Mineral Nutrition and Florists' Crops Diseases

10

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Abstract

The health of any ornamental crop is a direct function of the nutritional status of the plant. Disease susceptibility or resistance is often governed by the speed in which the plants can directly react to infection by plant pathogen and/or indirectly by their ability to tolerate predisposing stresses such as drought.

Information is presented herein on the role of essential minerals N, P, K, Ca, Mg, S, Cl, Fe, Mn, Cu, Zn, B, Mo, and Ni along with beneficial elements Si and Al for their effects on suppressing diseases in ornamental crops.

Keywords

Plant health • Host defense • Fertilizers • Disease management

Contents

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1 Introduction

The maintenance of plant health and disease suppression in florists' crops is a function of the plant's nutritional status (Datnoff et al. 2007). A proper and balanced nutrition can often govern the fine line between host susceptibility and plant disease resistance. It has been observed that sufficient nutrition can also delay the onset of pathogenesis beyond a critical threshold where the plant's marketability is not compromised by disease. Complete and balanced nutrition should always be the first line of defense against biotic stresses especially plant diseases. However, one critical obstacle in providing proper plant nutrition is the lack of information on optimal nutritional requirements for the vast array of different florists' crops. Many ornamental plants will vary in their nutritional requirements and each nutrient can affect disease susceptibility differently. For example, the nitrogen sufficiency range for cut flowers is 3.1–4.7, while the range for herbaceous perennials is 2.2–3.2 (Barker and Bryson 2007). As a consequence, each ornamental plant's nutritional requirements need to be thoroughly understood on a "case by case" basis. Unfortunately, detailed information on the fertility requirements of specific ornamental crops is often lacking. Furthermore, the fertilizer requirements necessary to maximize plant health when a pathogen is present may differ from those required when the pathogen is absent (Elmer and Datnoff 2014).

In many cases, the nutrient amounts needed for plant disease suppression may far exceed a healthy plant's normal nutritional requirement for that nutrient, suggesting that many nutrients may function in multiple defense and/or physiological mechanisms for disease suppression. 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. For example, although Ca only composes approximately 0.5% of the dry weight of most plants, it is routinely applied in great quantities to potting mixes and field soil to affect soil pH and to suppress certain plant diseases.

Plant disease resistance mechanisms that are affected by nutrition include those metabolic pathways that lead to the production of lignin, phenol, phytoalexins, and other defense-related compounds. Many of these pathways utilize enzymes that require B, Cu, Mn, Mo, and Zn as cofactors or activators. Other elements like K and Cl affect disease through 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. Although each nutrient's effect on plant disease will be reviewed, nutrition must be viewed holistically since all nutrients affect the uptake and function of other nutrients and can ultimately increase or decrease plant disease development. A detailed list of ornamental plant diseases suppressed by macro-, micro-, and beneficial nutrients is summarized in Table 1.

2 Nitrogen

The fourth most abundant element in plants after hydrogen, carbon, and oxygen is nitrogen (Huber and Thompson 2007). Nitrogen is a component of amino acids, enzymes, hormones, phenolics, phytoalexins, and proteins, all of which can have direct effects on plant growth and disease development. Although most growers are familiar with symptoms of N deficiency, most do not recognize the role that N form may play in enhancing or suppressing disease. Nitrogen can be applied as a salt of the oxidized anion NO_3^- or as the reduced cation NH_4^+. Most ornamentals 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, in ornamentals, excess nitrate can increase Pythium diseases by increasing salt stress and increase Botrytis blight by promoting green and succulent tissue (Gladstone and Moorman 1989).

Once absorbed by the plant, NO_3-N and NH_4-N are metabolized differently and can have opposite effects on diseases. This, in turn, has led to many of the conflicting reports found in the literature regarding the role of N and plant disease, which 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 (Haygood et al. 1982; Chase 1990) but increased bacterial leaf spot and cutting rot on chrysanthemum caused by *Pseudomonas cichorii* and *Erwinia chrysanthemi*, respectively (Jones et al. 1985; McGovern et al. 1985). 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, and gladiolus are usually less severe when the N is applied as NO_3-N and more severe when applied as NH_4-N (Huber and Thompson 2007). The opposite is true for Verticillium wilt and Thielaviopsis diseases. Studies have shown that applying ammonium sulfate provided good suppression of Verticillium wilt on eggplant, maple, and snapdragon. In addition, 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 either enhance or decrease disease protection.

3 Phosphorus

Phosphorus plays a vital role in cell division and energy transfer, as well as a regulatory role in the transport of sugars and starches within the plant (Prabhu et al. 2007). The examples where P has been shown to be effective in suppressing plant disease in ornamental plants are few. For example, P has been shown to suppress root rot in geranium caused by *Pythium ultimum* (Gladstone and Moorman

Table 1 Some differential responses to macro-, micro-, and beneficial nutrients in some ornamental host-pathogen interactions

Nutrient	Hosts	Diseases	Pathogens	Effect	Reference(s)
Nitrogen					
Ammonium	Syngonium	Blight	*Xanthomonas* sp.	Decrease	Chase (1989)
	Chrysanthemum	Cutting rot	*Erwinia chrysanthemi*	Increase	McGovern et al. (1985)
	Chrysanthemum	Leaf spot	*Pseudomonas cichorii*	Increase	Jones et al. (1985)
	Schefflera	Leaf spot	*Xanthomonas hederae*	Decrease	Chase (1990)
	Pansy	Root rot	*Thielaviopsis basicola*	Decrease	Copes and Hendrix (1996)
Nitrate	Carnation	Root rot	*Gibberella zeae*	Increase	Stack et al. (1986)
	Chrysanthemum	Wilt	*Fusarium oxysporum*	Decrease	Woltz and Engelhard (1973)
	Cyclamen	Wilt	*Fusarium oxysporum*	Decrease	Elmer and Daughtrey (2012)
	Geranium	Root rot	*Pythium* sp.	Increase	Gladstone and Moorman (1989)
	Gladiolus	Corm rot	*Fusarium oxysporum*	Decrease	Engelhard and Woltz (1978)
Phosphorus	Geranium	Root rot	*Pythium ultimum*	Increase	Gladstone and Moorman (1989)
	Gladiolus	Yellows	*Fusarium oxysporum* f. sp. *gladioli*	Decrease	Prabhu et al. (2007)
Potassium	Aster	Wilt	*Phialophora asteris*	Increase	Burge and Isaac (1977)
	Carnation	Bacterial wilt	*Pseudomonas caryophylli*	Decrease	Nelson and Laurie (1951)
		Stem rot	*Gibberella zeae*	Increase	Stack (1989)
		Wilt	*Fusarium* sp.	Decrease	Gasiorkiewicz (1960)
	Pelargonium	Stem rot	*Xanthomonas pelargonii*	Decrease	Kivilaan and Scheffer (1958)
	Philodendron	Leaf blight	*Erwinia chrysanthemi*	Increase	Haygood et al. (1982)
	Snapdragon	Wilt	*Verticillium dahlia*	Decrease	Dutta and Isaac (1979)

Calcium	Rose	Gray mold	*Botrytis cinerea*	Decrease	Starkey and Pedersen (1997)
	Vinca	Root rot	*Phytophthora parasitica*	Decrease	Von Broembsen and Deacon (1997)
Magnesium	Calendula	Seedling disease	*Pythium aphanidermatum*	Increase	Gill (1972)
	Carnation	Wilt	*Fusarium oxysporum*	Decrease	Lyakh (1986)
Manganese	Chrysanthemum	Wilt	*Fusarium oxysporum*	Decrease	Malini (1961)
Chloride	Cyclamen	Fusarium wilt	*Fusarium oxysporum* f. sp. *cyclaminis*	Decrease	Elmer (2002)
Nickel	Daylily	Rust	*Puccinia hemerocallidis*	Decrease	Reilly et al. (2005)
Silicon	Gerbera daisy	Powdery mildew	*Podosphaera fusca*	No effect	Moyer et al. (2008)
	Morning glory	Anthracnose	*Colletotrichum gloeosporioides*	Decrease	Kunoh and Ishizaki (1975)
	Paper daisies	Anthracnose	*Colletotrichum gloeosporioides*	Decrease	Muir et al. (2001)
	Rose	Powdery mildew	*Sphaerotheca pannosa*	Decrease	Voogt (1992), Shetty et al. (2012)
	Sunflower	Powdery mildew	*Golovinomyces cichoracearum*	Decrease	Kamenidou (2005)
	Tigergrass	Leaf spot	*Exserohilum rostratum*	Decrease	Brunings (2008)
	Zinnia	Powdery mildew	*Golovinomyces cichoracearum*	Decrease	Kamenidou (2005) (unpublished data WH Elmer)
Aluminum	Vinca	Damping off	*Phytophthora parasitica*	Decrease	Benson (1993)

1989) and yellows in gladiolus caused by *Fusarium oxysporum* f. sp. *gladioli* (Prabhu et al. 2007). Most general reports on P and plant disease in other cropping systems suggest that increasing phosphorus above that which is necessary for proper growth may be associated with an increase in plant disease development. 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 Al, Fe, and Mn to form insoluble products, making P less available. In alkaline soils, P reacts with Ca and reduces P availability. Therefore, maintenance of an appropriate soil pH is very important to maximize availability of P and plant health.

Products containing phosphorous acid (H_3PO_3), and its salts (phosphonate, phosphate, or phosphonic acid), have been developed and marketed to control plant diseases caused by *Phytophthora* and *Pythium* (Brunings et al. 2012). Phosphorous acid has a mixed mode of action involving direct toxicity to the plant pathogen along with enhancing the plant's defense response. These products do not provide any appreciable P nutrition to the plant, and their mode of action is not through normal pathways associated with P metabolism. Similarly, monopotassium phosphate (MKP) has been marketed as a foliar spray to induce local and systemic protection against some foliar pathogens in several crops.

The role of beneficial mycorrhizal fungi in P nutrition and disease development also deserves attention (Elmer and Datnoff 2014). Mycorrhizae form a symbiotic relationship with the plant's roots. These fungi improve plant health and may reduce disease damage. Many ornamentals have mycorrhizal associations that are likely interrupted during propagation cycles. 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 ornamental production for management of soilborne disease. Their use may allow other nutrients to be more available since added P could lead to the precipitation of other elements. Much research is still needed to identify the P demands of ornamentals that respond to supplemental applications of mycorrhizae.

4 Potassium

Potassium is found in large quantities in plant tissues and may exceed nitrogen levels for certain plants. Potassium improves water and nutrient uptake, increases cellulose and protein content, and enhances and regulates at least 60 different plant growth enzymes (Prabhu et al. 2007). 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 any specific generalizations. For example, investigators have noted that applying K suppressed bacterial diseases on carnation and geranium (Nelson and Laurie 1951; Kivilaan and Scheffer 1958) but increased bacterial leaf blight on philodendron (Haygood et al. 1982). Similar observations have been made for fungal pathogens attacking ornamental plants where K would increase or decrease diseases (Menzies and Colhoun 1976). 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 ornamentals 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 (Elmer 2007). 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 (Gladstone and Moorman 1989).

5 Calcium and Magnesium

Calcium and Mg are the second and third most abundant essential nutrients, respectively, in a plant (Rahman and Punja 2007). 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 for cell wall stabilization. Calcium also 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 ornamentals 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 gray mold caused by *Botrytis cinerea* (Starkey and Pedersen 1997). 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 found to be healthier when the complete fertilizer solution was amended with $Ca(NO_3)_2$ (Von Broembsen and Deacon 1997). 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 zoospore (Rahman and Punja 2007). These results demonstrated that there is an important 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 (Jones and Huber 2007). 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 regarding the effect of Mg on plant diseases. 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 for normal growth, a nutritional imbalance developed that promoted plant stress and more disease. For example, the addition of extra Mg to the potting soil was associated with increased damping off of calendula (Gill 1972). On the other hand, applications of Mg suppressed Fusarium wilt of carnations when grown on calcareous soils (Lyakh 1986). The latter study was probably a result of the added Mg correcting a deficiency due to the high Ca concentration.

6 Chlorine and Sulfur

In the past, 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, Cl has been routinely applied as a companion ion for NH_4-N, K, and Ca fertilizers (Elmer 2007). The contribution of Cl has long been underestimated in crop production and plant health. Reports are still erroneously assigning the effect of Cl to the accompanying cation. 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, not K, 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. Chloride ions also alter the quantity and quality of organic solutes that are exuded into the rhizosphere, thus reducing the germination of and infection by 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. Monocots tend to be more tolerant of high amounts of Cl, but there is no information on how ornamental grasses would respond to Cl applications. Cyclamen plants inoculated with *Fusarium oxysporum* f. sp. *cyclaminis* and exposed to Cl salts were larger and had fewer symptoms of disease than plants that received no Cl (Elmer 2002). Any studies with Cl must ensure that salt levels do not build up and predispose plants to root infection by *Pythium*.

Sulfur (S) is an essential element and a component of proteins (Haneklaus et al. 2007). This element also is probably the oldest recorded fungicide known (Agrios 2005). Sulfur has been used for over 100 years to suppress powdery mildew, certain rusts, and leaf blights such as black spot of rose. 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 a component in their fertility programs. When this element is used, it is frequently applied as $NH_4(SO_4)_2$, Ca_2SO_4, or $MgSO_4$. These salts, however, are almost exclusively applied with the aim of supplying the cation. When lowering the soil pH, elemental S and $AlSO_4$ are often used. Currently, there is very little information available on how sulfur nutrition affects ornamental diseases. However, 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 plant defense products. As air quality improves and atmospheric S decreases further, growers may need to be more attentive to S nutrition.

7 Effect of Micronutrients on Diseases

The metals iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), and boron (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 (Datnoff et al. 2007). 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 plant pathogens. One quick method to correct aboveground deficiency symptoms and boost resistance to foliar diseases is to apply a foliar application of the micronutrient needed. However, since micronutrients are not translocated basipetally to the roots, a foliar application would not be very effective for suppressing a root-infecting pathogen. Although most ornamental growers lump micronutrient deficiencies all together, future research may allow for prescribed applications to optimize and balance micronutrient fertility to increase protection from disease.

Proper Fe nutrition not only improves plant development and health, this metal indirectly affects disease in the rhizosphere where its availability may limit the growth of pathogens (Expert 2007). One of the major situations in which Fe influences plant disease is through siderophores. Siderophores are low molecular weight molecules (<1500 Da) that possess a high affinity for Fe^{3+}. They specifically capture Fe^{3+} ions and transport them back into the microorganism that produces them. So, certain microorganisms have the ability to acquire Fe and rob the potential plant pathogen of Fe in the rhizosphere or even within the plant. However, the siderophores can also release their Fe^{3+} ions to iron-deficient plants. Therefore, microbial siderophores present in soils may increase Fe availability on the root surface, depending on their different chemical, physical, and absorptive characteristics. Mechanisms involved in these processes have been poorly defined, and no research to date has been conducted using ornamental-pathogen systems as a model.

Although a rich body of information exists on the role of Mn nutrition on plant disease (Elmer and Datnoff 2014), very little research has been conducted using ornamentals. Manganese affects the production of many host defense products such as lignin, tannins, and phytoalexins. Manganese functions primarily as an activator of enzymes, including dehydrogenases, tranferases, hydroxylases, and decarboxylases. Mn is an activator of several enzymes in the shikimic acid pathway for production of important secondary metabolites that lead to the production of phenolics, cyanogenic glycosides, and the deposition of ligneous defense barriers. More directly, Mn can reduce growth of the pathogen, which may explain why these organisms evolved mechanisms for oxidizing Mn to unavailable forms. Growers need to be aware that Mn is most available to plants at a soil pH levels of 5.0–6.5 and is unavailable when above 7.8. Mn-transforming microbes play a major role in this soil availability.

Zinc nutrition is essential to the metabolism associated with important plant defense pathways against fungal and bacterial pathogens, and although examples are found only for vegetable and field crops, they may have relevance to ornamentals (Elmer and Datnoff 2014). Examples of bacterial and fungal species affected by Zn include *Xanthomonas*, *Pseudomonas*, *Rhizoctonia*, *Puccinia*, *Fusarium*, and *Bipolaris*. Zinc plays an important role in the disease resistance signaling proteins and protects plant cells from toxic oxygen radicals. Zinc also influences fungal growth and secondary metabolism by indirectly altering host susceptibility. The availability of zinc also affects fungal pathogens and modulates the accumulation of citric acid, stimulates glucose uptake, and pigment and antibiotic production by microbes (Duffy 2007).

Copper activates many enzyme systems involved in plant defense (Elmer and Datnoff 2014). Copper affects plant disease by three known mechanisms. Direct toxicity as a bactericide or fungicide is the most common one. However, the effects of Cu on plant resistance and pathogen virulence can also operate simultaneously. For example, Cu enhances production of polyphenol oxidases that are involved in plant defense against infection. In addition, the element is also involved in the production of antimicrobial compounds and general disease resistance. Copper has been identified as a micronutrient for some plant pathogens, and the limited availability of this element can result in the pathogen becoming avirulent.

Molybdenum is essential to higher plants and plays a role in activating the nitrate reductase enzyme (Elmer and Datnoff 2014). Molybdenum has been shown to denature the protein coat of viruses and disrupt zoospore production, but only in vegetable production systems. Manipulating Mo nutrition to date has not been demonstrated to be effective for managing plant diseases.

Boron plays a crucial role in plant defense by improving cell wall integrity and enhancing phenol metabolism (Elmer and Datnoff 2014). Studies on field crops have found that minor B deficiencies can lead to increased plant disease susceptibility. Examples of pathogens negatively affected by B include species of *Fusarium*, *Leveillula*, *Plasmodiophora*, *Puccinia*, and *Verticillium*.

Nickel (Ni) has been regarded as an essential element due to its direct role in activating urease in plants, but Ni fertility has received little, if any, attention among ornamental growers. Nickel is absorbed as Ni^{+2} 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 in rust on daylilies (Graham et al. 1985; Reilly et al. 2005). The mechanisms for this reduction in disease are not known, but the metal may boost defense mechanisms, induce resistance to disease, and directly inhibit the pathogen. The widespread use of Ni in ornamental disease management is yet to be explored.

8 Effect of Beneficial Elements on Diseases

Although not all elements are viewed as essential, a growing number of experiments have shown that beneficial elements can suppress a number of plant diseases. The ameliorating effects of these elements are frequently only realized when the plant is under an abiotic or biotic stress such as a plant disease. These findings suggest that these nutrients probably play a role in host defense mechanisms.

Although silicon (Si) is the second most abundant element in the earth's crust, many soils are known to be low or limiting in this element and include some of the following soil orders: Entisols, Histosols, Inceptisols, Oxisols and Ultisols (Tubana and Heckman 2015). Soilless mixes would also be deemed to be low in plant available Si. Silicon is root absorbed as monosilicic acid ($Si(OH)_4$), and plants are known to accumulate this element in great quantities (between 1% and 10% dry weight). Consequently, all plants contain Si and some plants in quantities that may exceed a number of essential mineral nutrients. However, Si was largely absent from plant experiments or used as a crop amendment until the early twentieth century since visible deficiency symptoms were lacking. Nowadays, silicon is known to dramatically decrease the intensity of a number of plant diseases, which include damping off, leaf blights, leaf spots, galls, powdery mildews, root rots, rusts, and wilts (Datnoff and Rodrigues 2015a). Although research on some ornamentals has begun, most ornamental plants have not been thoroughly assessed for the role of Si in suppressing plant disease. Of the ornamentals examined to date, morning glory, paper daisy, rose, tigergrass, and zinnia have all shown improved plant protection following silicon application (Brunings 2008; Locke et al. 2006; Rodrigues et al. 2015a). While the underlying mechanisms that govern disease protection are still not completely understood, research has shown that Si can form a mechanical barrier through polymerization below the cuticle and in the cell walls (Rodrigues et al. 2015b). This was the first proposed hypothesis to explain how this element reduced disease development. New insights, however, have shown that silicon's effect on plant resistance to a number of plant diseases may also occur through mediated host plant resistance mechanisms against pathogen infection. On the basis of research conducted to date, the following facts about silicon in relation to plant disease suppression are known: A minimum silicon concentration is needed to suppress a plant disease; once that level has been obtained, plant disease suppression increases proportionally as the silicon concentration increases in plant tissues; silicon supply to the plant must be continuous or the disease-suppressing effects will be reduced or nonexistent; silicon will influence many components of host resistance, which include the incubation period, latent period, lesion number, and lesion size; silicon may confer resistance to susceptible and partially resistant plants at almost the same level as complete genetic resistance; only when applying silicon to the roots will this element change plant responses to pathogen infections at both the physiological and molecular levels; and silicon may suppress plant disease as effectively as fungicides (Datnoff and Rodrigues 2015b). Given the low Si content found in most soilless horticultural media and a number of soil orders, it would seem prudent to consider Si amendments as a simple, inexpensive method to reduce plant disease development.

Recent research has shown that aluminum (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 reductions in many plant diseases caused by species of the soilborne plant pathogens *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* infecting vinca (Benson 1993). Given the problems ornamental 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.

9 Summary

Mineral nutrition clearly has marked effects against plant diseases (Datnoff et al. 2007). These mineral elements often serve as the first line of defense against disease. A few examples have been highlighted where manipulating the mineral nutrition can reduce disease in ornamental plants (Kamenidou 2005). However, the fractionation of the data and disarray of concepts have hindered a working plan for using nutrition as a current disease management practice. Experimental studies to date have only focused on one plant, one element, and one disease in isolation of other variables and provide only “snapshots” of information. This dearth of experimental data on ornamentals, combined with the gigantic number of ornamental plant species whose fertility requirements differ widely from each other, makes the development of this disease management strategy a daunting task. Growers are encouraged to consider their fertility regimes based on the aforementioned information and make adjustments first on a small scale and then expand as the results justify. Researchers are encouraged to explore an ornamental'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.

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