi. From a nutritional perspective, Cu deficiency leads to impaired defense compound production, accumulation of soluble carbohydrates, and reduced lignification (wood development), all of which contribute to lower disease resistance.

These effects are well illustrated by the severity data for the fungal disease greasy spot on citrus (Table 2). A greenhouse study was conducted in which trees were fertilized with a complete nutrient solution at full strength; at a one-tenth strength so all nutrients were deficient; or at full strength with different nutrients omitted from the solution. After just two weeks, almost all of the nutrient deficient plants had significantly greater disease severity compared with the well-fertilized control trees.

Bacterial Diseases: Mineral nutrition affects susceptibility to bacterial infections in much the same way that it affects fungal infections. Potassium and Ca play key roles in forming an effective barrier to infections. When K, Ca, and, often, N levels are deficient, plants are more susceptible to bacterial attacks. A frequent symptom of B deficiency is the development of "corky" tissue along leaf veins and stems as a result of the irregular (misshapen) cell growth that occurs when B is deficient. These irregular cells are more loosely bound than normal cells, essentially producing wounds through which bacteria can enter.

Disease relationships to K content are quite consistent across plant species. A published review of 534 research articles found that K reduced bacterial and fungal diseases 70 percent of the time and insect and mite attacks 60 percent of the time. Unlike other nutrients, the generalization can be made for K that *an adequate supply usually results in an increased resistance to attack by all parasites and pests.*

Calcium affects the incidence of bacterial disease in a variety of ways. First, Ca compounds play an essential role in the formation of healthy, stable cell walls. Adequate Ca also inhibits the formation of enzymes produced by fungi and bacteria that dissolve the middle lamella and allow penetration and infection. Ca deficiencies trigger the accumulation of sugars and amino acids in the apoplast, which lowers disease resistance. Fruit tissue that is low in Ca is also less resistant to bacterial diseases and physiological disorders that cause rotting during storage.

Soilborne Fungal and Bacterial Diseases: Mineral nutrition affects soilborne diseases in many different ways. A micronutrient-deficient plant usually has depressed defense capabilities against soilborne diseases. However, in some cases, nutrients can have direct effects on soilborne pathogens. For example, soil-applied manganese (Mn) can inhibit

TABLE 2

Greasy spot severity on 'Hamlin' sweet orange trees grown under different nutritional treatments in a hydroponics experiment. Trees were fertilized weekly with full or one-tenth strength Hoagland's complete nutrient solution or complete nutrient solution with one or more nutrients omitted.

	Symptom severity rating*	
	2 weeks	4 weeks
Full strength Hoagland's solution	1.6c**	3.1c
One-tenth strength	4.5a	5.0a
Full strength –Mg	3.3ab	4.8a
Full strength –Ca	3.8ab	5.2a
Full strength –B	1.7c	3.5bc
Full strength –Mn	3.2b	4.4a
Full strength –Zn, Cu, Mo, Fe	3.3ab	4.2ab

*Disease severity on the lower 20 leaves war rated on the scale of 1=No infection, 2=0-25% infection, 3=25-50% infection, 4=50-75% infection, 5=75-100% infection, 6= leaves abscised.

**Letters indicate significantly different means.

the growth of certain fungi. Also, nitrites are toxic to some *Fusarium* and *Phytophthora* species. Nitrites are formed from ammonium nitrogen in the nitrogen cycle as it is converted to nitrates by beneficial soil bacteria.

In other cases, the use of ammonium-based fertilizers can increase the incidence of some diseases, whereas nitrate-based fertilizers can have the opposite effect. One explanation for this effect is how these different N forms affect soil pH. Ammonium fertilizers generally decrease soil pH over time, particularly in soils with low buffering capacity, and nitrate fertilizers tend to either slightly increase soil pH or have no effect. However, some studies have found that the effects these two N fertilizer forms have on soilborne diseases are independent of soil pH, further indicating the complex relationship of mineral nutrition and disease.

Pests: Pests are organisms such as insects, mites, and nematodes that are harmful to cultivated plants. In contrast to fungal and bacterial pathogens, visual factors such as leaf color are important factors in pest susceptibility. Nutritional deficiencies can discolor leaf surfaces and increase susceptibility to pests. For example, many insects are attracted to yellow reflecting surfaces (i.e., surfaces that appear yellow in color to the human eye), and many nutrient deficiencies result in yellow leaf coloration.

Three primary pest defenses of plants are:

- Physical surface properties such as color and hairs
- Mechanical barriers such as tough fibers, silicon crystals, wood formation
- Chemical/biochemical such as content of attractants, toxins, repellents

Mineral nutrition affects all three defense systems. Generally, young or rapidly growing plant parts are more likely to suffer attack by pests than older, slower-growing parts. Therefore, there is often a correlation between N applications (stimulation of growth) and pest attack. Boron deficiency reduces the resistance to pest attack in the same ways it reduces resistance to fungal infections. It is used in the synthesis of flavanoids and phenolic compounds, which are a part of the plant's biochemical defense system.

In the game of baseball, no home runs are scored without touching first base. In the strategies of integrated pest management, mineral nutrition is first base. Optimizing mineral nutrient levels — especially at critical stages when pest populations are threatening — is both cost effective and agronomically sensible.