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Mineral Nutrient Management and Plant Disease

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Introduction and background

A major goal in crop production is to produce healthy plants and healthy crops in a sustainable manner. The concept of plant health involves more than pest control and protecting the plants from pests; it also involves other disciplines, which include crop management, ecology, and climatology. The final goal is to grow the crop under optimal production conditions and to produce high, sustainable and economic yields with minimal disturbance of the environment. Mineral nutrition is an important component in this system. Its management can affect not only the yield, but also plant health and the environment.

Properly balanced nutrition is a critical factor in allowing crops to realize their full yield potential. The application of fertilizer to accomplish this balance is a universal practice in commercial crop production. Macro- and microelements have long been recognized as being associated with size, quality, and yield of crops, and also with changes in levels of the incidence of disease (Rush *et al.*, 1997). Pathogens, as well as crops, have nutritional requirements of their own. Two major objectives of nutrient applications to crops for protection from pathogens are to avoid plant stress, which may allow crops to better withstand pathogen attack, and to manipulate nutrients to the advantage of the plant and disadvantage of the pathogen (Palti, 1981). Not only is the supply of an individual nutrient important, but also balanced, crop-specific nutrient ratios are crucial for improving plant health by adequately supplying the plant during its development under varying environmental conditions. Through an understanding of disease interactions with each specific nutrient, the effects on the plant, pathogen and environment can be effectively modified to improve disease control, enhance production efficiency and increase crop quality (Walters and Bingham, 2007).

A plant disease is the result of the interactions between three major components: the host plant (its resistance to the pathogen), the pathogen (its capacity to develop and induce a disease) and the biotic (e.g. microbial antagonists) and abiotic (e.g. mineral nutrients, temperature) environment (Fig. 1).

Any external factor introduced into this system, e.g. a pesticide or a mineral nutrient can positively or negatively affect any one or all of the above components, leading to a decrease, increase or no effect on disease incidence and severity. However, as will also be shown below, generalizations should not be made: a particular mineral nutrient may be associated with an increase in severity of a certain disease in one crop but with suppression of another disease in a different crop or have no effect. Also, an environmental stress does not always suppress plant resistance. Each interaction is specific for the particular mineral nutrient, the specific plant and the specific pathogen. In this article we concentrate on interactions between mineral nutrients and plant diseases, with emphasis on the major elements, NPK.

From the viewpoint of plant health, two aspects of mineral nutrients may be considered: their role in achieving optimal yields and their effect on plant diseases.

The effect of mineral nutrition on plant diseases has long been recognized. As early as the 1940s and 50s, intensive studies were carried out on the interactions between mineral nutrients

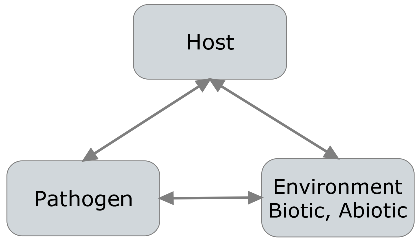

Fig 1. The interactions involved in plant disease.

and plant diseases, especially in Wisconsin, USA. For example, it was found that potassium deficiency increased the severity of Fusarium wilt in cotton, whereas applying high levels of this fertilizer reduced incidence of the disease. Similar results were obtained with Fusarium wilt of tomato and cabbage, but the opposite was found with clubroot disease in cabbage. It was also found that a balanced NPK nutrition, especially at high concentrations, reduced Fusarium wilt in tomato. It should be emphasized that most of these experiments were carried out under controlled conditions in the greenhouse. Whether these findings were of relevance to field conditions was not always clear, and only in a few cases were results obtained on a large-scale under realistic field conditions. Nevertheless, the above early studies indicate the potential of this approach, which may be utilized as a tool for reducing the incidence of plant diseases.

There have been attempts since then to harness mineral nutrition as a tool for disease reduction. However, in many cases these have resulted in failure, apparently because the methods of application have been inadequate and knowledge of the nature of the interactions between the mineral nutrients and plant disease has been limited. It is now recognized that there is a need to explore ways in which to use mineral nutrition to bring about a reduction in the incidence of disease without affecting yield and quality. This approach is now possible because better and more sophisticated tools for controlled fertilizer application, and its

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monitoring, are now available especially in soilless cultures.

Interactions of three major minerals with plant diseases are briefly reviewed below.

Nitrogen

Nitrogen is the most commonly used fertilizer and is essential for the production of many cellular components (Huber and Thompson, 2007). It may be absorbed by plants in either a reduced or an oxidized form. The rapid rate of nitrification in many cultivated soils provides nitrate (NO_3) for plant uptake which is internally reduced to amino acids prior to utilization by cells. The two forms of nitrogen absorbed by the plant are assimilated differently and can have a profound effect on diseases. The uptake and assimilation of nitrate leads to an increase in pH at the root/soil interface, the rhizosphere, whereas with ammonium (NH_4) nutrition the rhizosphere is acidified. This basic difference between forms of N supply can have a major impact on the activity of root-borne diseases which can be sensitive to pH. Most of the contradictions in reports of the effects of N on diseases may result from a failure to recognize the different effects of the various forms of nitrogen (Huber and Thompson, 2007). Interactions between nitrogen and other nutrients are well known. For example NO_3 nutrition stimulates K uptake and *vice versa* promoting the synthesis of organic N compounds, whereas NH_4 uptake competes with K uptake which can be restricted. On the other hand, uptake of phosphate is relatively favoured by NH_4 nutrition in comparison with NO_3 as the N source.

The effect of nitrogen on plant diseases is extensively reported. A general concept is that nitrogen frequently tends to increase disease incidence. However, there are also cases of a decrease in incidence of diseases induced by nitrogen fertilizers. This apparent contradiction appears to result from differences in rate of application, time of application, form of nitrogen, and soil conditions. Interactions with other nutrient elements have also to be considered. Nitrogen can affect disease incidence in various ways including effects on cellulose formation in the plant, on root and leaf exudates and consequently on pathogen growth and virulence, as well as on plant response. Damping-off disease in beans caused by *Rhizoctonia solani* is more severe with plants receiving NH_4 than in plants receiving NO_3. Again, this demonstrates that the type of interaction is specific to the nutrient type, the host and the pathogen.

Effect of foliar spray of K and P (KH_2PO_4; MKP) on Nova mandarin (Duncan grapefruit X Dancy tangerine) resistance to pests and disease after six weeks in cold storage. Left and right: 0 K & P (non-treated control); middle: 4 and 6 kg K_2O and P_2O_5 ha^{-1} respectively. The damage on the infected fruit is caused by Phytophthora citrophthora and Penicillium spp. Photo by A. Ovadia and M. Assaraf, Yavne, Israel, 2005.

For strategies to reduce disease with nitrogen nutrition, it is recommended to maintain a balanced fertilizer program with a full sufficiency of nitrogen for optimum plant growth and yield. Also, nitrogen has to be applied appropriately in order to avoid periods of excessive nitrogen supply or nitrogen deficiency. Nitrogen nutrient management has to take into account the potential response of the major crop pathogens to nitrogen in order to adjust it to minimize potential adverse effects.

Phosphorus

Phosphorus is an essential plant nutrient and its deficiency in soils significantly reduces yields of crop plants. Phosphorus is an essential element of the building blocks of life, the ribonucleic acids (RNA), as well as being required for many additional biochemical and physiological processes including energy transfer, protein metabolism and other functions (Prabhu *et al.*, 2007a).

There are reports indicating a reduction in disease incidence by phosphorus with the opposite also being found, although it appears that phosphorus has a predominantly beneficial effect. For example, phosphorus reduces the progress of some rusts and other foliar diseases and is especially beneficial in counteracting high levels of nitrogen. However, high levels of phosphorus alone in sugarcane have been associated with a high severity of rust. Phosphorus alone, or in combination with potassium, increased resistance of wheat to powdery mildew. Application of phosphorus increased Fusarium wilt in tomato at pH 6.0 but suppressed it at pH 7.0 and 7.5. The severity of Rhizoctonia disease in soybean increased as a result of phosphorus deficiency in the soil, emphasizing the importance of balanced and adequate nutrition. There are also cases in which phosphorus reduced incidence of certain nematode and bacterial diseases. There are many other examples of the interaction between phosphorus and plant diseases. It is especially interesting to note that in certain cases foliar application of phosphate salts has been shown to induce resistance to various diseases in cucumber, beans and other crop plants. As with other mineral nutrients, phosphorus management for disease control should aim to both improve crop productivity and disease control. In other words, phosphorus has to be supplied in

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adequate amounts and in the appropriate form and methods of application. These have to be adjusted according to crop requirements and edaphic conditions. Foliar sprays of phosphorus can confer local and systemic protection against some foliar pathogens, e.g. powdery mildews in grape, mango, apple, wheat, and peppers, rust on maize and others. This means of application offers another potential benefit which deserves further consideration.

Potassium

Potassium is a basic nutrient for plant life and plays many essential roles in plant nutrition. Leaves of potassium deficient plants are chlorotic and often show necrosis at the margins with plant growth and root development depressed. It has been argued that potassium-deficient plants might be pre-disposed to diseases (Prabhu *et al.*, 2007b) and indeed in many cases, potassium application has been shown to reduce the incidence of both foliar and soil-borne diseases, while in a few cases the opposite has been found to be true. For example, out of 165 cases of effects of potassium on fungal, bacterial and nematode diseases (compiled by Prabbu *et al.*, 2007b), 117 cases (71 per cent) resulted in a decrease in diseases whilst 29 per cent showed an increase. The beneficial effect of potassium application in reducing diseases, e.g. Verticillium wilt is especially evident in potassium-deficient soils. Potassium deficiency also predisposes cotton to Fusarium wilt, thus adequate potassium fertilization contributes to plant health. The effect of potassium on diseases is also influenced by interaction with other nutrients. For example, blast severity in rice is low when there is a high K:N ratio in leaf tissue, whereas a low K:N ratio increases the disease. The accompanying anions in K salts applied as fertilizers may also affect the disease. In some cases, the increased resistance to disease by potassium has been attributed to various mechanisms, e.g. decreased cell permeability and decreased susceptibility of tissue to maceration and penetration by the pathogen. Moreover, potassium in combination with phosphorus induces the development of thicker cuticles and cell walls which function as mechanical barriers to invasion and infection by pathogens.

As with other mineral nutrients, appropriate management practices of potassium relating to application can improve the uptake of potassium by plants and consequently increase crop production, while reducing disease incidence. Again, this involves adequate application rates, appropriate timing and methods of application, and other practices which increase potassium availability in the soil. Potassium has significant potential as a tool for reducing diseases, which needs further investigation.

Concluding remarks

Mineral nutrients may reduce the incidence of diseases in certain cases or increase them in others, depending on the particular mineral nutrient, the host plant, the pathogen and other factors. Appropriate management which takes into account fertilizer form and rates, and time and mode of application, has the potential to achieve high crop productivity while reducing the incidence of diseases, or at least avoiding their increase. A key factor is the supply of plants with a well balanced form of nutrition and avoidance of stress e.g. soil salinity. There is currently a big gap between promising results obtained under controlled conditions and the implication, as well as the application of these findings to farming practice. It is hoped that the introduction of sophisticated methods of application and better understanding of the mechanisms underlying the beneficial effects of mineral nutrients in reducing disease incidence will enable the realization of this approach on a large scale. Appropriate management of mineral nutrition which leads to a reduction in the incidence of disease is also an additional tool for minimizing the use of pesticides. This is a significant benefit to the environment. To achieve this important multidisciplinary goal, there is a need for joint research between plant pathologists and soil scientists.

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The paper "Mineral Nutrient Management and Plant Disease" is also available at:

K Center/Potassium and Stress and Plant Disease