CAES
The Connecticut Agricultural Experiment Station
Putting Science to Work for Society since 1875

FACT SHEET

USING MINERAL NUTRITION TO SUPPRESS PLANT DISEASES

Dr. Wade H. Elmer
Department of Plant Pathology and Ecology
The Connecticut Agricultural Experiment Station

One of the fundamental strategies for maintaining plant health and suppressing plant diseases is managing nutrition. Proper nutrition can often influence the fine line between host susceptibility and resistance. Plant pathologists commonly refer to the "disease triangle" to illustrate the components needed for disease to occur. Equal importance is given to three factors of the triangle that consist of a plant's susceptibility, a conducive environment, and the presence of virulent pathogens on disease (Figure 1). Altering any of the three components directly affects the severity of the disease or whether disease occurs. For example, many diseases caused by *Botrytis* spp., *Pythium* spp., or *Phytophthora* spp. can be suppressed by manipulating the environmental component, i.e., reducing moisture levels in the soil or atmosphere. Additionally, certain nutrient regimes can suppress *Fusarium*, *Rhizoctonia*, *Thielaviopsis*, *Verticillium*, and powdery mildews by increasing the resistance of the host. This handout will briefly discuss the governing role of nutrition in minimizing plant susceptibility.

Complete and balanced nutrition should always be the first line of defense. One major problem in providing proper nutrition is that many plants vary in their nutritional requirements and that nutrition can affect disease differently. Each "case by case" needs to be understood, and detailed information on the fertility requirements of specific crops is often not known. Furthermore, the fertilizer regimes necessary to maximize plant health when a pathogen is present can differ from the fertilizer regimes required when the pathogen is absent.

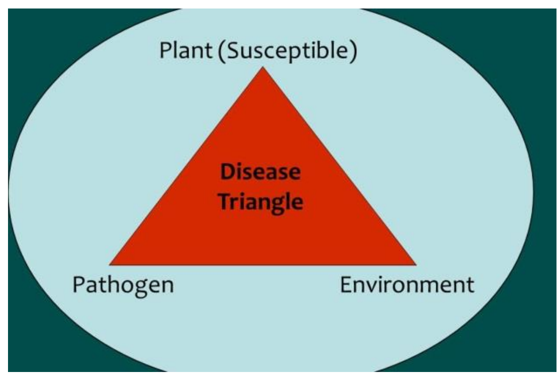

Figure 1. Disease triangle.

In many cases, the amount of an element needed to suppress disease far exceeds the plant's nutritional requirement for that element indicating that many elements may function in multiple mechanisms in suppressing disease. Chemical interactions with the soil, pH, and/or with specific communities of microorganisms can, in turn, influence the development of disease. For example, the form of nitrogen can have striking effects on plant disease through root-mediated changes in pH, microbial profile in the rhizosphere, and alterations in the availability and function of micronutrients. In addition, Ca only composes approximately

0.5% of the dry weight of most plants, yet Ca is routinely applied in great quantities to field and greenhouse soil to affect soil pH and to suppress certain plant diseases.

Both essential and beneficial elements can directly and indirectly affect defense mechanisms in plants. Direct effects include metabolic pathways that lead to the production of lignin, phenol, phytoalexins, and other defense-related compounds. Many of these pathways utilize enzymes that require Mn, Cu, Zn, Mo, and B as cofactors or as activators. Other elements like K and Cl influence osmotic relations, water cycling, and root exudation, which, in turn, influence beneficial microbes. Indirect mechanisms include effects on nitrification, soil pH, and chemical transformation of micronutrients like Mn. Below, each element will be discussed for its effect on plant disease, but one should recognize that nutrition must be viewed holistically, since all elements affect the uptake and function of other elements and can ultimately increase or decrease plant disease.

Nitrogen

Nitrogen is the fourth most abundant element in plants and is an essential component of amino acids, enzymes, hormones, phenolics, phytoalexins, and proteins, all of which can have direct effects on disease development. Although growers pay close attention to N deficiency symptoms, most do not recognize the role that N form may play in enhancing or suppressing disease. Nitrogen is available as the oxidized anion NO_3^- or the reduced cation NH_4^+ and the form can affect the uptake of other elements(Figure 2). Most plants can use either form, but due to phytotoxicity associated with NH_4-N, especially with seedlings, most growers apply N in the NO_3-N form. However, excess nitrate can increase *Pythium* diseases by increasing salt stress and increase Botrytis blight by promoting green and succulent tissue.

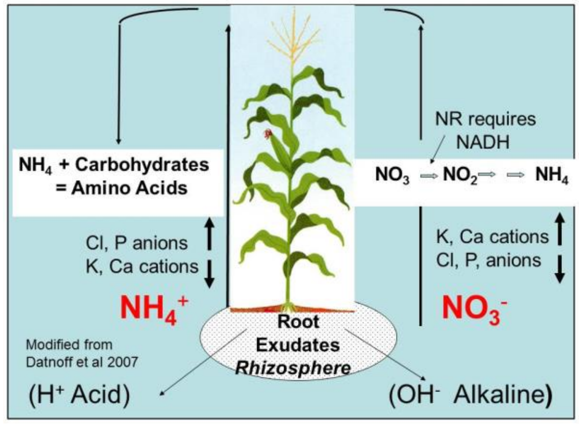

Figure 2. Effect of ammonium (NH_4) versus nitrate (NO_3) on plants (NR = Nitrate reductase), (courtesy of D. M. Huber).

Nitrate-N and NH_4-N are metabolized differently and can have opposite effects on diseases. In fact, many of the conflicting reports found in the literature regarding the role of N and plant disease may be due to a failure to recognize and/or report the N form. For example, increasing N suppressed bacterial leaf spots on philodendron and bacterial blight on schefflera, but increased leaf spot on chrysanthemum and tomatoes. However, when the form of N is known, some general rules can be made for certain diseases. For example, Fusarium wilts and root rots of carnation, chrysanthemum, cyclamen, tomatoes, gladiolus and watermelons are usually less severe when the N is applied as NO_3-N and more severe when applied as NH_4-N (Figure 3). The opposite is true for Verticillium wilt and Thielaviopsis diseases.

Figure 3. Effect of NH_4NO_3 versus $CaNO_3$ nutrition on Fusarium wilt of cyclamen.

Applying ammonium sulfate to eggplant, maple, and antirrhinum provided good suppression of Verticillium wilt. Growers should pay attention to the ion that accompanies N. Depending on the plant and the disease, the companion ion (Ca, K, Cl, and SO_4) may enhance or decrease protection from disease. The role of these elements is discussed below.

Phosphorus

Phosphorus is the second component listed in the analysis of fertilizers (N-P-K) due to its vital role in cell division, energy transfers, and its regulatory role for transport of sugars and starches within the plant. Although there are exceptions, most reports on P and plant disease suggest that increasing phosphorus above that which is necessary for proper growth may be associated with increased disease. In fact, those cases where P reduced disease may have been in situations where the element was deficient. Cases where the disease became worse following P application might have been in soils where excess P decreased the availability of other elements which, in turn, increased the plant's susceptibility. In most soils, maximum availability of P would be expected in the slightly acid to neutral pH range. In acid soils, P reacts with Fe, Al, and Mn to form insoluble products, making P less available. In alkaline soils, P reacts with Ca and reduces P availability. Therefore, attention to soil pH is very important to maximize availability of P and plant health.

Alternate formulations of P salts such as phosphonic acid and phosphonate have been developed and marketed for control of *Phytophthora* and *Pythium* diseases of plants. Phosphonic acid is not naturally occurring and has a mixed mode of action involving direct toxicity to the plant pathogen along with boosting the plant's natural defense system. These products do not provide any appreciable P nutrition and their mode of action is not through normal pathways associated with P metabolism. Similarly, mono-potassium phosphate (MKP) has been marketed as a foliar spray to induce local and systemic protection against some foliar pathogens in several crops, but at the time of this writing, MKP is not registered on plants.

Another important consideration is the role of beneficial mycorrhizal fungi in P nutrition and disease development. Mycorrhizae are beneficial fungi that form a symbiotic relationship with the plant's roots (Figure 5). These fungi improve plant health and reduce disease damage. Many plants have mycorrhizal associations that are likely interrupted during propagation cycles. If mycorrhizae are present or have been added, there may be a need to alter the P applications since mycorrhizal infection can be inhibited by increased P availability. Commercial applications of mycorrhizae are available and may have value in plant production for management of soilborne disease. Their use may also allow other nutrients to be more available since added P could lead to the precipitation of other elements like Ca. Much research is still needed to tailor the P demands of plants that respond to supplemental applications of mycorrhizae.

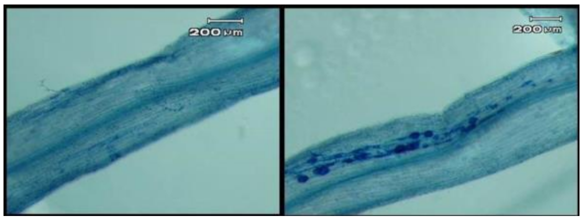

Figure 4. Asparagus roots with arbuscular mycorrhizae (right) and roots without (left).

Potassium

Potassium is absorbed in large quantities by plants and may exceed nitrogen levels for certain plants. Many diseases can be increased or decreased on the basis of K nutrition alone or when combined with other elements. Unfortunately, no patterns have emerged with K and plant disease that would allow for generalizations. For example, investigators have noted that applying K suppressed bacterial diseases on carnations and geraniums, but increased bacterial leaf blight on philodendron. Many times these discrepancies are a result of investigators not mentioning the form of K. Potassium is most often applied as KCl, K_2SO_4, or KNO_3 and the form can be of great importance in disease management. The accompanying ion can often dictate the response of a plant to K, and this factor may explain the large number of discrepancies regarding K and plant disease. Although studies on plants are rare, there are a number of reports on other crops that show that the positive response to K fertilization was only associated with the KCl form and not any other K forms (Figure 5). In addition, diseases of many grain crops like soybeans and oats were suppressed by KCl but not K_2SO_4. The role of Cl will be discussed below. Another important principle of N, P, and K nutrition is that providing more of these fertilizers than what is required by the plant can aggravate disease caused by species of *Pythium*. When Pythium root rot is a persistent problem, growers should consider a balanced nutrient solution containing relatively low levels of N, P, and K and proportionally higher levels of Ca and K.

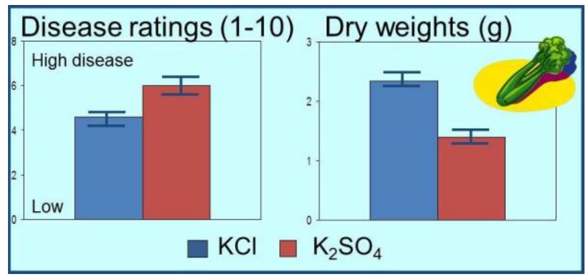

Figure 5. Effect of KCl versus K_2SO_4 on Fusarium wilt of celery (courtesy of R. Schneider).

Calcium and Magnesium

Calcium and magnesium are the second and third most abundant basic elements in a plant. Calcium concentrations in plants are usually twice that of Mg. Calcium is extremely important in normal cell growth where it forms Ca pectate in the middle lamellae of the cell and functions in many enzymatic reactions involved in defense mechanisms. Calcium is commonly applied as $CaCl_2$, $CaSO_4$, or $Ca(NO_3)_2$. The role of Ca in the management of plant disease has received much attention, but examples for plants are few.

Many previous studies investigating the role of $Ca(NO_3)_2$ credited all of the plant disease suppression to the NO_3, and failed to recognize the Ca ion. Unfortunately, most studies do not examine different sources of Ca and its companion ion to demonstrate the contribution of Ca to plant disease control. A study on roses found foliar applications of $CaCl_2$ reduced the incidence of grey mold

(*Botrytis cinerea*). The same study found that increasing Ca concentrations in the soil improved the shelf life of the flower. Calcium may also influence the spread of *Phytophthora* spp. in water. Vinca plants that were flood-irrigated and then infected with *Phytophthora* spp. were healthier when the complete fertilizer solution was amended with $Ca(NO_3)_2$. Other studies demonstrated that Ca applied as either $CaCl_2$ or $Ca(NO_3)_2$ in water or in Ca-free soluble fertilizer solutions suppressed the release and the motility of the swimming spore. These results demonstrate the urgent need to understand more about how Ca amendments interfere with *Phytophthora* in recirculating irrigation systems.

Magnesium is usually applied as $MgSO_4$ or $MgCl_2$ and has been associated with both increased disease and disease suppression of plants. Of 46 studies investigating the role of Mg on plant disease, 22 found that Mg decreased disease, 18 found that Mg increased disease, and 6 found that there was little or no difference. Since the data are so conflicting, no real patterns can be discerned. It may be that many of these studies corrected a Mg deficiency and the result was a healthier plant with more vigor and disease resistance. When Mg was applied in excess of what is required for normal growth, a nutritional imbalance developed that promoted plant stress and more disease. The few examples on plants may illustrate this point. The addition of extra magnesium to potting soil was associated with increased damping-off of calendula. Similarly, applying high rates of Mg to pepper and tomatoes increased bacterial leaf spots. On the other hand, when carnations were grown on calcareous soils, applications of Mg suppressed Fusarium wilt. The latter study was likely a result of the added magnesium correcting a deficiency due to the high Ca concentration.

Chlorine and Sulfur

For centuries, Cl has been routinely applied as a companion ion for NH_4-N, K, and Ca fertilizers. Historically, Cl applications were thought to have little value in improving plant growth because Cl was thought to be highly available in soils and not essential. However, the role of Cl has long been misunderstood in crop production. Even in the last decade, the benefits of Cl are still mistakenly being ascribed to the accompanying cation (see section on potassium). For example, while it is well documented that proper K nutrition will suppress some plant diseases, many subsequent studies that examined different forms of K found that the ameliorating effects on disease were restricted to KCl amendments suggesting that Cl was the active ion.

Nutritionally, Cl is regarded as a micronutrient, yet, as in the case of Ca, benefits are achieved with rates that far exceed the plant's nutritional requirements. High rates of Cl salts have marked effects on inhibiting soil nitrification, enhancing availability of Mn and other micronutrients, and on increasing beneficial microorganisms. As an element, Cl^- is the only inorganic anion that is not structurally bound to a metabolite. Its major role is to serve as a charge-balancing ion. When a cell absorbs Cl^-, it accumulates in the cell vacuole and lowers the cell water potential below that of the medium surrounding the cell. Water then flows into the cell and increases hydrostatic cell pressure so it maintains a pressure that exceeds the force exerted by the plasmalemma. The cells remain turgid and are able to grow even when drought conditions prevail. Theoretically, plants that get root diseases in wet soils might be protected by supplying sufficient Cl to the plants so that they could still grow normally in soils with lower moisture deficits. Studies are needed to validate this theory. Chloride ions also alter the quantity and quality of organic solutes that are exuded into the rhizosphere, thus reducing the germination of and infection from root pathogens. Another major role of Cl in disease suppression comes from its effect on increasing the availability of Mn, which has direct effects on host resistance. This will be discussed below. Monocots like asparagus and barley tend to be more tolerant of high amounts of Cl, but there are a few dicots like beets that respond well to Cl when a disease is present (Figure 6).

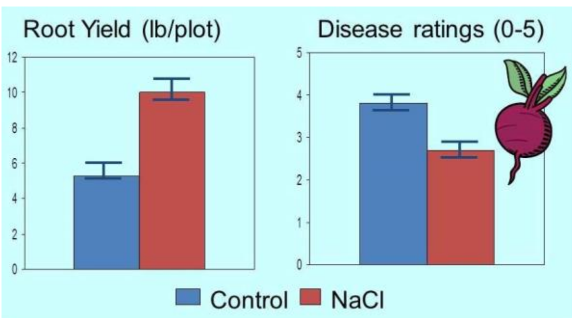

Figure 6. The effect of NaCl on yield and root rot of table beets.

Sulfur is an essential element and a component of proteins, and it is the oldest recorded fungicide in use on plants. Sulfur has been used for over a hundred years to suppress powdery mildew and black spot of rose, and many other rust diseases of plants. However, the significance of soil-applied S on plant disease only recently became evident when S deficiency symptoms were noted following the drastic decrease of SO_2 emissions from coal-burning facilities. Most growers do not consider S nutrition as a component in their fertility programs. However, it is frequently applied as $NH_4(SO_4)_2$, Ca_2SO_4, or $MgSO_4$. These salts are almost exclusively applied with the aim of supplying the cation. When manipulating the pH is the sole objective, elemental S and $AlSO_4$ are often used. At the time of this writing, there is scant information on how sulfur nutrition affects plant diseases but, on field crops, several studies have shown that proper sulfur nutrition can induce resistance to plant pathogens through its effect on the function and availability of S-containing amino acids. Cysteine, methionine, and glutathione play roles in protein synthesis of many defense products. As air quality improves and atmospheric S decreases further, it is possible that growers will need to be more attentive to S nutrition.

Effect of micronutrients on diseases

The metals Fe, Mn, Zn, Cu, Mo, and B have diverse but essential roles in plants, functioning as cofactors or activators of enzyme systems. Many of these enzyme systems play pivotal roles in disease resistance in the production of defense barriers. In general, the concentrations that correct visual deficiency symptoms in plants are often far below the levels needed to ensure proper health and defense against disease. Most micronutrients become less available as the pH rises so growers should be aware that although crops that favor alkaline soils may not show deficiencies, they may be more susceptible to attack from pathogens. One quick method to correct aboveground deficiency symptoms and boost resistance to foliar diseases is to apply a foliar application. However, since micronutrients are not translocated basipetally to the roots, this application would not suppress a root disease.

Proper Fe nutrition not only boosts plant vigor and health, it indirectly affects disease in the rhizosphere where its availability may limit the growth of pathogens. A rich body of information exists on the role of Mn nutrition on plant disease. Manganese affects the production of many host defense products such as lignin, tannins, and phytoalexins. Zinc nutrition is associated with important plant defense pathways against fungal and bacterial pathogens. Zinc protects plant cells from toxic oxygen radicals and plays an important role in the production of disease resistance-signalling proteins. Although inorganic Cu was used as one of the earliest fungicides, nutritionally it functions as a component of several polyphenoloxidases that produce phenols in cell walls. These phenols become the precursors that lead to lignin and melanin defense barriers. Molybdenum nutrition is involved in nitrate metabolism and may influence many of the same disease suppression mechanisms that NO_3 affects. Boron plays a crucial role in cell wall integrity and phenol metabolism. Studies on field crops have found that minor B deficiencies can lead to increased plant susceptibility. Although most plant growers lump micronutrient deficiencies all together, future research may allow for prescribed applications to optimize and balance micronutrient fertility to increase protection from disease.

Effect of beneficial elements on diseases

As stated above, not all elements are viewed as essential, but a growing number of experiments have shown that many nontraditional elements can suppress a number of plant diseases. It is interesting that the ameliorating effects of these elements are frequently only realized when the plant is under disease pressure which, once again, implicates their influence in host defense mechanisms.

Silicon is not taken up by all plants, but plants that accumulate Si have shown marked resistance to certain plant diseases. Si is root-absorbed as monosilicic acid and most grasses will absorb this element in great quantities (between 1 and 10%). Although Si is available in many kinds of soils, peat-based soilless mixes are usually deficient in Si. This may suggest that many grasses grown in peat-based soils might gain protection from diseases caused by mildews and rust if adequate Si was added to the growth medium. Although research on some plants has begun, most plants have not been assessed for the role of Si nutrition on disease. Of the plants examined, begonia, geranium, morning glory, paper daisy, poinsettia, rose, and zinnia have all shown protection from biotic and abiotic diseases following application of Si (Figure 7). The underlying mechanisms that govern disease protection are not clear, but data have shown that Si can affect disease via enhancing physical barriers to infection in the tissue as well as alterations in host defense responses. Given the low Si content found in most horticultural media, it would seem prudent to consider Si amendments as simple, inexpensive methods to reduce plant disease.

Nickel has been regarded as an essential element due to its direct role in activating urease in plants, but Ni fertility has received no attention among plant growers. Nickel is absorbed as Ni^{+2} and is taken up in minute quantities. However, on hydrangea and pyracantha, Ni deficiency has been observed and was thought to occur when other micronutrients were applied in excessive quantities. Applications of Ni as a foliar spray have been associated with reductions

Figure 7. Incidence of powdery mildew on zinnias treated with and without silicon.

in rust on daylilies. The mechanisms are not clear, but the metal may boost defense mechanisms, induce resistance to disease, and directly inhibit the pathogens. The use of Ni in plant disease management is yet to be explored.

Recent research has shown that Al is similarly taken up in plants at low levels and may be associated with plant health. It has been a long-held practice to lower soil pH with $AlSO_4$, which is accompanied by disease reductions for many plant diseases caused by *Verticillium* and *Thielaviopsis*. However, evidence may suggest that the Al ion is partially responsible for suppression of disease through its effect on the germination of fungal spores in soil. Applications of different forms of Al to peat soils at pH 4 and 6 were followed by reductions in the densities of *Phytophthora parasitica.* Given the problems plant growers face with *Phytophthora* diseases in peat-based media, additional research on Al amendments is definitely warranted and may lead to another simple, environmentally-safe management strategy for disease control.

Summary

Mineral nutrition has marked effects on plant diseases and fertilization can often serve as the first line of defense against disease. However, this management strategy is still in its infancy due to a lack of information. A few examples have been highlighted where manipulating the mineral nutrition can reduce disease. Another more important goal was to underscore the paucity of information on how fertility could advance a major strategy for disease control and how that could have an immediate impact on the greenhouse industry. Unfortunately, the fractionation of the data and disarray of concepts have hindered a working plan for disease management. Experimental studies that focus on one plant, one element, and one disease in isolation of other variables provide only "snapshots" of information. This dearth of experimental data on plants, combined with the gigantic number of plant species whose fertility requirements differ widely from each other, make the development of this strategy a daunting task. Growers are encouraged to consider their fertility regimes against the aforementioned information and make adjustments first on a small scale, then expand as the results are warranted. Researchers are encouraged to explore a plant's horticultural and disease response to a wide array of elements applied in many combinations. The role that each element plays in disease must be viewed in the greater context of its numerous interactions with other elements, the host, soil medium, and with beneficial and pathogenic microorganisms.

Selected References

Datnoff, L. E., W. H. Elmer, and D. M. Huber. 2007. *Mineral Nutrition and Plant Disease.* APS Press, St. Paul, MN, 278 pages.

Engelhard, A. W., ed. 1989. *Soilborne Plant Pathogens: Management of Diseases with Macro- and Microelements*. American Phytopathological Society, St. Paul, MN.

Epstein, E. 1972. *Mineral Nutrition of Plants: Principles and Perspectives*. John Wiley and Sons, New York.

Huber, D. M., and R. D. Watson. 1974. Nitrogen form and plant disease. Annu. Rev. Phytopathol. 12:139-165.

July 2015

Dr. Wade Elmer
The Connecticut Agricultural Experiment Station
Department of Plant Pathology and Ecology
123 Huntington Street, P.O. Box 1106
New Haven, CT, 06504

E-mail: Wade.Elmer@ct.gov
Phone: (203) 974-8503

Website: www.ct.gov/caes

CAES
The Connecticut Agricultural Experiment Station
Putting Science to Work for Society since 1875