Mineral Nutrition Contributes to Plant Disease and Pest Resistance[1]

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Mineral nutrients are essential for the growth and development of plants and microorganisms and are important factors in plant-disease interactions. How each nutrient affects a plant's response to disease, whether positively or negatively, is unique to each plant-disease complex. This publication briefly summarizes plant mineral nutrition and what is known about how different nutrients affect different types of plant diseases (fungal, bacterial, viral, and soilborne) and pests.

In general, nutrient-pathogen interactions are not well understood due to their complex nature and dependence on a number of external factors. Plant nutrient deficiency/toxicity may affect disease susceptibility through plant metabolic changes, thereby creating a more favorable environment for disease development. When a pathogen infects a plant, it alters the plant's physiology directly or indirectly, particularly with regards to mineral nutrient uptake, assimilation, translocation, and utilization. Pathogens may immobilize nutrients in the soil or in infected plant tissues. They may also interfere with translocation or utilization of nutrients, inducing nutrient deficiencies or toxicities. Soilborne pathogens commonly infect plant roots, often damaging the roots and thereby reducing the plant's ability to take up water and nutrients. The resulting deficiencies may lead to secondary infections throughout the plant by other pathogens. Plant diseases can also infect the plant's vascular system and impair nutrient or water translocation. Such infections can cause root starvation, wilting, and plant decline or death, even though the pathogen itself may not be toxic.

Fertilizer Nutrients

In addition to carbon (C), hydrogen (H), and oxygen (O), which plants take up from the surroundings via leaves and roots, there are 13 mineral nutrients that are essential for normal plant growth and development. These nutrients, their general relative abundance in plants, and their roles in plant biology are listed in Table 1. These nutrients are often viewed simply as plant food necessary for better plant growth and yield. However, mineral nutrition also influences growth and yield by affecting plant resistance or susceptibility to pathogens and pests.

Although disease resistance is genetically controlled, it is considerably influenced by environmental factors. Some disease resistance genes in plants are only activated by specific environmental stimuli. Mineral nutrition is an environmental factor that can be easily controlled in agricultural systems, the effects of which can be substantial.

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. Mineral nutrition can affect two primary resistance mechanisms:

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1. The formation of mechanical barriers, primarily through the development of thicker cell walls.

2. The synthesis of natural defense compounds, such as phytoalexins, antioxidants, and flavanoids, which provide protection against pathogens.

A balanced nutrient supply, illustrated for citrus in the form of a "nutrient pyramid" (Figure 1), ensures optimal plant growth and is usually considered optimal for disease resistance as well. As a rule, plants with an optimal nutritional status have the higher resistance (tolerance) to pests and diseases compared to nutrient deficient plants. Susceptibility increases as nutrient concentrations deviate from this optimum. The interaction between plants and disease organisms and pests is complex. However, the roles of mineral nutrients are well established in some areas of host-disease interaction. The goal is to recognize these interactions and see the possibilities and limitations of disease and pest control by mineral nutrition and fertilizer applications.

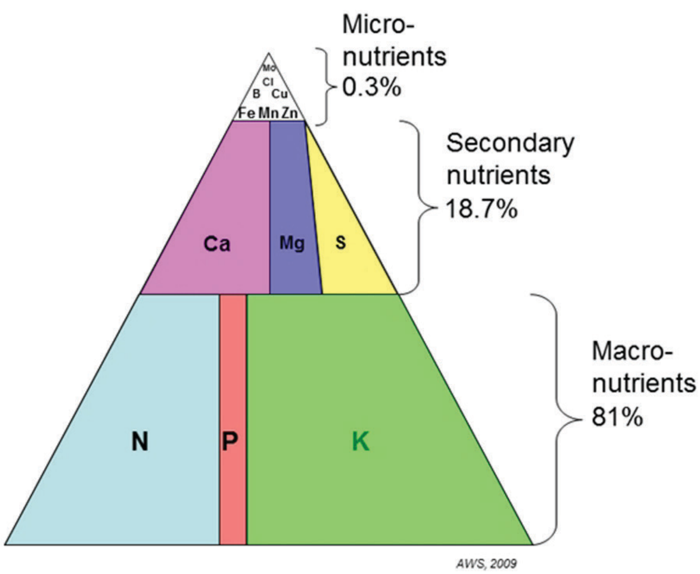

Figure 1. A schematic representation of the relative balance of macronutrients, secondary nutrients, and micronutrients for citrus. All of the nutrients are required and must be present in the proper ratios to build a balanced and complete pyramid.
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Fungal 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 that stimulates 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) is essential for the synthesis of proteins, starch, and cellulose in plants. Cellulose is a primary component of cell walls, and K deficiency causes cell walls to become leaky, resulting in high sugar (starch precursor) and amino acid (protein building blocks) 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, which 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.

As stated previously, 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 tissue. As leaves age, the accumulation of silicon (Si) in the cell walls helps form a protective physical barrier to fungal penetration. Excessively high N levels lower the Si content and increase susceptibility to fungal diseases.

Other micronutrients play a role in disease resistance, too. Copper (Cu) is a plant nutrient that is widely used as a fungicide. The amount required, however, is much higher than the nutritional requirement of tree. 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.

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.

Adequate N levels increase plant resistance to most bacterial diseases; however, excessive N can have the opposite effect. As a rule, parasites that live on senescing (dying) tissue or that release toxins in order to damage or kill the host plants thrive in low N situations. However, some bacteria actually increase under high N conditions. These bacteria usually depend on food sources from living tissue.

Disease relationships to K content are more consistent. A review of 534 research articles found that K reduced bacterial and fungal diseases 70% of the time and insects and mites 60% of the time. Unlike for 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*. Potassium deficiencies created by overapplication of dolomite or magnesium lower this resistance.

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 bacteria and fungi, which dissolves the middle lamella, allowing penetration and infection. Calcium 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.

In general, similar principles govern the effect of both micronutrients and macronutrients on disease resistance: *Any* nutritional deficiency hinders plant metabolism and results in a weakened plant, which lowers disease resistance.

For instance, the lack of one small ounce of molybdenum (Mo) per acre can lower disease resistance by impeding the production of nitrate reductase. This is an enzyme that contains two molecules of Mo, and it is required to convert nitrates to proteins. This example also illustrates the importance of *balanced* nutrition—no nutrient functions in isolation from the others. *All* essential nutrients are critical for the proper metabolic functioning of higher plants.

Viral Diseases

Nutritional factors that favor the growth of host plants also favor virus multiplication. This holds true particularly for N and phosphorus (P). However, despite the rapid multiplication of the virus, visible symptoms of the infection do not necessarily correspond to an increase in mineral nutrient supply to the host plant. In fact, symptoms of viral infections sometimes disappear when N supplies are large, even though the entire plant is infected. Visible symptoms are dependent upon the competition for N between the virus and the host cells. This competition varies with different diseases and can be influenced by environmental factors, such as temperature.

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 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. This two-step process is shown in Figure 2.

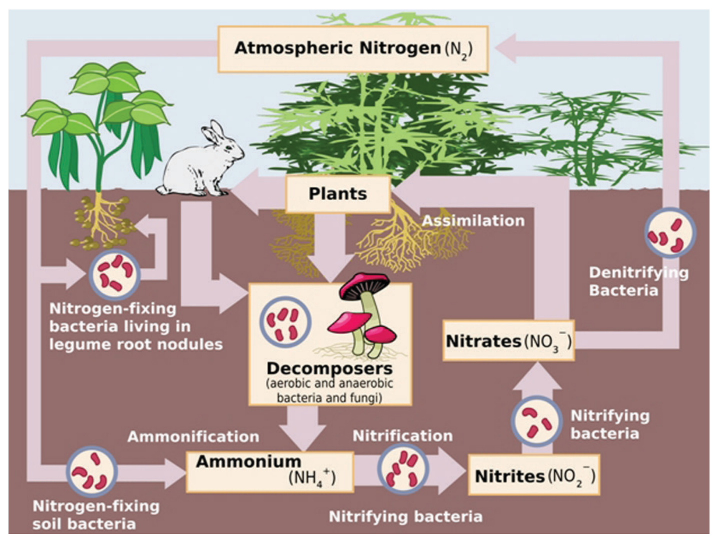

Figure 2. A schematic representation of the nitrogen cycle. Ammoniacal nitrogen enters the system through the fixation of atmospheric nitrogen by bacteria, the decomposition of organic matter by bacteria and fungi, or through fertilizer application. Ammonium is oxidized to nitrite and then nitrate by bacteria through a process known as nitrification. Plants take up (assimilate) nitrogen as either ammonium or nitrate.
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The use of ammonium-based fertilizers can increase the incidence of some diseases (e.g., *Fusarium* and *Phytophthora* root rots), whereas nitrate-based fertilizers generally 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 discolor leaf surfaces and increase susceptibility to pests. The Asian citrus psyllid, *Diaphorina citri*, for example, tends to settle on yellow reflecting surfaces (i.e., surfaces that appear yellow in color to the human eye).

Three primary pest defenses of plants are:

1. Physical surface properties: color, surface properties, hairs

2. Mechanical barriers: tough fibers, silicon crystals, lignification

3. Chemical/biochemical: content of attractants, toxins, repellents

Mineral nutrition affects all three defense systems. Generally, young or rapidly growing plants are more likely to suffer attack by pests than older, slower-growing plants. 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.

Summary

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.

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Table 1. The 13 essential mineral nutrients required by all plants for normal growth and development.

Nutrient	Chemical symbol	Relative abundance (%)	Function in plant
Nitrogen	N	100	Proteins, amino acids
Potassium	K	25	Catalyst, ion transport
Calcium	Ca	12.5	Cell wall component
Magnesium	Mg	8	Part of chlorophyll
Phosphorus	P	6	Nucleic acids, ATP
Sulfur	S	3	Amino acids
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 fixation